Building Teacher-Scientist Partnerships: Teaching About Energy Through Inquiry.(Statistical Data Included)

by Elaine Caton, Carol Brewer and Fletcher Brown

This study evaluated the effectiveness of teacher-scientist partnerships for increasing the use of inquiry in precollege classrooms. It assessed the influence of the Teaching About Energy Through Inquiry Institutes for middle and high school teachers and energy scientists on participants' attitudes about science and science education, use of inquiry instructional techniques, and student attitudes about their classroom environments. Participant surveys, institute and classroom observations, lesson plans, and interviews indicated increased appreciation for inquiry, greater confidence in teaching using inquiry, and greater use of inquiry in the classroom. Student surveys and classroom observations pointed to higher levels of student satisfaction and less friction among classmates during inquiry-based investigations implemented after the institutes. Moreover, scientist partners reported increased familiarity with principles of science education and best teaching practice, which are essential skills and knowledge for disseminating results of scientific research to nonscientific audiences, as well as their own students. These results suggest that collaborations between teachers and research scientists can positively affect the environment for learning science in precollege and college classes. Successful collaborations are most likely to occur when equal status for teachers and scientists in the partnership is stressed and partners have the opportunity to explore inquiry-based curricula together.

A team of energy science engineers and middle and high school science teachers pores over a box of what appears to be household junk. They have been charged with building a windmill that can generate enough electricity to light a small light bulb. In place of their high-tech, state-of-the-art equipment, the engineers see utility knives and hammers, styrofoam balls, copper wire, and nails. Instead of textbooks and a well-rehearsed laboratory setup, the teachers see an odd array of simple materials with no instructional guidelines. Everyone is a bit out of their element and intrigued by the challenge of developing a source of energy from junk. A partnership for science inquiry investigations has begun.

Providing hands-on experiences is often stated as a goal of science instruction and reform programs. Yet sometimes the "hands-on" experience has been a guided exercise in which finding the "right" or known answer was stressed, and students were provided with explicit instructions telling them what to do and when to do it. It is little wonder that science instruction often discourages academically able students early in the elementary and middle school years. The cornerstone of recommended reforms consists of inquiry-rich, investigative experiences for all students, from grade school through graduate school. So how can science instruction be organized to "induce students to enjoy science from the first day"? According to many studies (e.g., Alper, 1994; Hays 1994; National Research Council [NRC], 1996, 1997), the answer is to connect the student to the community of scholars, personalize the learning experience, and place science content and learning in a broader, relevant context.

To address these recommendations, the national movement to reform science education calls for a shift in focus to include the student in the process (American Association for the Advancement of Science, 1990; National Commission of Excellence in Education, 1983; NRC, 1996). In particular, science curricula that use student-centered inquiry methods have been shown to be highly effective in improving content learning, science process and creativity, logic, language skills, and attitudes toward science and science learning (Bredderman, 1982; Ebert-May, Brewer, & Mired, 1997; NRC, 1997; Refiner, 1973). These methods have been especially effective for students characterized as "slow" (Carpenter, 1963) and "disadvantaged" (Bredderman, 1982) learners and groups currently underrepresented in scientific professions.

Teachers uncomfortable with science tend to focus instruction on the end products of scientific investigations (Alper, 1994; Mechling & Oliver, 1983). They may be more reluctant to use inquiry-based methods that stress the process of science due to inadequate training to teach science and lack of access to teaching materials and the most recent scientific information (Caton, Brewer, & Manning 1997; Greene, 1991). Consequently, numerous studies report that teachers want training programs that are investigation oriented and that give them access to local materials and human resources (Greene, 1991; Hays, 1994; Mechling & Oliver, 1983; Yager, 1991). Moreover, professional development programs that stress hands-on science learning focused on process and application improve teachers' attitudes about science content and raise their comfort levels with teaching science (Brewer & Manning, 1995; Caton et al., 1997; Feazel & Aram, 1990; Greene, 1991; Sandman, 1988).

