WHAT MAKES INQUIRY SO HARD? (AND WHY IS IT WORTH IT?)

Despite growing consensus regarding the value of inquiry-based teaching and learning, the implementation of such practices continues to be a challenge for many teachers. The Cornell Science Inquiry Partnerships (CSIP) program aims to provide sustained and long-term support for teachers who wish to implement inquiry-oriented teaching. Through CSIP, university graduate student fellows work with middle and high school teachers to develop and implement inquiry-based lessons and units. This study investigated challenges and rewards inherent in this process. Analysis of teacher interviews, focus group sessions, classroom observations, and ongoing discussions with teachers and fellows suggests that the participants face multiple barriers to engaging their students in open-ended inquiry. The most commonly perceived barriers include district or state mandated curricula, insufficient time for inquiry, student expectations and abilities, concern about the potential for not accomplishing specified learning goals, and fear of the unknown. Through partnerships with university fellows, teachers are able to address these concerns and become increasingly comfortable with inquiry-based teaching and learning. Benefits reported by teachers and students include increased motivation and interest in science, a greater degree of higher order thinking leading to deeper understandings, and development of abilities to work independently in designing and conducting valid scientific experiments and interpreting the results.

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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).

The various approaches to inquiry span a continuum with varying degrees of self-directed versus teacher- or curriculum-directed learning (National Research Council, 2000). In guided inquiry, the teacher provides the focus questions, then prompts and supervises the approaches used by students to address these questions. At the more open-ended end of the continuum, the teacher facilitates the process of students choosing their own questions and the methods by which they will investigate these questions. This may mean that the teacher and students become co-researchers, together choosing questions and strategies to find answers that initially are unknown to all (D'Avanzo & McNeal, 1997). Teachers exhibit a wide variety of conceptions of inquiry. Some relate it to learning that is driven by questioning from the teacher or students, but many think of it as including 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).

Although inquiry-based learning is central to current science education standards, it still is far from the norm in U.S. classrooms, and efforts to meet this goal face a number of challenges. (National Research Council, 2001; Weiss, 1997). Implementation of inquiry learning is hampered by the fact that teachers view factual knowledge as the most important student outcome, achievable through repeated drill and practice (Cronin-Jones, 1991). Another challenge to implementing inquiry-based learning is that teachers tend to teach using the methods through which they were taught, relying on textbooks, lectures, and demonstration labs rather than 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).

These challenges to reforming science education are summarized by Tobin and McRobbie (1996) in terms of 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).

Another impediment to implementing inquiry-based learning is the fact that it can be intimidating, especially for teachers who have no experience in conducting scientific research. Teachers lacking research experience feel unprepared to lead students in formulating questions, designing experiments, and representing data – activities that are pedagogically risky but also central to current conceptions of science education reform (Kennedy, 1997; Singer, Marx, & Krajcik, 2000; Windschitl, 2003).

Another common hurdle to implementing inquiry-based teaching is teachers' reluctance to feeling out of control of what is going on in their classroom (Uno, 1997). In traditional demonstration-style laboratory exercises, the teacher knows in advance what the outcome will be, and unexpected results mean that something has gone wrong. Teachers with no research experience tend to view unexpected results in inquiry projects in this same light, rather than as interesting scientific findings that can lead to further investigations. 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). Working with messy data, understanding the complexities of decision-making under conditions of uncertainty, and incorporating the public, economic, and social influences on science, extend the realm of classroom science beyond the traditional "cookbook lab" approach in which the outcome of laboratory experiences is predetermined (Amerine & Bilmes, 1990).

University Fellows as Teaching Partners

Through an NSF-funded Graduate Teaching Fellows in K-12 Education (GK-12) program, the Cornell Science Inquiry Partnerships (CSIP) program places graduate students in middle and secondary schools as teaching fellows.[1] The fellows work with teachers to develop and implement inquiry-based lessons and units. CSIP aims to enable students to frame sound scientific questions and investigate these questions by gathering and interpreting appropriate evidence. As teachers work with fellows to facilitate these projects, our goal is for them to become more familiar and comfortable with inquiry-based teaching.

