Teacher/Scientist Partnerships as Professional Development: Understanding How Collaboration Can Lead to Inquiry

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Abstract

Despite growing consensus regarding the value of inquiry-based teaching and learning, the implementation of such practices continues to be a challenge. Hurdles include state-mandated high-stakes exams, other time related constraints, teachers' perceptions of their students' expectations and abilities, and teachers' fear of launching into the unknown. Through Cornell Science Inquiry Partnerships (CSIP), an NSF Graduate Teaching in K-12 Education (GK-12) program, science graduate students work intensively with secondary teachers to help them overcome obstacles to implementing inquiry-based learning, including original scientific research. CSIP fellows bring new science content and teaching strategies into secondary classrooms while simultaneously receiving feedback from teachers on ways to improve their lesson plans, classroom management strategies, and communication skills. The scaffolding provided through these partnerships and the associated CSIP learning community enables teachers to take increased risks in their classrooms. When fellows and teachers collaborate to facilitate student inquiry projects, together they deal with unexpected or unknown outcomes, address misconceptions, and determine how open-ended inquiry-based learning can best be used in specific classroom settings. This helps teachers overcome their initial hesitation and see the benefits that inquiry learning can produce in terms of motivation and achievement of students at a variety of grades and achievement levels.

Introduction and Theoretical Framework

Engaging K-12 students in inquiry-based learning is a cornerstone of current and long-standing efforts at science education reform (American Association for Advancement of Science, 1993; National Research Council, 1996, 2000). The National Science Education Standards call for "inquiry into authentic questions generated from student experiences [to be] the central strategy for teaching science" (National Research Council, 1996, p. 31). Learning is viewed in terms of processes though which students collaboratively construct shared meaning while working in teams, tackling real-world problems, and addressing questions for which no single correct answer exists. The overall goal is to help students gain skills they will need to become lifelong learners who can access, analyze, and synthesize information and apply it to a diverse range of new situations and problems.

As defined by the Standards, inquiry is both a pedagogical strategy and a learning goal. Students engaged in inquiry-based learning construct their own knowledge by doing: they ask scientifically oriented questions, plan investigations, use appropriate tools and techniques to gather data, formulate explanations from appropriate evidence, evaluate their explanations in light of alternatives, and then communicate and justify their proposed explanations (National Research Council, 2000). In doing so, students not only learn content but also develop understanding of how scientists study the natural world. Through explicit and implicit instruction, they also learn about the nature of science, defined to include the values, beliefs, and assumptions that underlie the creation of scientific knowledge, in contrast with other ways of knowing about the natural world (Lederman, Wade, & Bell, 1998; McComas, Clough, & Almazora, 1998).

Despite growing consensus regarding the value of inquiry-based teaching, implementation of such practices continues to be a challenge for many teachers. One problem is confusion about what exactly is meant by "inquiry." The various approaches to inquiry span a continuum with varying degrees of self-directed versus teacher- or curriculum-directed learning (National Research Council, 2000). Teachers exhibit a wide range of conceptions of inquiry, representing either approaches along the continuum or misconceptions about what is meant by this term. Some define inquiry as learning driven by questioning, but many think of it as any sort of hands-on activity. Not surprisingly, these varying conceptions and misconceptions shape the ways in which inquiry is or is not implemented in classrooms (Keys & Bryan, 2001; Llewellyn, 2001).

Another challenge to implementing inquiry-based learning is that many teachers view factual knowledge as the most important student outcome, achievable through repeated drill and practice (Cronin-Jones, 1991).Modeling their teaching on the way they were taught, teachers feel more comfortable relying on textbooks, lectures, and demonstration labs rather than facilitating inquiry-based experiences (Davis, 2003; Loucks-Horsley, Love, Stiles, Hewson, & Mundry, 2003). Even among teachers who profess interest in inquiry-based teaching and view science as a continuous process of discovery, many give greater priority in practice to transmitting facts than to enabling students to carry out their own investigations (Tobin & McRobbie, 1997).