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One promising strategy to demystify science for teachers who are uncomfortable with this subject may be collaboration between teachers and scientists (see Alper, 1991; National Research Council, 1997). When teachers work on investigations with scientists, they can develop increased interest in and understanding of scientific processes and have greater confidence in their ability to teach science using inquiry methods (Brewer & Manning, 1995; Caton et al., 1997). Moreover, such collaborations are a two-way street. Many research scientists affiliated with universities or colleges have teaching requirements and have an interest in science education at the precollege level, as well. Yet researchers tend to have little or no formal training in teaching and often have inadequate knowledge of methods appropriate for teaching younger students. Participation in precollege science education programs can teach valuable lessons about education to researchers as they work with experts in the education field.

Successful teacher-scientist partnerships are challenging to achieve, however, and little is known about the effects of such collaborations on participants and their students. Challenges in facilitating teacher-scientist partnerships include breaking down the hierarchies that often exist between the two professions, making true collaboration and exchange possible. Scientists also must be aware of the limited resources available in most schools and encourage investigations that are practical and possible, given time and money constraints. And finally, both scientists and teachers will encourage long-term interest, deeper understanding, and appreciation in their students if the process of science, as well as its products, are emphasized.

To explore the effectiveness of teacher-scientist collaborations for bringing inquiry into precollege classrooms, two institutes on Teaching About Energy Through Inquiry for middle and high school teachers and energy scientists were evaluated. These institutes took place in 1996 and 1997 and were sponsored by the Montana Organization for Research in Energy (MORE) and The University of Montana (UM). The institutes were designed to bring teachers and research scientists together on a level playing field, emphasizing contributions of expertise from all participants. The assessment objectives were to determine the influence of these institutes on (a) collaborations between scientists and precollege teachers, Co) use of inquiry to teach science, (c) participants' attitudes about science and science education, and (d) students' attitudes about their classroom environment while participating in inquiry investigations.

Methods

The 1996 energy institute was 3 days long; the 1997 institute was 2 days long and was modified somewhat from the previous year, based on participants' feedback and leaders' observations. However, most activities were very similar; some sessions were shortened and the sequence changed slightly. Each institute began with brief introductions of participants and the institute goals. In the 1996 institute, a presentation on content related to teaching about energy using inquiry followed. After the presentation, the group engaged in an open-ended inquiry related to wind energy. In 1997, the wind energy inquiry immediately followed the introductions.

In the wind-energy inquiry, teams of 4-5 teachers and scientists (pre-assigned by leaders to mix genders, professions, schools, and grade levels) collaborated to build working windmills using only kits of everyday supplies and equipment, such as cardboard, plastic, rubberbands, magnets, wire, and nails (see Snetsinger, Brewer, & Brown, 1999). Teams had 2 1/2 hours to design and build a windmill that would generate the maximum amount of electricity. Each team presented their design and tested the energy output of their windmill with a voltmeter. Participants had the opportunity to ask questions of presenters and enter into general discussions of wind energy concepts.

The wind energy inquiry was followed in the 1997 institute by an inquiry-based exploration of solar energy (this did not take place the 1st year). In this investigation, teams examined the effects of variables like angle and shade on solar energy output, using floodlights, protractors, and cellophane sheets (see National Center for Appropriate Technology, 1986). Involving a preconstructed device for controlling and measuring variables, this was a more guided inquiry but still used low-tech equipment and divergent questions. A group discussion on the effectiveness of the activities followed this session. Participants were asked to reflect on what they felt as they went through the inquiry (e.g., frustrated, excited, curious); how their teams handled the cooperative work situation; and what they had learned about wind energy.

The 2nd day of the institutes began with another facilitated discussion of the inquiry experiences and the practicality of applying these methods to the precollege classroom. Participants considered how the experience affected their own views of teaching energy and other science through inquiry. They were asked to appraise how they would adapt such a lesson

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for their own students and to consider how they would include content information in the lesson. Next, the research scientists and engineers presented information about their areas of interest and study. This session was followed by a third inquiry-based project on petroleum energy. During this investigation, groups were asked to build a pipeline of CPVC pipe that would transport petroleum across a miniature landscape from an oil well to an oil tanker (see Caton, Brewer, Brown, & Berkey, 1998). The engineers needed to consider speed of delivery, cost of materials, and cost of potential hazards to humans and the environment. The designs were evaluated using a point system in which groups attempted to minimize points accumulated during construction.