CSIP fellows represent a variety of academic disciplines in the natural, physical, and social sciences and engineering. They spend an average of five hours per week in preparation and ten hours per week teaching collaboratively with partner teachers. Teachers from about 20 schools are invited to participate each year in a two-day summer orientation session and periodic school year workshops. Each spring we hold a student research congress on the Cornell campus. Students from all participating classes are invited to present posters or short oral presentations about their CSIP projects. During the congress, students peer review each other's work using a rubric developed by the fellows.

Working in classes ranging from remedial through advanced placement science, CSIP fellows develop and lead inquiry-based projects designed to meet the curricular needs of each classroom.

[1] For more information about CSIP, visit our website: http://csip.cornell.edu.

These projects range in length from a single class to an entire school year. The approaches employed by fellows generally fall into one of the following four categories:

1. *Open-ended research*: an original experiment or series of experiments designed and conducted by students with facilitation by the fellow and teacher,
2. *Remodeled labs*: traditional lab and field activities that have been adapted by fellow/teacher teams to meet curriculum requirements through a more inquiry-based approach,
3. *Nature of science lessons:* activities designed to help students understand how scientists study the natural world, and
4. *"Inquiry moments:"* 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.

In the ideal case, CSIP fellows facilitate projects in which the teacher, fellow, and students work together as co-researchers on genuine research endeavors. Where this is not possible, fellows work with teachers to fit shorter-term inquiry projects into curriculum plans. The underlying goal is that students will learn to frame scientific questions and use these questions to guide the process of gathering and interpreting appropriate evidence. The four approaches are discussed in more detail below.

Open-Ended Research

CSIP fellows help teachers to implement research projects based on published curriculum resources developed at Cornell (Carlsen, Trautmann, Krasny, & Cunningham, 2004; Krasny, Trautmann, Carlsen, & Cunningham, 2002; Schneider, Krasny, & Morreale, 2001; Trautmann, Carlsen, Krasny, & Cunningham, 2001; Trautmann, Krasny, Carlsen, & Cunningham, 2003), and they also design and implement their own research projects with middle and high school students. Long-term, open-ended research projects fit most readily into courses that are not constrained by state-mandated final exams. For example, in a teacher-designed high school ecology class at an alternative school, a CSIP 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).

Remodeled Labs

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.

When another fellow began working in a high school botany class, he noticed that the students recently had completed a bean-sprouting activity in which some sprouts had grown far longer than others. The fellow led a discussion of potential reasons for the large variability in growth rates and had the students design follow-up investigations to address their newly developed hypotheses. The goal of the original teacher-led project had been merely to observe the sprouting process, but the fellow was able to make the experience more inquiry-oriented with his follow-up discussion of experiments that the students could conduct to investigate phenomena they had observed.

Nature of Science Lessons

The *nature of science* has been described as the values, beliefs, and assumptions that underlie the creation of scientific knowledge, contrasted with other ways of knowing about the natural world (McComas, Clough, & Almazora, 1998). Science education reform efforts emphasize the importance of students not only learning science content, but also developing an understanding of how scientists study the natural world (National Research Council, 2000). One way in which CSIP fellows address nature of science issues is through ongoing discussions about topics such as experimental design and data analysis. Fellows also have developed activities to address specific aspects of science such as the role of observation versus inference, or the ways in which bias can influence scientific results. 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 had been pieced together and thus was a fake (Gift & Krasny, 2003).

"Inquiry Moments"

In conjunction with any of the above three approaches, CSIP fellows sometimes use informal, spontaneous discussions to get students thinking about what they are doing and how it relates to broader issues in science. This may involve the whole class or one-on-one interactions as fellows talk with students working on various aspects of designing experiments, collecting data, or interpreting their results. It can be as simple as pausing to reflect on why they are doing this particular activity and how it relates to other topics they have addressed over the course of the year. Students typically learn science as a series of separate topics and may not see the connections from one topic to the next, so this sort of reflection can help them to develop deeper overall understandings. One teacher commented that the fellow in his classroom continually worked to set the context for learning by having students address the "so what?" question of why they should care about the topic on hand. Another fellow took opportunities during the course of a yearlong research project to stop and ask students to reflect on their original research question. In doing so, he kept the inquiry process focused on questions that could be addressed scientifically and helped the students use what they had learned to shape their continuing investigations.