Tobin and McRobbie (1996) define four cultural myths that contribute to teachers' perception of science as a body of truths to be imparted to students. The transmission myth views the teacher as the principal source of knowledge to be delivered to students. The second myth relates to the need for efficiency, which translates into content coverage being considered more important than learning with understanding. This relates closely to the remaining two myths, which concern teachers' perceived need to maintain the rigor of the curriculum and prepare students to succeed on examinations. Teachers feel pressured to maintain control of classroom learning so that content will be covered efficiently without time being wasted. Collectively, these four myths result in significant emphasis on low level learning, focusing on learning of facts and algorithms that will enable students to obtain correct answers on exams. Because these myths are shared by teachers and society alike, they support the status quo and hamper efforts at science education reform (Tobin & McRobbie, 1996). As high stakes exams become ever more prominent at the state and national levels, the pressure to prepare students for test-taking presents a formidable challenge to inquiry-based teaching. In New York State, where passing a Regents science exam has become a high school graduation requirement, test preparation is an overriding concern of high school science teachers (Veronesi & Voorst, 2000).

Perhaps the most challenging obstacle to inquiry is teachers' reluctance to feel out of control of what is going on in their classroom (Uno, 1997). Teachers who have never conducted scientific research feel unprepared to lead students in formulating questions, designing experiments, and representing data – activities that are pedagogically risky but also central to inquiry-based learning (Kennedy, 1997; Singer, Marx, & Krajcik, 2000; Windschitl, 2003). Although grappling to understand the meaning of messy data or unexpected results provides rich opportunities for learning, teachers without research experience tend to be more comfortable with the traditional "cookbook lab" approach in which the outcome of laboratory experiences is predetermined and unexpected results are viewed as failures rather than as interesting scientific findings that can lead to further investigations (Amerine & Bilmes, 1990).

A critical question for science educators is how to provide professional development that will help teachers overcome the considerable challenges they face in implementing inquiry in their classrooms. Engaging students in truly open-ended inquiry requires a teacher to have appropriate pedagogical tools, confidence, an understanding of science in its social context, experiences with scientific inquiry, and agreement with the goals of reform-based science education standards (Avery & Carlsen, 2001; Barnett & Hodson, 2001).

Research Context

Over the past five years, the Cornell Science Inquiry Partnerships (CSIP) has provided fellowships to 44 Cornell graduate students through NSF's Graduate Teaching Fellows in K-12 Education (GK-12) program. CSIP fellows, representing a wide range of science and engineering fields, spend ten hours per week teaching collaboratively with secondary teachers in classes ranging from remedial through advanced placement science. They spend an additional five hours per week developing curriculum resources based on their expertise and the interests and needs of their partner classes. CSIP teachers participate voluntarily because of their interest in providing new experiences for their students and improving their ability to teach using inquiry-based strategies.

One of the goals of CSIP is to help teachers gain familiarity and comfort in inquiry-based teaching through working with fellows to develop and guide activities in which students frame scientific questions and conduct activities to address these questions. In classes with flexible curricula and teacher interest, fellows facilitate projects in which the teacher, fellow, and students work together as co-researchers on genuine research endeavors. In classes that are constrained by preparing students for standardized exams, fellows are more likely to work with teachers to develop short-term projects aimed at developing students' understandings of required concepts. The approaches used by CSIP fellows generally fall into these categories:

- *Open-ended research*: an original experiment or series of experiments, monitoring projects, or other research designed and conducted by students.
- *Remodeled labs*: traditional labs and field activities that have been adapted by fellow/teacher teams to meet curriculum requirements through a more inquiry-based approach,
- *Nature of science lessons:* activities designed to lead to an understanding of how scientists study the natural world, and
- *Other:* new approaches to addressing required topics; interactive "meet-the-scientist" presentations about the fellows' research; and "inquiry moments," or spur-of-the-moment topics, insights, or questions introduced by fellows in response to opportunities that arise in the midst of regular classroom discussions and activities.

The goal of this study is to investigate ways in which collaborations between fellows and teachers have helped teachers overcome the significant hurdles to implementing inquiry-based learning in secondary level science classes. In particular, we focus on the following research questions:

1. What obstacles influence teachers' receptivity to the implementation of open-ended student inquiry?
2. In what ways can partnerships with science graduate students help teachers overcome the obstacles to inquiry-based teaching?