Later, institute personnel facilitated teacher-led discussions of the challenges involved in teaching with inquiry in the precollege classroom and methods effective for teaching young students. Participants were asked to list potential challenges to adapting such lessons for their classrooms and to brainstorm solutions to those challenges. They considered class management, scheduling and time constraints, equipment and materials needed, and relevancy to students' lives. They also were asked to address how inquiry methods conform with what they know about how students of different ages learn.

The afternoon of the 2nd day (and the entire 3rd day of the 1996 institute), participants worked in school teams with scientists to develop plans for inquiry-based energy curricula and investigations and to plan future collaborations. Teams planned inquiry investigations based on workshop examples or on their own interests and experiences. They were asked to plan a future interaction between teachers and scientists (e.g., visit by scientist to school, e-mail consultation, etc.). Each team presented their plan to the larger group at the end of the institutes.

The institutes were limited to certified science and math teachers interested in energy education. Participating scientists were from science departments and affiliated campuses of UM and Montana State University. In 1996, 4 teachers (all high school teachers) and 8 scientists participated in the pilot institute. In 1997, 25 teachers (11 from middle school and 14 from high school) and 6 scientists attended the institute. Thus, the composition and dynamics of the teams were necessarily different between the years. In the 1996 institute, group leaders were particularly aware of the potential for the scientists to unduly influence group discussions and decisions and carefully facilitated interactions to ensure that teachers participated fully. In 1997, facilitation focused more on ensuring that middle school teachers felt comfortable contributing to activities.

The inquiry-based projects, which formed the core of the institutes, were predicted to have two important effects: They would break the ice among participants, who had to communicate and actively work together on inquiries, thereby increasing the level of collaboration; and they would break down the hierarchies that tend to exist between scientists and teachers. Without expensive, high-tech equipment and advanced, specialized methods, research scientists and teachers were working together in a venue in which all could participate, with an emphasis on basic problem solving and scientific processes. Furthermore, the positive interactions and the experiences with inquiry were expected to influence teaching practices and collaborations after the institutes.

Institute Assessments

Participant surveys. Participants completed pre- and post-institute surveys. Pre-institute teacher surveys asked open-ended questions related to workshop goals, attitudes toward science, and perceived obstacles to integrating energy investigations into the classroom. Pre-institute scientist surveys asked questions related to experience with and interest in working with teachers, workshop goals, familiarity with teaching methods, and obstacles to integrating work in their field into precollege classrooms. Teachers and scientists also were asked to rate (using a Likert scale of 1 to 5) the importance of various topics related to the workshop.

Post-institute surveys were identical for teachers and scientists. Participants rated the value of institute discussions, investigations and interactions, and resources. Open-ended questions probed for details on positive and negative aspects of the institute experience, changes in skills and attitudes about teaching through inquiry, effectiveness of collaborations and interest in continued collaboration, investigations, and obstacles to integrating inquiry.

Institute Observations. During the 2- and 3-day institutes, two investigators observed the nature of group dynamics and collaborations among participants. These observations were recorded in a narrative form throughout the institutes.

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Classroom Assessments

Student surveys. The goal of student surveys was to describe the level to which inquiry activities were integrated into the curriculum and how students collaborated in groups during inquiry investigations. "My Class Inventory" (MCI) surveys, as modified by Fisher and Fraser (1981), were given to students of participating middle school teachers before and after the 1996 institute. These surveys measured five elements of the classroom environment: student satisfaction with the class, class cohesiveness, friction among classmates, difficulty of work, and classmate competitiveness. The MCI was administered in seven pre-institute classes and five post-institute classes to a total of 230 students. Mann-Whitney U tests of ranks were used to evaluate whether pre- and post-institute scores differed significantly.

Classroom observations. Two observers assessed classroom activities using the "Inquiry Quotient" (IQ) questionnaire (Lawson, Devito, & Nordland, 1976) and made descriptive observations of classes in progress. During their IQ training, the observers evaluated the same classes using the IQ forms. After these observations, they compared their scoring procedures and results, with the assistance of a project facilitator. These comparisons were made twice before data were collected for this study, to standardize the protocol between observers.

