Preparing Teachers to Use Problem-centered, Inquiry-based Science: Lessons from a Four-Year Professional Development Project

James D. Lehman
lehman@purdue.edu

Melissa George

Peggy Buchanan

Michael Rush

Recommended Citation

Preparing Teachers to Use
Problem-centered, Inquiry-based Science:
Lessons from a Four-Year Professional Development Project

James D. Lehman

Melissa George

Peggy Buchanan

Michael Rush

Abstract

Calls for reform in science education stress the need for inquiry-based, integrative methods that provide students with opportunities to solve authentic problems. Project INSITE, a four-year professional development effort in Indiana, was designed to help teachers integrate problem-centered science methods in their classrooms. This approach was characterized by use of a meaningful driving question anchored in a real-world context; student-conducted investigations that resulted in the creation of products; collaboration among students, teachers, and the community; and use of technology as a tool for gathering and sharing information. Quantitative and qualitative evaluations of the project suggest that it was generally successful in promoting positive teacher perceptions, fostering learner-centered classroom approaches, and leading to implementation of inquiry-based science in many classrooms.

Keywords: project-based learning, science education, teacher professional development, middle/secondary school

Introduction

Major reform documents in science education, such as Science for All Americans (Rutherford & Ahlgren, 1991) from Project 2061 of the American Association for the Advancement of Science and National Science Education Standards from the National Research Council (1996), have stressed the need for a scientifically literate populace. For the most part, these reform initiatives have recommended an inquiry-based approach to science education, real-world problem solving for students, the use of cooperative learning strategies, a focus

on content depth rather than breadth, and teachers as facilitators of learning rather than deliverers of information (Moreno, 1999).

A constructivist view of learning underlies this call for science education reform. At its core, the constructivist position argues that knowledge is not transmitted directly from one person to another but must be actively built by the learner (Driver, Asoko, Leach, Mortimer, & Scott, 1994). While constructivism is often viewed from either cognitive (within the individual) or sociocultural (within a community of learners) perspectives (Cobb, 1994), science learning can be seen to entail both personal and social processes (Driver et al., 1994). As a result, most calls for reform in science education emphasize engaging students in inquiry to promote active development of understanding by individuals, and having students collaborate while learning to promote communication and the development of shared meaning. In order to help students apply what they learn to real-world situations, it is argued that learning should be situated in authentic activity (Brown, Collins, & Duguid, 1991) such as real-world problem solving (Savery & Duffy, 2001). Technology is often mentioned as an important element of science education reform efforts because it is seen as a unique agent that can anchor students' learning and/or support or augment the construction of meaning (Cognition and Technology Group at Vanderbilt, 1997; Kozma, 1991).

A problem-based learning model is one that captures many of the key principles of a constructivist perspective of learning (Savery & Duffy, 2001). A similar approach to science teaching/learning in schools that incorporates these reform elements is project-based science (Krajcik, Czerniak, & Berger, 1999). Project-based science is characterized by a driving question that is meaningful to the learners and anchored in a real-world context; student-conducted investigations that result in the development of products; collaboration among students, teachers, and the community; and the use of technology, particularly computers, to help students represent and share ideas (Krajcik et al., 1999; Singer, Marx, Krajcik, & Chambers, 2000). This approach has been shown to be effective in promoting students' science learning (Schneider, Krajcik, Marx, & Soloway, 2002).

While conceptions vary, project-based learning has much in common with problem-based learning and other experiential forms of learning. Torp and Sage (2002) defined problem-based learning (PBL) as "focused, experiential learning (minds-on, hands-on) organized around the investigation of messy, real-world problems" (p. 15). PBL is characterized by engagement of students as stakeholders in the problem situation, organization of the curriculum around a holistic problem, and creation of a learning environment in which teachers coach student thinking and guide inquiry (Torp & Sage, 2002). These characteristics are shared by project-based science, which can be viewed as one of a family of related instructional approaches. Both PBL and project-based science emphasize collaborative construction of knowledge, problem solving, and transformation of traditional

student and teacher roles (Hmelo-Silver, 2004). They differ in relatively minor ways. For example, while direct instruction is not used in a pure PBL approach, in project-based science teachers may sometimes provide direct instruction to students when they need information for problem-solving activities (Hmelo-Silver, 2004).