Research Methods

The overall goal of this study was to investigate the challenges and rewards inherent in implementing student-directed learning in CSIP classes. In particular, we chose to focus on the following research questions:

1. What barriers influence teachers' receptivity to the implementation of open-ended student inquiry?
2. In what ways can classroom assistance by university fellows help teachers overcome the obstacles to inquiry-based teaching?
3. What benefits do teachers perceive from inquiry-based learning once they have seen its successful use in their classrooms?

The study employed a qualitative approach based on grounded theory, constant comparative analysis, and the case study method (Glaser, 1969; Patton, 1990; Strauss, 1987; Yin, 1994). Data sources included teacher interviews, the Inquiry Teaching Belief instrument (Harwood & Hansen, 2004), recorded focus group sessions, classroom observations, and ongoing discussions with teachers and fellows.

During the 2001-2002 and 2002-2003 academic years, we interviewed a total of 21 teachers, including all the teachers who had been engaged in long-term partnerships with one or more fellows, plus five more who had worked with fellows on a short-term basis. Most of the interviews took place face-to-face at the teachers' schools, although four were conducted via telephone, and one via email. Each interview lasted 20 to 45 minutes. The interview protocol consisted of 10 questions designed to explore ways in which fellows impacted partner teachers and their students. At the beginning of the current school year (2003-2004), we interviewed 14 teachers, half of whom were new to CSIP and the other half of whom had had at least one year of previous experience in the program. These interviews were conducted face-to-face during a day-long workshop on campus. Each interview lasted 30 to 45 minutes and entailed a series of questions designed to assess the teachers' beliefs about effective science teaching, understandings of inquiry-based teaching and learning, and perceptions of inquiry in relation to their own teaching. In this paper, we focus on the perceptions of the teachers with regard to the research questions above.

Results and Discussion

<u>Barriers to Inquiry</u>

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 constraints related to time, (c) students' expectations and abilities, and (d) teachers' fear of launching into the unknown. These constraints were articulated across the board, by new and veteran teachers, and by teachers new to CSIP and others with one or more years of experience in the program.

High Stakes Exams

In New York State, students must pass two Regents science courses and at least one Regents science exam in order to graduate. The pressure to prepare students for these exams is an ever-present worry for many teachers. 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.

A natural outcome of the intense focus on the end-of-the-year exams is the perception by teachers of their role being to help students master a particular body of knowledge, which at times translates into specific teaching strategies designed for test preparation. One teacher said that she gives tests at the end of each unit with a format similar to the Regents in order to accustom the students to the type of multiple choice questions they would see on the exam. Another teacher discussed her views on the potential benefits and failures 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.” Another teacher described inquiry labs as extra labs that get used during the week or two before semester breaks. That way if someone missed one of these labs, it would not jeopardize their ability to do well on the state science exam.

Some teachers described the 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.

Not surprisingly, the extent to which teachers feel pressured to cover set curricula depends on the courses they teach. An 8th grade teacher described her science curriculum as “a mile long and an inch deep,” stating that she can go in-depth on some topics but must provide general overviews of others. Teachers teaching elective courses such as botany or environmental science have the most flexibility in implementing innovative teaching practices. Those teaching Regents Earth Science are most likely to complain about the amount of material they must cover to prepare students for the final exam. For example, one Earth Science teacher described this curriculum as “jam packed,” and went on to say, “…so we find ourselves the last week of school teaching brand new stuff while we're reviewing the old stuff. It's crazy, it's really crazy.”

The Living Environment (Biology) Regents exam and curriculum offer more flexibility than Earth Science because they were revised a few years ago to cover less material and incorporate understandings related to experimental design and data analysis. Even given this curriculum flexibility and increased emphasis on the processes of science, however, some teachers hesitate to implement more inquiry-based teaching practices. For example, one Living Environment teacher told us:

> 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?

Another stated, “If you look at the state guidelines they are very general. They could certainly be addressed through an inquiry-based class, but that’s not what they’re testing on the exam. There are an explicit set of things.”