Methods

These research questions were addressed using classroom observations, pre and post interviews with teachers, post interviews with fellows, focus group discussions with teachers and fellows, evaluation of fellows' written curriculum resources, and evaluation of student work in class and at a student research congress held annually on the Cornell campus. Teacher interviews in the 2003-04 school year employed the Cognitive Clustering Model (Harwood & Hansen, 2004) to engage teachers in discussion of their conceptions of inquiry and its applicability in their teaching. In addition to providing post assessments of their conceptions of inquiry teaching, end-of-the-year interviews of teachers and fellows also explored the scientist/teacher relationships, the perceived nature and success of each fellow's curriculum project, and the perceived impacts of CSIP on the teacher, fellow, and students.

Interviews and focus group discussions conducted in 2003-04 were transcribed in entirety and analyzed using Nvivo® software. In previous years, interviews were recorded and summarized. Content analysis was performed using a qualitative approach based on grounded theory and constant comparative analysis (Glaser, 1969; Patton, 1990; A. L. Strauss, 1987). Using the research questions to guide the analysis, the data were coded using the pattern of open coding, axial coding, and selective coding advocated by Strauss and Corbin (1990).

The nature of scientist/teacher partnerships was examined through triangulation of data from interviews of fellows and teachers, classroom observations, and analysis of projects conducted by students and curriculum resources produced by fellows (Guba & Lincoln, 1983). A combination of qualitative and quantitative methods formed the basis for developing grounded interpretations of the data (Glaser, 1969; Guba & Lincoln, 1983; Scriven, 1983; Silverman, 2000). Classroom observations were performed using an ethnographic approach. Notes were taken throughout each visit to capture the trajectory of the lesson, teacher dialogue and actions, student dialogue, and other relevant information. Handouts and other materials related to the lesson were collected. Following each observation, the participating teacher and fellow were asked to send an email reflecting their impressions of the successes and challenges of the lesson.

Results and Discussion

Obstacles to Inquiry

CSIP teachers identified four major hurdles affecting their ability to incorporate inquiry teaching strategies into their classroom: (a) state-mandated curricula and the accompanying high-stakes final exams, (b) other time related constraints, (c) students' expectations and abilities, and (d) teachers' fear of launching into the unknown. These constraints were articulated across the board, by new teachers and those with decades of experience in the classroom.

<u>High Stakes Exams</u>

Although CSIP teachers are self-selected for an interest in innovative teaching practices, many expressed concern about tension between teaching in ways that they consider to be best practices versus the need to cover a predetermined body of topics, concepts, and principles in order to prepare students for Regents final exams. (New York requires students to pass two Regents science courses and at least one Regents science exam in order to graduate.) Some teachers described the Regents exams as both the guiding framework for their course and the primary motivator in their teaching. For example, one said:

> I think my role is to give kids opportunity to do [science] in a meaningful way that accomplishes my objective of getting them ready for the state

> exam at the end the year and a larger objective of opening career possibilities to them. I think it's my role to organize the body of knowledge in such a way that kids can master what they have to, but to also provide enough opportunities for hands-on and other activities that will excite their interests and kind of solidify the abstract concepts for them.

A natural outcome of the intense focus on Regents exams is the perception by teachers of their role being to help students master a particular body of knowledge. At times this translates into teaching strategies specifically designed for test preparation. One teacher described inquiry labs as extra labs that get used during the week or two before semester breaks so that anyone who was absent would not jeopardize their ability to do well on the Regents final exam. Another teacher said that she creates all of her tests with a format similar to the Regents in order to accustom her students to the type of multiple choice questions they would see on the exam. Conflicting ideas about effective teaching strategies are illustrated in this teacher's reflection on the potential benefits and drawbacks of worksheets:

> I've never been a worksheet sort of person, but I will say that I think that sometimes my students have not been as well prepared for Regent exams as if I'd had them do a worksheet. On the other hand my daughter went to a high school where kids did great on Regents exams and did all kinds of worksheets and didn't learn any kind of science.

Perhaps surprisingly, Regents exams dictate teaching even in classes in which the students are not at risk of failing:

> You don't want to change – your classroom works, your kids are getting through the Regents exam. Why bother changing? You know, I've got 100% passing rate right now with the new Regents… All of us teachers at (our school) have had 100% passing rate for the last couple of years. Why do we want to change, why do you want to upset the basket?

Although teachers teaching elective courses have greater flexibility in implementing innovative teaching practices than those teaching Regents courses, they nonetheless face other hurdles to inquiry described below.

