

Impacts of Participation in a GK-12 Fellowship Program on Teachers' Conceptions and Use of Inquiry Science

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Abstract

The goal of this study is to determine to what extent participation in partnerships with university scientists and science educators can influence teachers' conceptions of inquiry and receptivity to use of inquiry-based teaching practices. Through an NSF-funded Graduate Teaching Fellows in K-12 Education (GK-12) program, we are placing graduate and undergraduate science students in local secondary schools as teaching Fellows to guide student environmental science research and inquiry activities. Our research results indicate that the teachers who are most receptive to student-directed inquiry are those with personal experience conducting scientific research. These teachers have been able to introduce new topics or to teach existing topics in innovative ways with the Fellows' assistance. However, the teachers for whom the program has had the most dramatic pedagogical benefits are those with no previous experience in scientific research. These teachers have reported gaining skills and/or the confidence needed to implement open-ended student inquiry in their classrooms. The underlying question of our continuing research is how GK-12 programs can best be designed to help classroom teachers successfully make the difficult transition to open-ended, inquiry-based teaching practices.

Introduction

Cornell Environmental Inquiry Research Partnerships (CEIRP) is an NSF-funded GK-12 program that places Cornell graduate and advanced undergraduate science students in local secondary schools as teaching Fellows. CEIRP Fellows spend ten hours per week teaching collaboratively with partner teachers in classes ranging from remedial through advanced placement science and engage students in various types of inquiry, depending on the needs of each classroom. Partner teachers are invited to participate in a three-day summer orientation and a weekly seminar throughout the school year. The goal of CEIRP is for the university Fellows to work with middle and high school teachers in guiding student research in environmental sciences. One of its objectives is for teachers to gain new perspectives on open-ended student inquiry as their students participate in inquiry projects under the guidance of CEIRP Fellows.

The objectives of this paper are to explore:

- Teachers' conceptions of inquiry, and
- The ways and extent to which working with CEIRP is helping teachers implement inquiry-based teaching strategies in a wide range of secondary science courses.

Theoretical Underpinnings

How does each teacher define inquiry, and how is this carried through in terms of actual teaching practices? Teachers exhibit a wide variety of conceptions of inquiry, ranging from any sort of hands-on activity to learning that is driven by questioning from the teacher or students. Not surprisingly, these varying conceptions shape the ways in which inquiry is implemented in classrooms (Keys and Bryan 2001; Llewellyn 2001). 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 and Carlsen 2001; Cunningham 1995).

Although engaging K-12 students in original inquiry or research is a cornerstone of current science education reform, efforts to meet this goal face a number of challenges. These include the need to balance content vs. open-ended inquiry while dealing with over-packed curricula and the pressure to prepare students for high stakes exams. Test preparation is an overriding concern of high school science teachers in New York State, where passing a Regents science exam has become a high school graduation requirement (Veronesi and Voorst 2000).

For teachers who do find time to include inquiry-based instruction, another challenge is how to find research topics that are appropriate, feasible, and interesting to high school students of widely ranging backgrounds and ability levels. Furthermore, teachers must grapple with how to balance open-ended inquiry with the need to provide sufficient structure to ensure that the projects will be good learning experiences. 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 and Bilmes 1990). These factors present significant hurdles to teachers who have not had personal experience conducting scientific research (Singer et al. 2000; Windschitl 2003).

Researchers in science education have examined ways of infusing nature of science lessons through the dissemination and implementation of innovative curricula and through various teacher development programs (Costa et al. 1998; Helms 1998; Kelly et al. 1993; Millar 1989; Roth and McGinn 1997). Professional development workshops provide teachers with opportunities to exchange ideas, develop materials and activities for their classrooms, network, and draw on each other for support and creativity (Avery and Carlsen 2001). The goal of our investigation is to evaluate the impacts of CEIRP Fellows, as participating members of this type of professional community, on teachers' conceptions of inquiry and their subsequent classroom practice.

Definitions of Inquiry

In CEIRP, we define inquiry to be the process through which students ask scientific questions and then work to answer these questions in a systematic manner. This is in accord with the National Science Education Standards (NSES), which define inquiry to encompass activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (National Research Council 1996). 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).

Although this definition of inquiry seems quite specific in its attention to the scientific research process, its implementation encompasses everything from half-hour exercises to yearlong investigations. In CEIRP, Fellows work with partner teachers to determine where and how inquiry can best be used to meet class-specific needs and enhance established curricula. In the ideal case, CEIRP 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 central theme in our approach to inquiry is to engage students in experiences that explore the nature and process of science, providing experiences that open the door to science, are relevant to students' lives, and cultivate their critical thinking skills.