All participating teachers were contacted individually to arrange visits for collecting IQ data. Because of difficulties scheduling visits to classrooms, particularly given the distances to many Montana schools, observers visited a subset of classes from schools within approximately 100 miles of the UM campus. Five teachers (4 from middle school) were observed both before and after the 1996 institute. Pre-institute visits were arranged for times when teachers were presenting science lessons, which ranged from physical to life science. Post-institute visits were made during energy science lessons. Paired sample t-tests were used to evaluate whether scores differed significantly between pre- and post-institute classrooms. Analysis of Variance (ANOVA) was used to test for interactions between observer and time of survey (pre or post).

Lesson plans. Participating teachers submitted lesson plans for implementing inquiry-based units in their classrooms, based on what they had learned in the institutes. Lesson plans described the classroom lessons they had planned, as well as the nature of anticipated collaborations with scientists and other teachers and use of other resources. These were evaluated based on the degree to which lessons were open ended.

Participant interviews. Participants from the May 1996 workshop were interviewed the following December. Interview questions pertained to the extent of post-institute collaboration between teachers and scientists and use of inquiry-based lessons in classrooms during the first half of the current school year.

Results

Participant Surveys

Pre-institute surveys. All 29 teachers completed pre-institute surveys (Table 1). Teachers were primarily interested in the discovery aspects of science, both in their own teaching and in their goals for the institutes. Lack of time, resources, and training were perceived as the greatest challenges to inquiry-based teaching (Table 2), and teachers hoped to increase their content knowledge and comfort level with inquiry and other teaching strategies and to network with other teachers and scientists.

Table 1 Responses by Participating Teachers to Pre-Institute Survey Questions

Questions and responses	# of Responses (n = 29)
Is there something about teaching science that excites you?	
Discovery, experimentation, newness	9
Hands-on nature	5
Applicability to everyday life	4
Is there something about teaching science	

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that turns you off?.	
Lack of time and resources	8
Tedious and repetitious nature	5
Lack of knowledge	2
Your primary goal for participating in workshop?	
Learn new, hands-on teaching methods	14
Learn more about inquiry	6
Learn more content knowledge	5
What will be the greatest obstacles for integrating energy investigations into your curriculum?	
Time	15
Lack of resources	8
What do you foresee as your greatest need for bringing energy investigations into your classroom?	
More materials and space	5
Time	4
New curriculum	2
Training	2

Table 2 Pre-Institute Ratings of Issues Related to Energy Education

Topic	Mean Rating
Teacher Surveys (n = 29)	
Availability of materials	4.8
Resources	4.4
Gaming content knowledge	4.4
Comfort level with conducting open-ended investigations	4.2
Cooperative learning strategies	4.0
Networking with other teachers	4.0
Networking with scientists	3.9
Alternative assessment	3.8
Ongoing support from workshop leaders	3.7
Working with scientists	3.6
Learning cycle and scientific method	3.5
Scientist Surveys (n = 9)	
Working successfully with teachers	3.9
The scientific method and inquiry	3.8
Support network for teachers	3.8
Improving teaching skills	3.8
Ongoing support from workshop leaders	3.6
Comfort level with conducting open-ended investigations	3.5
Adequacy of research site for class visits	3.2

Note: Issues were rated on a Likert scale of 1 (not important to me) to 5 (of great importance to me).

Nine scientists returned pre-institute surveys (Table 2). Scientists' goals for participating in an institute were to learn more about the needs of teachers and inquiry instruction and to make science more accessible to the nonscientific public. None were familiar with teaching methods for middle and high school. Lack of knowledge about the needs of students was noted as an obstacle for integrating investigations into school curricula.

Post-institute surveys. Twenty-six teachers and 12 scientists returned post-institute surveys. All participants reported that they highly valued teacher-scientist collaborations and interactions during the institutes (Table 3). Institute materials, group discussions, collaborative planning time, and inquiry-based investigations also were given very high ratings. Most participants were positive about the inquiry and collaborative aspects of the institute (Table 4). Facilitating communication with scientists was suggested by several teachers as essential to continued collaboration and use of inquiry.