<u>Time Constraints</u>

Time constraints were cited by teachers as hurdles to implementing inquiry in elective courses as well as those with a tightly prescribed curriculum. One concern, brought up by several teachers, was that more class periods are needed for inquiry-based labs compared with traditional lab exercises. For example, one teacher explained that many of the labs he uses end up "not having much of an inquiry component to them" because inquiry requires more time and students may not come up with the correct results or interpretations:

> …the biggest thing about inquiry is that it takes time to digress away from your expected outcome. So [for some of the] State labs that we're required to do,

> inquiry is not something that you want because you've got to have kids understand exactly the content of the lab and how you get from A, to B, to C.

A related concern brought up by two teachers was the idea that it takes too much time for students to “figure it out for themselves.” Both of these teachers had relatively naïve conceptions of inquiry as a type of unstructured learning in which students discover scientific concepts and principles entirely on their own:

> When they can figure it out for themselves, inquiry based, no question about it… but the time factor doesn't allow for that. You know, the discovery learning. Put a whole bunch of materials in front of the person and say, “Discover, figure out what you can about it, and then report back.”

A final time-related concern related to the teachers’ preparation time rather than time in class. Several teachers stated that they do not have sufficient time during the day to develop inquiry-based labs or activities for their courses. They argued that designing inquiry-based activities requires extra time which isn’t readily available. For example, one teacher mentioned that he currently teachers “five classes a day officially, six unofficially, and I have one half-hour of prep time.” He felt that one of the biggest things anyone could do to support teachers would be to give them more preparation time for their teaching, especially if the goal was to develop inquiry-based laboratories or activities.

<u>Student Expectations and Abilities</u>

Eleven of the fourteen teachers interviewed at the beginning of the 2003-04 academic year said that inquiry is a good idea but might not be practicable with their students. Interestingly, their concerns were related to students at both ends of the achievement scale. Some teachers referred to students who can’t handle the independence that an inquiry investigation entails, whereas others referred to students who are strong academically but become frustrated with inquiry because it breaks from their accustomed route to academic success.

One teacher summarized her feelings about the difficulty that some students have with inquiry learning by stating simply that “some students feel lost.” She mentioned that this feeling can be exacerbated when such a student is paired in a group with one or more other students who have similar reactions to an inquiry environment. A similar sentiment was expressed by other teachers in terms of students needing to understand the basic elements of a scientific investigation before they can “do inquiry.” One teacher stated,

> We're finding that you sure can't just jump into (inquiry), expect them to go through all the steps and have any clue. You have to start with a very simple, tiny little experiment and have them work their way up to more complicated things. This is just like some of the labs that are coming out of the state. They're definitely not something that you do right at the beginning of the year. They are inquiry things that they have to learn just how to go about. How to write a hypothesis, how to understand what are independent variables and dependent variables, and how you have to keep

other variables the same. They have to have some concept of what you're doing before you can actually do an experiment.

One teacher said that a mixture of teaching styles is necessary "…because there are kids that just can't handle [inquiry]. And there are kids that can't handle straight traditional learning either, so you have to give all students a little bit of something every week otherwise they will shut down." A similar comment was made by another teacher who framed the issue in terms of flexibility. When asked whose flexibility she was referring to, she said,

> The kids and teacher both. And it's sometimes hard for both to be flexible because you know this is new. Like I said, we do have a pretty good portion of kids who come from [a private school], and it's hard for them to be flexible you know. And some kids just have a hard time with (inquiry). That pushing them out of the box. So everybody has to be flexible.

Another concern expressed by teachers with regard to inquiry was that their students expect them to provide structure and guidance and wouldn't be satisfied with a more open-ended form of learning. One teacher said:

> I think there are a lot of students, particularly some of the brighter students, who want me to give them directions and they want to do it and they want to do it better than anybody else, and they want to get the right answer and they get very frustrated when I tell them, "Well, maybe that would work. Why don't you try it? You can always do it again if it doesn't work." They're thinking, "Do it again? No, I did it right the first time." So it's frustrating, but I think for those kids the experience is a really good lesson.