Procedure

This study uses 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 include teacher interviews, written questionnaires, recorded focus group sessions, classroom observations, and ongoing discussions with teachers and Fellows.

Twenty-one teachers were interviewed. This included all the teachers who were engaged in long-term partnerships with one or more Fellows, plus five more who 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 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. Most of the interviews were conducted by the lead author, with the second author taking detailed notes, and were tape recorded but not transcribed. All three authors analyzed the data, sorting and organizing the teacher responses into themes. The initial study objectives framed the analysis, supplemented by several new themes that emerged from the data and are discussed below.

Results

Teachers' Conceptions of Inquiry

When asked how they would define inquiry, most CEIRP teachers mentioned questioning or experimenting (Table 1).

Table 1: CEIRP Teachers' Definitions of Inquiry.

Questioning
<ul style="list-style-type: none">• “Students answer questions that they have. Student-led experiments. Not cookbook recipe labs. More discussion questions. Kids keep a journal. Inquiry questions. Open ended. What did you notice instead of name and draw.”• “Start with a question. Do research and find out medium by which I can get my question answered.”• “Let kids experience something and get questions about it. It’s an experiential approach.”• “At the 9th grade level, I define inquiry-based learning as any activity in which students are required to pose and answer questions to complex questions with the aid of investigations that the student helps to design.”• “Inquiry is give a student an experience on their own and have them answer why? Why something happened? What might have gone wrong? When you start to answer your own questions you get more out of labs.”• “Setting out to answer a question using observation, research, critical and creative thinking to answer questions.”
Problem Solving
<ul style="list-style-type: none">• “A problem you’re interested in solving, need to develop thinking, techniques for solving.”• “Using observations/measurement of unknown quantities to illustrate science concepts/issues.”• “I do guided inquiry. I want them to think about experimental design, data, give them a structure for what they do. Need some guidance to get there. Ask a sensible question, design plan, and get something useful out of it. Sometimes we do exploration first. Inquiry engages students in such a way that they think and ask questions, and engage each other in questions. The focus is on students – what they know and can figure out. I’m not dispensing information, but shaping their background to allow them to do this.”

Implementing Inquiry

Over the past two and a half years, CEIRP Fellows have worked in a broad range of classes, from basic level through advanced placement, and have implemented inquiry in many ways. In our weekly seminars for Fellows, we have spent a considerable amount of time discussing various types of inquiry and how they can be implemented in the midst of all the constraints faced by classroom teachers in NYS. This has led to our development of a flexible model of inquiry. We have found that there are multiple lenses to inquiry, and inquiry can be entered at various points in classroom science. Classes with long-term partnerships and few curriculum constraints have carried out the most in-depth

investigations, but Fellows also have found creative ways to introduce inquiry even into the most constrained classes, as discussed below. The approaches used generally fall into these categories:

1. *Open-ended research*: an original experiment or series of experiments designed and conducted by students,
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 lead to an understanding of 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.

Open-ended research. Long-term open-ended research projects fit most readily into courses that are not constrained by NYS Regents exams. For example, in a teacher-designed high school ecology class at an alternative school, a CEIRP 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 CO₂ 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. Review of the students’ final reports indicated their awareness of the limitations of their data in proving or disproving their hypotheses (Phillips and Krasny 2001). The teacher commented that prior to having worked with this Fellow, he had wanted to engage his students in open-ended research but felt he lacked the ability to do so. After seeing the example implemented through participation in CEIRP, he felt able to make the transition from structured to open-ended inquiry.

During the current school year, this same teacher has been working with a CEIRP Fellow to facilitate a yearlong investigation of the science of aquaponics. The students have been carrying out extensive investigations of aquatic chemistry and nutrient cycling – exploring the complex interactions between producing fish, hydroponically growing lettuce, and culturing bacteria to transform the ammonia-rich fish wastewater into nitrate that can be used to support growth of lettuce.

In a rural middle school, a Fellow working in a life sciences class created and led a month-long project in which students grew cucumber plants to select for the bitterness trait. Students exposed the plants to cucumber beetles and made predictions about which plants the beetles would prefer. In the midst of their experiments, they had an aphid outbreak and the plants were destroyed. Instead of concluding that the experiment had been a failure, the Fellow and teacher used this as an “inquiry moment,” discussing the fact that scientific research often does not turn out exactly as planned, and then reconfiguring the experiment to incorporate a lesson on biological control of insect pests.