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Table 3 Average Post-Institute Ratings

Activity	Teacher Responses (n = 26)
Collaborating with scientists	4.6
Collaborating with teachers	4.6
Institute materials and resources	4.4
Discussions on teacher-scientist partnerships	4.2
Group discussions of teaching plans	4.2
Collaborative planning for inquiries	4.1
Discussion of barriers and solutions to using inquiry	4.1
Energy investigations	4.0
Introduction to inquiry	3.9
Presentations of research results by scientists	3.5
Identifying central questions in energy education	3.9

Activity	Scientist Responses (n = 12)
Collaborating with scientists	4.5
Collaborating with teachers	4.3
Institute materials and resources	4.4
Discussions on teacher-scientist partnerships	4.0
Group discussions of teaching plans	4.5
Collaborative planning for inquiries	4.1
Discussion of barriers and solutions to using inquiry	4.3
Energy investigations	4.0
Introduction to inquiry	4.1
Presentations of research results by scientists	3.3
Identifying central questions in energy education	3.6

Note: Responses were rated on a Likert scale of 1 (not important to me) to 5 (of great importance to me). No significant differences were found in comparisons of responses from teachers versus scientists ($p > 0.05$; Mann-Whitney U test).

Table 4 Responses Given Most Frequently to Open-ended Questions From the Post-Institute Survey

Questions and Responses	# of Responses (n = 38)
What did you appreciate about the Institute?	
Inquiry activities	10
Group discussions	7
Reference materials	7
Describe changes in knowledge, skills, and attitudes about teaching through inquiry as a result of your institute experience.	
Greater understanding of benefits of inquiry teaching	11
More excited and confident about teaching with inquiry	8
Describe your comfort level with integrating an inquiry approach into your teaching.	
Very comfortable	11
Somewhat comfortable	10
Uncomfortable	2
What was your impression of the effectiveness of the scientist/teacher collaborations?	

Excellent/very effective	12
Good	10
Needed more time with scientists	6
Would you like to continue the scientists/teacher collaborations started during the institute? If yes, what can institute organizers do to facilitate interactions?	
Yes	17
Compose a list of addresses & e-mail addresses	8
What types of follow-up activities are needed to ensure that ideas developed in the institute can be implemented during the next academic year?	
Communication (newsletter mentioned several times)	11
Assistance from a scientist	4
For teachers: What are the obstacles to integrating energy inquiries into your curriculum?	
Time	18
Supplies	8
Space	6

Institute Observations

Narrative descriptions from the early portions of institutes indicated that group work often was dominated by scientists and male teachers in the groups. Observers reported, for example, "[Scientist] and male teacher working; three female teachers watching." However, by the 2nd day fewer participants assumed passive roles and more true collaboration was observed: "[Participants] were much more relaxed and comfortable with the challenge ... Scientists did not dominate [interactions] at all. There was a lot of great discussion going on in groups."

Classroom Assessments

MCI scores for levels of satisfaction and competition were significantly higher in all post-institute classes (Table 5). Scores for perceptions of classmate friction and class difficulty were lower in post-institute classes, although this difference was not significant for the level of difficulty. Average IQ scores were higher for post-institute classes in most categories (Table 6), but these differences were not statistically significant. Average scores were not significantly different for the two observers (p [is greater than] 0.05) in any category. There was no interaction effect between observer and time of survey (ANOVA, p [is greater than] 0.05) for any category.

Table 5 Comparison of Pre- and Post-Institute MCI Scores From Classes of Teachers Participating in the Energy Inquiry Institute

Scale	Pre-Institute Mean (n = 148)	Post-Institute Mean (n = 84)	p(a)
Satisfaction	8.9	10.8	< 0.001
Friction	10.7	9.5	0.010
Competition	10.8	11.7	0.018
Difficulty	7.4	7.3	0.816
Cohesiveness	6.8	7.4	0.139

(*) p-values of Mann-Whitney U test of ranks.