In project-based science, a driving question functions in the same manner as an ill-structured problem in PBL. In a typical project, a group of middle-school science students might tackle a driving question such as, "What is in our water and how did it get there?" The driving question, which is designed to be meaningful to the learners, provides a clear but broad framework that affords ample opportunity for student-led investigations in real-world contexts. Students must generate their own questions within the framework afforded by the driving question, plan investigations, and evaluate their feasibility. Once particular investigations are determined, students do background research as well as collect and analyze data, such as the results of tests of water samples collected from a local reservoir or class members' taps. In this process, they work together, collaborate with their teachers, and often communicate with knowledgeable members of the community who can assist with various aspects of the investigation. Science content is addressed as it arises naturally out of the context of the investigations. The results of the process are artifacts (e.g., water samples, test results, graphs, charts) and products (e.g., reports, multimedia presentations, portfolios) produced by the students. Computer technology can play an important role throughout the process as a tool for gathering information, analyzing and representing data, and communicating the results. The project provides a pivot around which science learning, as well as learning in other subjects, can revolve.

In this article, we report on the evaluation of a four-year professional development effort focused on project-based science education. We provide background about the project, an overview of the evaluation procedures, outcomes of the professional development activities, and a description of the implementation of project-based science units during the academic year. Lessons learned from the project are presented.

Project INSITE: An Indiana Project-based Science Initiative

Project INSITE, Institute for Science and Technology, was a school-based, teacher professional development project supported by the National Science Foundation and the Indiana Department of Education, that focused on project-based science. Deriving from earlier efforts related to the use of telecommunications in the classroom (Buchanan, Rush, Krockover, & Lehman, 1993), this initiative was aimed primarily at teachers in grades 5 through 9 and designed to provide the pedagogical and philosophical foundations for improving science education, develop a set of strategies to increase students' active learning of science, and develop approaches to significantly enhance the roles of both students and teachers in order to create an environment to encourage creativity, critical

thinking, and communication through the use of information technologies. The project, which ran from 1995 through 1999, involved a partnership of school districts, mostly in Indiana and led by the Eagle-Union Community Schools in Zionsville; Purdue University; businesses, including Dow Agrosciences and Eli Lilly; and others.

Each year of the project consisted of three phases of activity: (a) a summer institute for in-service (and some pre-service) teachers, (b) academic year implementation of project-based science units in K–12 classrooms, and (c) a follow-up for teachers (except for the final group of participants) during the subsequent summer. The key teacher-development activity each year was the initial summer institute, which was designed to introduce a cohort of participating teachers to project-based science and to help them develop the knowledge, skills, and dispositions to implement their own project-based science units in the classroom. Except for the final summer of the project, when an abbreviated institute was offered, the summer institute was a three-week experience for teachers consisting of a project-based science activity designed to model the sorts of experiences the teachers were encouraged to develop for their students, mini-workshops to help teachers develop personal knowledge and skills related to relevant pedagogy and technology use, field visits to businesses and other sites where teachers could observe science in action and interact with practicing scientists, and development of project-based science curricular units by teams of participating teachers for integration into their classrooms during the following academic year.

During the summer institute project-based science activity, teams of participants developed investigations related to a guiding question developed by the project staff, "What is in our water, and how did it get there?" This activity was intended to serve as a model of project-based learning for participants. It allowed participating teachers to engage in project-based science activities as learners; analyze the components of a project-based science activity in terms of the roles of the teacher, students, and technology; and reflect on the process. A team of facilitators, many of whom had been participants in a previous institute, worked with the participants to assist them during the activity. At the conclusion of the activity, it was hoped, participants would have developed, in a relatively short period of time, an understanding of project-based science, its benefits and limitations, and key elements of the approach.

As the institute continued, participants were given the opportunity to see science in action through a series of site visitations or field trips in the area, including the Dow Agrosciences research center, Eli Lilly research laboratories, the National Weather Service, and the U.S. Geological Survey. When not on site visits, participants took part in mini-workshops that covered a variety of topics related to technology (e.g., Excel, PowerPoint, the Internet) as well as relevant pedagogy (e.g., cooperative learning, alternative assessments).