Remodeled labs. Because long-term research is difficult to fit within the constraints of Regents science classes, CEIRP Fellows working in such classes have refocused existing labs so that they approach required topics using inquiry strategies. For example, cellular respiration is commonly addressed using laboratory exercises related to respiration in whole organisms. Last year one of the CEIRP Fellows designed two new labs that led students through investigations of the biochemistry of cellular respiration in muscle tissue, using techniques adapted from those used at the university level (Dearoff 2002). These new labs highlighted interconnections between biology, chemistry, and physics and were engaging to students because they explained the biochemical changes that lead to sore muscles following intense exercise.

In another example, when a CEIRP Fellow began working in a high school botany class, he noticed that the students already had carried out a bean-sprouting activity, and that just by circumstance some sprouts had grown far longer than others. The Fellow grabbed this opportunity to lead the students in questioning why some of their sprouts had grown more than others (heat register vs. countertop, sunny vs. dark, etc.), and to plan follow-up investigations that would address their questions. The goal of the original teacher-led project had been merely to watch the beans sprout, 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 et al. 1998). These have been described as activities designed to lead to an understanding of how scientists study the natural world (National Research Council 2000). Nature of Science concepts can be taught by adding an activity to ongoing investigations. For example, when students in a high school environmental science class were analyzing their water monitoring data, the CEIRP Fellow working with them decided that their data analysis would be much more meaningful if they had a better understanding of the potential sources of data variability and bias. After leading a discussion about data analysis, the Fellow later developed an activity designed to help students reach a better understanding of these topics (Warner 2002).

Another CEIRP Fellow used a discussion of a pair of articles published in the *National Geographic* and a hands-on activity with fossils to teach the students about peer review. The first article described the discovery of a new fossil that was thought to be a missing link between reptiles and birds, whereas the second article detailed how the scientists reacted when their manuscript about the fossil was rejected by several peer-reviewed journals. This rejection eventually led to the discovery that the fossil had been pieced together and thus was a fake. Comments made by students on a homework assignment after the activity indicated that they felt the most important role for peer review was helping scientists and journals to make sure their articles were true before publishing (Gift and Krasny 2002).

Another CEIRP Fellow introduced students to peer review by talking about his attempts to publish his research on predicting fish populations in Lake Ontario. When he brought to class some critical reviews he had received from journal reviewers, the students worried that the criticisms would make him want to quit science, but the Fellow

used the opportunity to teach about the collaborative process involved in publishing one's work. The partner teacher reported that struggling students gained a new perspective on viewing criticism as a learning opportunity, and he was gratified to see the personal interest they had taken in the Fellow's academic success.

“Inquiry moments.” Some Fellows use informal, spur-of-the-moment discussions to get students thinking about questions, such as why they are doing this particular activity or how it relates to other topics they have addressed over the course of the year. For example, one Fellow took opportunities during research projects to stop and ask students to reflect on their original research question. In doing so, the Fellow 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.

Impacts of CEIRP on Teachers' Conception and Implementation of Inquiry

After working with one or more CEIRP Fellows, all of the participating teachers who were interviewed expressed desire to continue using inquiry-based teaching practices, and many claimed that they had gained the skills and/or confidence needed to implement such practices on their own. Of the 21 teachers interviewed, 17 (81%) said they had learned new science content as a result of working with a CEIRP Fellow, and 15 (71%) indicated that they had learned new teaching strategies as a result of working with a Fellow. In response to a question regarding impacts of CEIRP fellows on teachers' learning new teaching strategies, eleven out of 21 (52%) brought up the idea that they had learned new strategies for asking questions or enabling their students to ask researchable science questions. One teacher described what he learned about the research process from his experience with a long-term partnership with a Fellow, “CEIRP 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 students.”

The teachers for whom the CEIRP program has had the most dramatic pedagogical benefits are those with no previous research experience. For these teachers, the obstacle to implementing inquiry-based learning sometimes is based on misconceptions about what inquiry really means. For example, some teachers envision inquiry in terms of “the scientific method,” typically seen as a rigid series of steps to be taught rather than an open-ended process of discovery. These teachers tend to be most comfortable with guided inquiry, in which the teacher specifies the question and the research methods that will be used. However, with the guidance of a Fellow, some teachers have told us they were able to make the leap to the riskier, less teacher-driven approach of open-ended student inquiry. In such cases, teachers have learned by watching CEIRP Fellows as they guided students through the processes of framing research questions, forming hypotheses, planning experiments, and then analyzing and interpreting the results. 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.