High-achieving students are adept at memorizing information and following directions to achieve high grades through traditional forms of assessment. Inquiry-based investigations can make these students uncomfortable because different types of learning are required. One teacher comments that some of her normally high-achieving students did not do as well as other students on inquiry projects:

> It made them absolutely crazy. It's kind of interesting. You'd think that the kids that got A's all their lives would be these great critical thinkers, but I found that that was the opposite, that some of my special ed kids were better at the critical thinking piece than my advanced kids.

Other teachers expressed similar concerns about students at any ability level. However, they also noted that students' discomfort with inquiry-based labs can be a good experience:

> Some kids want everything to be step-by-step. They want to be spoon-fed. And you know they are comfortable with that, and they don't like it to be fuzzy. So I don't think everybody will necessarily like inquiry-based. But will they benefit? Maybe it's good for them to see that the world is not always, you know, clear cut and perfect.

Several teachers with significant experience in inquiry-based teaching discussed the opposition they have faced from students when using inquiry strategies. For example, one said:

> I did a lot more inquiry exploration in the middle school. They would look at me and they would say, “You are a horrible teacher because you're not telling us the answer,” and I'd say, “I don't care. You have to find out the answer.”... What I find probably even more with the high school kids is that they are kinda like, “Just tell us what you want us to know,” so it's a struggle.

Although the extent to which science teachers tend toward a didactic, teacher-centered style of teaching has been well documented (Bryan, 2003; Eick & Reed, 2002; Rop, 2002; Simmons et al., 1999; Squire, MaKinster, Barnett, Leuhmann, & Barab, 2003), the degree to which students believe that learning should be primarily a transmissive endeavor is less well researched. Using an attitude questionnaire, Berg, et al. (2003) assessed college student perceptions of their own role and the role of their teacher in the context of an expository or open inquiry chemistry experiment. They found that some students defined good teaching in terms of presenting clear instructions, spelling out exactly what to do, and preparing students for the exam. The degree to which K-12 students have similar perspectives is a potential topic for future research.

Fear of the Unknown

Although fear of the unknown was not brought up by teachers in beginning-of-the-year interviews, those interviewed at the middle or end of each school year consistently have mentioned that working with fellows has helped them to overcome their reluctance to let students explore topics for which the outcome was not known. This finding applies to teachers of all types of courses, both with and without mandated curricula or high stakes final exams.

Of the four CSIP teaching approaches outlined in the Research Context section, open-ended research requires the greatest degree of willingness to relinquish control in order to accommodate open-ended learning. For teachers with no previous experience conducting scientific research, delving into projects with unknown outcomes requires a major leap of faith. After his class conducted a yearlong series of investigations under the guidance of a fellow, the teacher of an elective high school course reflected about this experience:

> “I couldn’t see the path ahead, which was scary but also exciting. It’s wonderful to present your mind with something it’s not familiar with. It’s also uncomfortable for me as a teacher. We were doing something tentative, and I was unprepared to answer questions. I’m responsible for spending time in a way that’s fruitful. If you put a lot of time into an effort that becomes hollow, that wouldn’t be a responsible use of class time…. It’s a matter of direction and leadership, groping down a path together. It requires a leap of faith, deciding that I think the path will lead someplace that will be worthwhile.

Overcoming the Obstacles

Although the obstacles to inquiry-based teaching are well documented, much less is known about effective means of helping teachers to overcome these obstacles. Our second research question addresses this gap by focusing on the ways and extent to which working collaboratively with university scientists can help teachers to implement short or long-term inquiry projects in their classrooms.

Teacher/Scientist Partnerships

Unlike most teacher professional development programs, CSIP takes place primarily in the teachers' classrooms as teachers and fellows work together to apply new teaching strategies. In some cases, the teacher observes the fellow in action but provides little or no input in the planning and implementation stages. In more collaborative partnerships, the fellow and teacher work together throughout all stages of developing and implementing a new curriculum unit. One teacher commented:

> [Fellow] and I worked very well together in the classroom. I don't think we ever had an activity where just [fellow] led or just I led… It ended up being a dialogue between us… It's always helpful for students to see their teachers or authority figures in dialogue, possibly disagreeing at times, you know, in kind of a positive and friendly way.

Experiencing inquiry in action in their own classrooms helps teachers to take risks that might otherwise seem insurmountable. For example, one teacher told us, "I had downloaded the bioassay curriculum, it looked interesting, and I thought about using it. But then I thought "If it didn't work, then what?'" When this teacher's classes conducted bioassay experiments under the guidance of a fellow, it turned out that the data did not agree with the class's predictions. As the fellow led the class through analysis of their findings, the teacher learned along with the students the ways in which open-ended experiments can get students to wrestle productively with nature of science issues such as data variability, bias, replication, and the need for experimental controls.