Table 6 Comparison of Pre- and Post-Institute I.Q. Scores for 5 Teachers Participating in the Energy Inquiry Institute

Scale	Pre-Institute Mean	Post-Institute Mean

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Lesson	2.9	3.1
Student Behavior	1.7	2.4
Teacher Behavior	2.7	2.7
Questioning Techniques	3.6	3.6
Composite	2.8	2.9

Note: Differences were not significant at $p = 0.05$ (paired sample t-test).

Qualitative descriptions of classroom activities documented mostly positive perceptions of questioning techniques and teacher behavior in pre-institute classes: "[Teacher] used both divergent and convergent questions well. [Teacher] gave clear instructions and fielded questions calmly." The level of inquiry in the lessons was low and student behavior poor: "This was a very guided lab. The constant [behavioral] distractions certainly impaired the [flow of the] lesson."

When teachers were observed implementing energy inquiries after the institute, the narratives noted greater use of open inquiry techniques in the lessons and improved student behavior:

> Each group had complete freedom in the design. [The teacher] spent far less time in this lesson on discipline than in the first [pre-institute] class I observed (15% and 60% of time, respectively). Almost everyone remained engaged throughout the whole class period.

Lesson Plans

Thirteen teachers submitted lesson plans after the second institute; 10 of these were implemented before the school year ended. While all lessons incorporated "hands-on" activities for teaching about energy, the degree of student inquiry in the lessons varied. Seven lessons used an open-ended approach to inquiry, in which the teacher offered only a general question or objective related to energy and, in some cases, a variety of materials to use. The remaining six lessons used a guided inquiry approach, in which teachers provided more direction about how the students should proceed with their investigations. However, the questions in all these lessons were divergent, and many design decisions were left to the students. Teachers gave very positive feedback on the lessons they implemented. One teacher wrote,

> The lesson was a big success, and with some fine tuning and integration into a larger unit, it will definitely be a big asset to my students and me. The concept of inquiry worked very well. The students bought into the question and, therefore, learned a great deal more from the solution.

Comments from other teachers included the following:

> The kids' interest and active participation remained high throughout. The open inquiry was successful.... I think the lab went extremely well.... Once they [students] got started, they really were thinking about how to best complete the [investigation].

Other teachers supplied information on post-institute collaborations with scientists and lessons they used incorporating inquiry. At least 7 teachers had collaborated with scientists on projects after the institute, and at least 1 scientist visited a class. In addition to the 13 teachers who submitted lesson plans, at least 4 others led hands-on activities related to energy; 3 of these were inquiry-based.

Follow-up Interviews With Teachers and Scientists

Of the 4 teachers in the 1996 pilot institute, 3 had used inquiry-based lessons on energy after the institute. One teacher led three different inquiries and gave high ratings (on a scale of 0-4) to student interest levels (3.5), inquiry levels (3), and success of the lessons (3). This teacher planned to use the investigations again and had been in contact with two

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participating scientists following the institute. A second teacher used a variation of an inquiry developed during the institute. This inquiry was more guided than those presented in the institute, and the teacher rated the students' interest and the success of the lesson as low (0). The teacher thought the lack of success was largely due to the low motivation of the students involved and planned to use the investigation again with a different class. A third teacher presented one of the energy inquiries developed for the MORE institute at the Montana Educator's Association 1996 Conference and received highly positive responses. All these teachers planned to use inquiry again. The fourth teacher had not yet reached the energy portion of the school's curriculum.

One teacher had been in contact with scientists following the workshop, although 2 others remained interested in doing so. They cited lack of time as the greatest obstacle to making contact with collaborating scientists. All teachers supported the use of inquiry in their classes and felt more comfortable using it in smaller classes and with certain age groups. Three teachers felt "very comfortable" using inquiry instructional strategies; the fourth felt "somewhat comfortable."

Two of the 6 scientists interviewed after the 1996 institute had been in contact with teachers; both arranged field trips to an energy site in Montana. The other scientists remained interested in working with teachers. Time and distance were given as the primary obstacles to collaborating with teachers, along with the difficulty of making their research relevant to students. Five scientists thought "hands-on" investigations were appropriate for middle and high school classes and suggested that field trips to research sites, computer exercises, and interactive World Wide Web home pages would facilitate integrating their research into classrooms. Most scientists felt "very comfortable" with inquiry, and all believed that teacher-scientist collaborations were worthwhile for energy education. Moreover, they were very enthusiastic about being involved in precollege classrooms, stating that "students will benefit from such partnerships."