Table 2: Example Teacher Reactions to CEIRP’s Four Types of Inquiry

Type of Inquiry	Type of Class	Quote from Teacher
<i>Open-ended research</i>	Rural Middle School: Life Science class	“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.”
<i>Remodeled labs</i>	Rural Middle School: Life Science class	“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.”
<i>Nature of science lessons</i>	BOCES New Visions Program: advanced seniors	“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?”
<i>“Inquiry moments”</i>	BOCES New Visions Program: seniors	“We take walks in the woods, get kids outside—it’s a 3 1/2 hour class—when we go outside for a hike something phenomenal happens—whether it’s seeing animal tracks or... Tim adds a lot of natural history—his delivery is not sarcastic or condescending, fresh and good sense of wonder. Kids don’t find him annoying, don’t shun him, they really appreciate his as a “teller”, he’s rewarding.”

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 in CEIRP, 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 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 CEIRP 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 who have had personal experience conducting research have benefited in different ways from their participation in CEIRP. 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.

In addition to one-on-one work with teachers, CEIRP Fellows and staff have conducted professional development workshops for teachers. At a recent workshop for the science department in one of our urban partner schools, the goal was to model inquiry by having teachers engage in a simple and economic hands-on lab that could be used to teach a variety of content topics, could be couched in a number of contexts, and would provide opportunities for students to wrestle with nature of science issues such as messy data, teamwork and negotiation, experimental design, and reconfiguring hypotheses based on anomalous data. Using soda bottles, this lab modeled the process of determining the relationship between volume and flow rate to construct a water tower to catch stormwater on top of an apartment building. Teachers were told that this experiment was an exemplar of a "quick, economical, and easy" way to implement inquiry in a wide range of science classes. Teachers were given handouts with intentionally ambiguous instructions in order to make the process open-ended and to encourage debate and collaboration. The teachers worked in groups while CEIRP Fellows and staff interacted and observed the process but didn't "tell the answers." The group took periodic breaks to discuss the process and the teachers' reactions.

At the end of the exercise, teachers presented their results, discussed the process, and brainstormed ways to cultivate "inquiry moments" in their classes. Seven (50%) of the fourteen teachers indicated that they definitely had gained new ideas about inquiry-based teaching strategies during the session, and four (29%) said they probably had done so. A chemistry teacher commented "An excellent activity. I was doubtful, but now convinced...I love inquiry but have always had reservations when it's applied to Regents level stuff." He went on to say that he would definitely implement ideas from this session in his classes in "small doses."

Conclusions

NSF-funded GK-12 programs such as CEIRP provide opportunities for teachers to interact with scientists in a collaborative learning community. As teachers and university Fellows work together to implement inquiry-based teaching, together they deal with unexpected or unknown outcomes, address misconceptions, and determine how inquiry can best be used in various types of classes. Through our experiences working with CEIRP Fellows and partner teachers over the past two and a half years, we have found that there are multiple lenses to inquiry-based learning, and many ways to successfully introduce inquiry into science classes. University Fellows can help teachers make the difficult transition to a more inquiry-based teaching style, with projects as short as a

single class or carrying on for an entire school year. Infusion of inquiry into traditional classrooms can happen in bold ways, when Fellows instigate open-ended research endeavors and help teachers to see the value of granting students the freedom to ask their own questions and wrestle with decision-making at many steps as they plan and carry out original experiments. It also can happen in much smaller ways such as when Fellows lead classroom discussions focused on issues in the nature of science that arise in the course of traditional lab and field activities. In this paper, we have discussed CEIRP's four approaches to inquiry-based teaching, and the impacts of working with Fellows on partner teachers' conceptions of inquiry and its utility as a viable teaching strategy.

Our experiences demonstrate that given appropriate guidance from science educators and teachers, science graduate students are able to develop and implement various approaches to teaching inquiry and about nature of science in high school classrooms. It also appears that teachers learn from the fellows through both long-term teaching partnerships and short workshops. Maintaining a community of practice as a resource for networking, professional development, and support for teachers' doing inquiry seems to be a valuable vehicle for perpetuating inquiry-based science classrooms.

For more information, visit our websites: <http://ceirp.cornell.edu> and <http://ei.cornell.edu/>.

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