Inquiry by definition takes many forms, and it is implemented in many ways by CSIP fellows to meet the needs of collaborating teachers and their classes. The most ambitious partnerships last the entire school year and enable the students to engage in long term research projects. For example, in a teacher-designed high school ecology class at an alternative school, a fellow led a yearlong project in which students designed and conducted their own soil science experiments. First, he introduced the students to nutrient cycling and forest ecology and taught them seven protocols for testing soil properties such as pH, permeability, and CO_2 production rate. Small groups of students next developed questions related to the overall topic of the effect of worms on forest soils (a focus of his own work at Cornell), and then designed a means to investigate their questions using the protocols they had learned (Phillips & Krasny, 2001). Another fellow worked with high school biology classes to investigate the extent to which humans react to olfactory cues, producing results rigorous enough for presentation at the Annual Meeting of the Association for Chemoreception Sciences (S. Olsson, Barnard, & Turri, 2004). Another fellow is publishing a book with the National Science Teachers Association based on genetics experiments that she designed and conducted with CSIP classes.

Because long-term research is difficult to fit within the curricular constraints of most science courses, another approach taken by fellows is to refocus required labs to use inquiry strategies. For example, a CSIP fellow remodeled an Advanced Placement Biology lab in which students observe the behavior of pillbugs subjected to differing environmental conditions. This lab commonly is carried out with a straightforward list of instructions so that all students do the same experiment and get roughly the same results. The alternative approach developed by a CSIP fellow led to similar conclusions in terms of pillbug behavior but gave the students wide-ranging latitude in terms of designing and conducting their own experiments to investigate pillbug responses to environmental conditions (S. B. Olsson, 2004).

Another way in which fellows have built inquiry-based lessons into a single class period is through discussions that get students thinking about issues related to the nature and process of science. One fellow taught middle school students about the role of peer review in science by using a hands-on activity with fossils and a pair of articles published in the *National Geographic* having to do with the discovery of a new fossil and the subsequent discovery that the fossil was counterfeit (Gift & Krasny, 2003). Following the December 2004 tsunami, a fellow from Cornell's hydraulics laboratory demonstrated to middle school students a computer simulation of wave travel, then discussed with them the difference between model predictions and ground truth data collected by scientists who currently were making wave height measurements along ravaged coastlines.

<u>CSIP Learning Community</u>

Although initially we focused primarily on the teacher/scientist partnerships in addressing our second research question, we have found that CSIP's keys to success in helping teachers overcome the obstacles to inquiry lie not only in the collaborative nature of these partnerships but also in the supportive learning community in which teachers and fellows interact. In CSIP, professional development for teachers and fellows encompasses a variety of opportunities intended to develop and sustain a learning community in support of inquiry-based instruction. Components of this learning community include annual orientation sessions, periodic teacher workshops and focus group sessions, an annual student congress, and a website on which we publish curriculum resources developed by fellows or fellow/teacher teams.

<u>Orientation.</u> Each year, CSIP begins with a 2-day orientation in which teachers and fellows work together to explore ways to implement inquiry in various types of secondary level science classes. This workshop is of considerable importance in terms of developing interpersonal relationships and establishing collective norms, expectations, and conceptual frameworks. Although each school year starts with a new group of fellows, many of the teachers remain in the program for multiple years, and those with prior CSIP experience become the experts, describing to newcomers the experiences they have had working with fellows in previous years.

CSIP fellows are graduate students from a broad range of academic disciplines. Few know each other at the beginning of the school year, but a sense of community develops through their shared outreach experiences. Throughout the year, the fellows participate in a weekly seminar in which they learn about pedagogical theories, issues, and strategies, share classroom experiences, and rehearse presentations in which they introduce themselves as scientists. Some fellows develop further rapport through coteaching in the same secondary classrooms, collaborating on development of curriculum resources, or getting to know each other while commuting together to distant schools. The regularity and intensity of interaction creates a strong sense of connectedness among fellows and sense of identity with CSIP. This is less true for teachers, who are dispersed across many schools and get together through CSIP only intermittently.