Discussion

The Teaching About Energy Through Inquiry Institutes were successful in facilitating teacher-scientist partnerships and increasing the use of inquiry by participating teachers. During the institutes, participants learned strategies for collaborating on science education projects, and collaboration continued after the institutes. Participants viewed interactions positively. Satisfaction with collaborations was probably due in large part to the nature of the institute environment, which stressed equal status for teachers and research scientists (as recommended by Feazel & Aram, 1990) and the two-way exchange of expertise. Small group work on engaging projects that used low-tech, commonly available materials helped participants overcome their reserve and establish a personal basis for collaboration.

These methods also were important in enabling teachers spanning seven grade levels to collaborate effectively with each other and the scientists during these institutes. Use of inquiry methods is conducive to teacher-driven adaptations of science lessons, allowing teachers to take broad concepts and modify them to fit their own teaching styles, as well as students' abilities. Therefore, middle and high school teachers are able to transfer similar experiences to the classroom in different age-appropriate ways.

Most teachers used inquiry-based investigations in their classes after the institute and gave positive feedback on those investigations. Information from student surveys demonstrates that their satisfaction with their science classes was greater during inquiry-based lessons than in the more guided lessons they completed before the institute. The only potentially negative impact was indicated by higher post-institute scores for perceived levels of competition in the classroom. Several of the inquiries used in post-institute classes involved student contests (e.g., building the fastest solar-powered car, designing the most efficient pipeline). This may have led to higher scores for competition. Educators concerned about competitiveness among students may want to consider emphasizing collaboration among groups rather than rivalry.

Observations in post-institute classes were of energy science lessons, which likely were influenced by the institutes more than were lessons on other science subjects. While it is difficult to assess the long-term effects on science teaching methods of participants, there are indications that the effects of the institute experiences went beyond teachers' simply learning a new activity and applying it in their classroom. Several projects that teachers reported doing with their students were quite different from those practiced in the institutes. For example, students designed solar-powered cars, analyzed and graphed honeybee activity data, and looked at the effects of weight on speed of vehicles. Additionally, interview results, while limited in scope, indicated that teachers developed multiple new lessons based on their experiences that

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tended to be inquiry rich.

These data suggest that scientist-teacher partnerships have the potential to make positive impacts on science instruction and learning in precollege classrooms. Ongoing collaborations among participants after the institutes probably is a key factor in maintaining interest in these methods and broadening their scope. Similar programs should emphasize follow-up meetings and facilitate contact among participants.

One unique outcome of these institutes is that participating scientists reflected on their own teaching as a result of their collaborations with participating teachers. Scientists reported becoming more familiar with principles of science education and best teaching practices, which are essential skills and knowledge for disseminating results of scientific research to a lay audience. Several related that they had tried to infuse more open-ended inquiries into their university or college laboratory courses, and two had secured funding to bring experts on inquiry teaching and science pedagogy to talk with them and their colleagues in engineering and physics departments.

Partnerships between teachers, scientists, and university science educators have the potential to improve significantly the content and effectiveness of science education. In the collaborations described here, regional scientists were critical partners to ensure that science offerings reflect current knowledge and are inquiry based. Moreover, these partnerships may be an exciting way for precollege teachers to influence science instruction in colleges and universities (see also Drayton & Falk, 1997). This area deserves further investigation.

In summary, to develop effective collaborations between scientists and teachers, the following components are necessary:

1. Bring together key partners involved in scientific research and education to develop a common vision for instruction and collaboration.

2. Foster interaction between scientists and educators through experiences focused on a shared vision, inquiry instruction, and learning related to the science content of interest.

3. Compile and develop (as needed) excellent curriculum resources that translate basic research so that it is accessible to a broad audience.

4. Develop and pilot a series of "demonstration curricula" in open and guided inquiry formats.

5. Develop and implement a plan to sustain and expand the program to include new collaborative partners.

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