Insufficient Time

Although time constraints are an integral part of the pressure caused by standardized testing in New York, teachers also explicitly cited other types of time-related concerns as hurdles to implementing inquiry in their classrooms. One concern, brought up by several teachers, was that greater time is necessary to carry out an inquiry-based lab compared with a traditional laboratory with a predetermined outcome. One teacher stated that he and the teachers he works with select among different versions of a lab depending on the amount of time they have available, choosing traditional verification-style labs when scheduling is tight. Another 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.” I've never done it, though, but that's the way they learn best, and they learn best too I think from each other. I think they can teach each other science.

A final time-related concern has to do with the teachers’ preparation time. 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.

Student Expectations and Abilities

Eleven of the fourteen teachers interviewed at the beginning of the 2003-2004 academic year said that they see their own students as barriers to doing inquiry. Interestingly, these concerns were related to two very different types of students. 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 goes beyond their accustomed process of memorizing information and excelling on exams.

Needing the Basics. 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.

At times such attitudes were balanced by statements that referred to both ends of the spectrum in terms of student comfort levels with inquiry. One teacher said that to do inquiry 100 percent of the time would be a mistake, "…because there are kids that just can't handle it. 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 the Catholic 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.

Student Expectations. The second way in which teachers perceive students as a barrier to inquiry is with regard to students who expect teachers to provide a significant amount of structure and guidance. 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 have become very adept at memorizing information presented to them by teachers and recalling that information in a way that enables them to do well on traditional forms of assessment. Having to do inquiry-based investigations can make these students uncomfortable because the answers are not so clear cut. One teacher comments that some of these 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 teacher 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.

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 is not predetermined. This applies equally to teachers of all types of courses, with or without mandated curricula or final exams.

Of the four CSIP inquiry categories outlined above, fear of unknown results was mentioned most frequently with regard to *open-ended research*, which requires both the greatest time commitment and 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. One teacher was quite reflective about his 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.

This teacher commented that prior to having worked with a fellow on a long-term research project, he had wanted to try something similar with his students but had not been able to overcome his fear that it might not lead to productive learning outcomes. In a follow-up interview, he described his initial “terror at not knowing what we would be accomplishing,” followed by “a sense of exhilaration that we all are learning something new together.”

Overcoming the Obstacles

We have found that through working with fellows, teachers have developed experience and greater confidence in their ability to use all four of the inquiry approaches described above. Example quotes are shown in Table 1.

Table 1: Example Teacher Reactions to CSIP’s Four Types of Inquiry

Type of Inquiry	Teacher Quote
Open-ended research	CSIP changes the way I think about inquiry – I’ve become more rigorous in the types of questions I pose to kids, improved my research techniques – and have passed this on to my students.
Remodeled labs	I hadn’t done much of this before. I didn’t realize that guided inquiry was effective. It has changed my perspective. I’m not just rewriting questions, but totally reformulating all of my labs.
Nature of science lessons	Working with [Fellow] helped us in thinking about data and how to interpret it, significance, how this reflects back on sampling and experimental design. Developing higher order questions. What does this mean? What is the significance?
“Inquiry moments”	He got them thinking by asking, “Why do you want to do that – how does it relate to what you’ve discovered so far?”

All of the teachers interviewed in Years 2 and 3 of the program expressed the desire to continue using inquiry-based teaching practices, and many reported having learned new teaching strategies and the confidence needed to implement such practices on their own without further assistance from a fellow.

The teachers for whom CSIP has had the most dramatic pedagogical benefits are those with no previous experience with scientific research. Without the perspectives gained through having carried out their own research, launching into a project for which the answers or expected outcomes are unknown can be daunting. Teachers have told us that they have learned by watching CSIP fellows guiding students through the processes of framing research questions, forming hypotheses, planning experiments, and analyzing and interpreting the results. One teacher said, “It taught me that there is a method to the madness behind science – it’s important to ask questions, form hypotheses, look at why things worked or didn’t.” Another commented that observing a fellow facilitating student research made her recognize the value of slowing down and being methodical rather than just charging ahead. A middle school teacher said he had learned “how meticulous research has to be. Keeping logs, recording observations, and the need for replication.” Teachers also have mentioned the usefulness of the assistance provided by fellows in working with real data, including how to respond to unexpected results, messy data, and uncertain conclusions.