Teacher Workshops and Focus Groups. Several times per year, CSIP teachers interact with each other and with the project team at workshops and focus group discussions. In these sessions, teachers share their experiences working with fellows. Those new to the program get the chance to learn from those with more experience, but even veteran teachers relish this opportunity to exchange stories and advice. Teachers consistently comment that CSIP get-togethers have helped them establish connections with other teachers and fellows, given them new ideas and heightened confidence to try something new in their classrooms, and reinforced their awareness of their own role as collaborators with an important role in the program. For example, after a session designed for teachers to meet new fellows, one teacher realized that they were as nervous as she was, and this experience transformed the way she perceived the fellows, her role in the project, and the reciprocal nature of CSIP partnerships:

> I've been really nervous about the program because of the brainpower of the grad students – it's been very intimidating, but after the Thurs. program I realize… they WANT to learn from us AND interact with our students (we're providing them with a "lab"). The two engineers said they want to be professors and it occurred to me as I was driving home that they will probably start out teaching freshmen and it might appeal to them to have a chance to re-familiarize themselves with 18 year olds before doing their post-docs!

Student Research Congress. Each year CSIP holds a student research congress that serves as a real-world context within which participating students can share their work. The students develop posters that present the rationale, methods, results, and interpretations of their experiments. Each student group receives written feedback from their peers and verbal feedback from fellows, CSIP staff, and teachers other than their own. This experience motivates students to achieve and gives teachers an opportunity to get ideas from what has been done at other schools.

Through the orientation, teacher workshops and student research congress, the CSIP learning community provides opportunities to make connections with others who have common interests and goals. Teachers connect with other teachers who are interested in trying something new, and they gain motivation and inspiration from each other. During orientation and throughout the year, teachers also make connections with one or more fellows whose academic background and teaching interests mesh well with their classroom needs. Often the teacher-fellow partnerships result in a relationship characterized as more than professional. Several teachers and fellows referred to one another as “friends” or “true colleagues” – people with whom they hope to keep in touch beyond the end of the year. When asked about the extent she felt connected to the fellow with whom she was working, one teacher said:

> I would like to have her for my daughter. At the end [of the final field trip], I said, “Well, I’ll see you in September, I hope,” and she said “No, we don’t get to do this anymore.” I said, “I thought we’d grow old together!”

Although some CSIP partnerships last yearlong and others a single day, we aim for all to be based on the principles of mutual trust and reciprocal learning. Because the fellows are actively engaged in scientific research, they bring specialized scientific knowledge and skills into the classroom. CSIP teachers consequently have the opportunity to learn current topics in science and aspects of scientific inquiry from the fellows with whom they work. Fellows in turn learn practical teaching skills as they collaborate with teachers to plan curriculum, design age-appropriate lessons, assess student learning, and address classroom management issues. Because of this reciprocity, fellows as well as teachers gain teaching skills while working together in teacher/scientist partnerships (Trautmann & Krasny, submitted).

Fellows typically start out the year feeling worried about classroom management but shift increasing attention to pedagogical issues as the year progresses. A fellow described the reciprocal nature of her relationships with the two teachers with whom she had worked intensively:

> They would be a great resource for education students – helping them think about what knowledge they needed to get out of this, what level of knowledge they need to have (for teaching), what level of language does it need to be, and the structure of the worksheets. (On the other hand) I was very much a resource for the science (side of things)…

The trust that builds through reciprocal partnerships, bolstered through the support of the CSIP learning community, helps teachers overcome their ‘*fear of the unknown*.’ Many teachers want to try new teaching strategies but don’t feel they have the necessary support or resources to do so (Tobin & McRobbie, 1996). Through working with CSIP fellows, teachers are scaffolded in trying new approaches that they consider risky or feel unprepared to lead without assistance. As one teacher stated:

> I think professionally it definitely let me try things that I probably wouldn’t have tried on my own. So, I definitely stretched myself beyond what I ever would have done individually. I think it broadened my style.