During the last week of the summer institute, teams of participants planned their own project-based activities for the coming academic year. To provide a framework for

the development of curricular units, each year of the project revolved around a different theme taken from the Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993). Project-based science units created by the teams of participating teachers were designed to (a) relate to the year's theme and explicitly address state and national science standards; (b) be multi-week in duration and involve multiple school sites; (c) adopt a learner-centered, project-based approach consisting of use of an organizing driving question, student-generated investigations and research, interdisciplinary elements, and use of local resources; and (d) integrate technology as a tool for communication, information acquisition, data manipulation and representation, and presentation.

During the academic year, participating teachers implemented their project-based science units. To provide ongoing support, the project employed a teacher-in-residence who worked with the teacher cohort. The teacher-in-residence was an experienced practicing teacher, knowledgeable about inquiry-based science teaching, who was released from regular teaching duties during the year in order to help participants implement their project-based science units in the classroom. During the last three years of the project, one individual who was a participant in the first year of the project served as the teacher-in-residence. He provided support to participants by visiting their classrooms and assisting as needed with implementation of their project-based science units (e.g., helping teachers with lesson plans, working directly with students, assisting with the use of technology).

Follow-up meetings were held during the academic year to keep participating teachers engaged in the project and maintain communication. During the following summer, the teacher cohort returned for a one-week follow-up session, during which the year's activities were discussed and analyzed and participants revised their project-based science units for final publication on the World Wide Web.

Participants

Participants in the project consisted of a total of 287 teachers from 51 school districts. Approximately 73% of participants were female and 27% were male. About 35% of participants were elementary teachers, 42% were middle or secondary school science teachers, 12% were teachers in other disciplines, and the remainder included specialists (e.g., media specialists, technology coordinators) and pre-service teachers. Students who took part in the teachers' curricular units during the school year were also participants in the project. Although the total number of student participants is not known, student reaction forms were gathered from over 700 students in each of the last three years of the project alone.

A qualitative analysis of ongoing implementation of classroom projects was un-

dertaken during the 1998-99 year of the project. A total of 23 teachers (out of 38 total participating in-service teachers that year) and their students were studied during this part of the evaluation. Participating teachers and students represented a total of 17 elementary, middle, and high schools and a range of curricular units. Participants for this analysis represented a convenience sample because all the classrooms were located in central Indiana and were engaged in project-based science activities at times when it was convenient for the evaluators to observe them.

Methods and Data Sources

The evaluation of Project INSITE was designed to address the process and product categories of Stufflebeam's (1983) CIPP evaluation model with special focus on Kirkpatrick's (1979) scheme for evaluation of training. Guiding questions were developed within this framework, including: What were participants' perceptions of the summer institute and projects? Did participants' attitudes toward science teaching and/or technology change as a result of the experience? Did participants acquire new knowledge or skills? Did participants' curricular development efforts reflect the goals of the project? What evidence was there of project-based science in participating classrooms? and What were students' perceptions of project-based science activities?

Data were collected from a variety of relevant sources to address the questions. These included pre- and post-institute questionnaires assessing participants' attitudes towards science teaching, attitudes towards computers, and technology usage; Likert-type surveys of participants' attitudes toward the institute; open-ended surveys of participants' perceptions of the project; review of participant-constructed portfolios of their projects; on-site observations of the institute and participating classrooms; informal interviews with participants and staff facilitators; and surveys of students' attitudes toward project activities. Quantitative data were compiled, and, where appropriate, pre- and post-institute data were statistically compared.

A qualitative analysis of ongoing implementation of classroom projects was undertaken during the 1998–99 year of the project with a sample of 23 teachers and their students from participating schools in central Indiana. Field notes from classroom observations, transcripts of audiotaped teacher-student and student-student interactions, and transcripts of audiotaped unstructured teacher and student interviews were analyzed via analytic induction (Goetz & LeCompte, 1984) to yield a qualitative description of activities in participating classrooms. Information from the data sources was read and reread to search for common patterns using the features of project-based instruction as a framework. Other evaluation materials referenced in this paper (surveys and portfolios), emails, phone conversations, and conversations with the teacher-in-residence served as secondary data sources to triangulate findings.