Several teachers said that although they had been aware of the value of student research, they would not have taken the initiative to implement it without the guidance of a visiting fellow. One teacher commented that she previously had been held back in facilitating open-ended student inquiry by her worry that the experiments might fail. Through her experiences working with a fellow, she learned that unexpected results are common in science and can be used productively to make new discoveries rather than viewed as classroom failures. Another teacher said, “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 CSIP fellow, the teacher was able to learn 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.

Teachers experienced in leading inquiry projects also have benefited through partnering with fellows. One said that the projects his students designed under the guidance of a fellow led to better conclusions than those done previously without the fellow because of the fellow’s focus in making sure that the students avoided “global unanswerable questions,” instead choosing questions they could address with an experiment. He noted that the fellow also kept the students on target throughout their investigations by continually reminding them to go back to their initial research question to frame decisions about changes they might want to make, avoiding what the teacher referred to as “flopping around and losing their focus.” Another teacher experienced in facilitating student inquiry said that her work with fellows had helped her to refine her concepts of experimental design, expanding these concepts to include new ideas about environmental monitoring and other sorts of research that don’t fit the traditional model of “the scientific method.”

Teachers with personal experience conducting scientific research have benefited in different ways from their participation in CSIP. These teachers have told us that they are interested in working with fellows primarily because of the access it provides to new subject matter and curriculum resource materials that fellows make accessible to them and their students. Because teachers don’t have time to keep up with current research, it is helpful for them to work with a fellow who can contribute new ideas and approaches for projects on topics such as environmental toxicology, aquaponics, or global climate patterns. A teacher of a senior-level research course stated:

> Last year when I had the CSIP fellows come in, my class took a huge step forward in being able to pursue topics in which I have no expertise. I have some topics where I can really guide the students for a long ways, but there are some things that I'm more interested in that I don't have a huge amount of expertise in.… I think it's nice with this situation not having to say, “Well, we can only address certain questions that I understand.”

Both experienced and inexperienced inquiry teachers have brought up the idea that fellows have helped them refine their ability to lead student discussions. One commented on a fellow’s “marvelous use of wait time,” which helped her see the value of allowing what at first seemed like uncomfortable silences while students grappled with a question and formulated an answer before responding. A teacher experienced in research told us that although he hadn’t learned new teaching strategies through working with fellows, he had learned techniques for questioning students in a way that stimulates thought and engages them in conversation.

Benefits Of Inquiry: Why Is It Worth It?

The overriding reason why CSIP teachers continue in the program is the increase in motivation and interest 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 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.

Student enjoyment of learning is another common theme in CSIP teachers' descriptions of what they have gotten out of partnerships with fellows. 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." In an attempt to determine whether CSIP projects have different impacts on students from different overall achievement levels, a Cornell graduate student who is not a fellow interviewed 20 students chosen from classes working with three CSIP fellows one or two days per week over the course of a semester or longer. The students who were interviewed were selected from low, medium, and high achievement level groupings designated by their teachers according to overall performance in science. These achievement categories appear to have little influence on students' perception of the value of their CSIP projects. All 20 students said that they found the projects led by fellows to be fun, and several added that these projects were more meaningful, exciting, or worthwhile than their usual experiences in science. One said, "It's easier to remember when you're doing something than when you're just reading something," and another remarked, "I don't like doing [book] research, that's boring – it loses my interest, and I don't do so well. But science keeps me on the voyage, keeps me thinking. It makes me think more. It's like a challenge. I like it."

However, this sort of enjoyment of learning doesn't 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 for which the answers or expected outcomes are not known in advance.

Some teachers also voiced doubts about the appropriateness of inquiry for their students. This applied to 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. Several teachers also talked 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.

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, et al., 2003), the degree to which students develop the belief 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.

In our experience working 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 may is not necessarily required for success on high-stakes exams.

In spite of the power of these myths, we have found that many teachers are interested in implementing open-ended inquiry in their classrooms. NSF's GK-12 program, the funding source for CSIP, provides the opportunity for teachers to collaborate in long-term partnerships with science graduate students. This makes it possible for teachers who are interested in inquiry-based learning but reluctant to undertake it on their own to work hand-in-hand with scientists. As CSIP fellows and teachers work together 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 various types of classes. This helps teachers overcome their initial hesitation and see the benefits of inquiry on 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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