Implications

In CSIP, teams of teachers and fellows implement inquiry activities ranging from structured to open ended and from single class periods to yearlong projects. Once teachers have initiated inquiry projects, they commonly tell us about the increase in motivation, interest, and enjoyment of learning they see in their students. One teacher commented, “Students gain motivation when they do ‘real science,’ and I’ve never seen my students work as hard as when they were preparing their posters to bring to the student congress." Another said that her students had learned "what science is about and the hard work it takes to get answers." A teacher of a lower track science class said that participating in CSIP projects gave her students the opportunity of "finding an aspect of science that they're interested in and can even get excited about." A teacher of a research course for high school seniors remarked that inquiry projects are better than traditional labs because they leave a lot more room for higher order thinking. She commented that the fellow she worked with was adept at leading discussions that triggered students' thinking about the meaning of their results. Rather than just getting the right answer, the students grappled with uncertainties about what they had learned and how these findings fit with other topics they had studied over the course of the year.

However, student excitement about projects and enjoyment of learning do not necessarily happen right away. Students who are accustomed to learning what they need to know for the test may initially be frustrated by projects in which there is no uniquely correct answer. Teachers, too, may be wary of inquiry when their students' projects seem to lack clear direction. One teacher described his class's yearlong involvement with CSIP as a path that got built brick-by-brick. Together, the students, teacher, and fellow chose a project and carried it out as genuine co-researchers, with nobody being able to anticipate the outcome. The teacher stated that if they had had to quit part way through this process, he would not have recognized it as a success because of all the time that had been spent in apparent floundering as the class collectively explored options for their research project. The initial frustrations evolved into excitement on the part of the teacher and his students about the project itself and about their growing abilities to work independently in designing and conducting valid scientific experiments and interpreting their results.

Conclusion

Teachers participating in CSIP have described a complex range of barriers to incorporating open-ended inquiry in their classrooms. Not surprisingly, time constraints and the need to prepare students for high-stakes exams commonly were identified by teachers as impediments to implementing inquiry. Other barriers included concern about the possibility of not accomplishing specified learning goals and hesitancy toward breaking with traditional models of teaching. Teachers with no prior experience conducting scientific research were most likely to be intimidated by the prospect of launching into a project without predetermined answers or outcomes.

Teachers also voiced doubts about the appropriateness of inquiry for their students at both ends of the achievement scale. For example, several teachers voiced concerns about the readiness of lower achieving students to delve into inquiry and suggested that these students would need to be walked carefully through straightforward cookbook-style labs before engaging in even the most structured sorts of inquiry. On the other hand, teachers also were worried about the challenges of conducting inquiry with students who excel in traditional educational settings but become frustrated or annoyed when the expected answers are not spelled out clearly and concisely.

In our experience with CSIP teachers, we have found evidence of all four of the cultural myths identified by Tobin and McRobbie (1996) as contributors to teachers' perception of science as a body of truths rather than a process of discovery. The transmission myth, which views the teacher as the principal source of knowledge to be delivered to students, is seen in teachers' discomfort with not knowing the answers to students' questions or the expected outcomes of their open-ended experiments. The needs for efficiency, maintaining the rigor of the curriculum, and preparing students to succeed on examinations together explain the reluctance of many teachers to divert from traditional models of teaching to try implementing the potentially more risky approach of inquiry-based learning. As Tobin and McRobbie (1996) point out, collectively these myths translate into content coverage being considered more important than learning with understanding because in-depth understanding is not necessarily required for success on high-stakes exams.

In spite of the power of these obstacles to inquiry, we have found that many teachers are interested in implementing open-ended inquiry in their classrooms. NSF's GK-12 program provides the opportunity for teachers to collaborate in long-term partnerships with science graduate students and participate in a learning community comprising fellow teachers and university scientists and educators. The scaffolding provided through these partnerships and associated learning community enables teachers to take increased risks in their classrooms. When fellows and teachers collaborate to facilitate student inquiry projects, together they deal with unexpected or unknown outcomes, address misconceptions, and determine how open-ended inquiry-based learning can best be used in specific classroom settings. This helps teachers overcome their initial hesitation and see the benefits that inquiry learning can produce in terms of motivation and achievement of students at a variety of grades and achievement levels.

Because participation in CSIP is voluntary, we cannot claim that similar benefits would be felt by teachers who are not as motivated to try inquiry-based teaching. However, for teachers interested in making the leap to open-ended student inquiry, collaboration with science graduate students appears to be an effective means of overcoming initial hurdles and gaining confidence in the value of this less teacher-driven approach to student learning.

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