Pre-institute questionnaires were administered to participants during an initial project orientation session that took place about six weeks prior to the beginning of the summer institute. Post-institute questionnaires were administered at the end of the institute. Items on these questionnaires were used to assess participants' attitudes toward science teaching and attitudes toward computers before and after the institute. Attitudes toward science teaching were assessed using items adapted from the work of Bratt (1973). This scale consisted of two items in each of twelve categories (twenty-four items total) designed to assess participants' views of science teaching. Six of the item categories (the odd-numbered ones) corresponded to learner-centered perspectives of science teaching, and six of the item categories (the even-numbered ones) corresponded to teacher-centered perspectives of science teaching. Scores in each category could range from 0 (disagreement) to 6 (agreement), where more learner-centered attitudes toward teaching science were indicated by agreement with learner-centered category items and disagreement with teacher-centered category items. The computer attitudes scale was adapted from the work of Anderson, Hansen, Johnson, and Klassen (1979) and had been used successfully in previous technology-related teacher development projects. The instrument consisted of twenty Likert-type items (e.g., "Working with a computer makes me feel uneasy or tense"), in which each positively worded item was scored 1 for strongly disagree, 2 for disagree, 3 for undecided, 4 for agree, and 5 for strongly agree, and each negatively worded item was scored in reverse fashion. Individual item scores were summed to yield a computer attitude score of 20 to 100, where higher scores represented more positive attitudes.

Participants' reactions to the summer institutes were gathered through the use of survey forms as well as through interviews with participants. Participants were able to respond to open-ended survey items on an institute evaluation form (e.g., "How have your students benefited from the project activities?"). Students' perceptions of the project were collected through the use of a student reaction form, developed for the project, consisting of eight Likert-type items (e.g., "In this project, I feel like I learned a lot of science"), five semantic differential items (e.g., "Which word from the pair of words comes closest to how you feel about the project? boring . . . exciting"), and five open-ended questions (e.g., "What did you like most about the Project INSITE activity?"). This form was completed by students in participating classes after the conclusion of project activities.

Results and Discussion
Evaluation of the Summer Institute

To address the guiding questions about participating teachers' perceptions of the summer institute, their attitudes toward science teaching and technology, and their learning, we conducted an evaluation of the summer institute. We looked for evidence of changes in teachers' attitudes toward science teaching and toward technology, and we also examined teachers' perceptions of the summer institute.

Each year of the project, a pre-institute/post-institute questionnaire was used to assess participants' attitudes toward science teaching. Table 1 summarizes the pre-institute and post-institute means for each summer institute of the project. As described above, the science attitudes scale yielded individuals' attitudes toward science teaching in 12 categories, where the odd-numbered categories were indicative of learner-centered perspectives toward science teaching and the even-numbered categories were indicative of teacher-centered perspectives. It was hoped that more learner-centered perspectives would be observed after the summer institutes, because Project INSITE was intended to promote a learner-centered perspective of science teaching among participating teachers.

The data in table 1 indicate that participants' science teaching attitudes were relatively consistent and tended toward learner-centered across the entire project. Paired samples t-tests were used to compare pre-institute and post-institute means in each category. With the exception of the fourth summer, participants tended to show unchanged to somewhat more learner-centered attitudes toward science teaching after the institute when compared to before. In most cases, statistically significant changes were noted in several categories. The fourth summer institute results, which showed two significant changes toward more teacher-centered perspectives, were an apparent anomaly.

The data in table 1 show that after three of the five summer institutes, participants' responses to items in category 4 (There are certain facts in science that children should know) declined significantly. Because category 4 was a teacher-centered category, this means participants came to disagree with statements indicative of this position more after the institute than before. This was a desired outcome, because Project INSITE promoted a view of science as a process that students should engage in rather than an established body of facts to be acquired.

After three of the five summer institutes, participants' responses to items in category 6 (Science teaching should be a matter of telling children what they are to learn) also declined significantly. Again, because category 6 was a teacher-centered category, this means that participants came to disagree with statements indicative of this position more after the institute than before. Similar results were obtained for items in category 10 (Teachers should be the authority in the classroom; they ought to be there to teach and the students should be there to learn from them).

Finally, after every summer institute, there was a clear decrease in participants' scores in category 12 (The teachers should be the sole determiners of activities; they should plan and evaluate each day's work), another teacher-centered category. This change was statistically significant ($p < .05$) every year except for the anomalous fourth summer institute. Participants' growing disagreement with this position after the institute indicates that they were embracing the ideals of project-based science, where students have a significant role in determining what projects they pursue in the science classroom.

Table 1
Participants' Science Teaching Attitudes Means, Pre-Institute and Post-Institute

Statement Describing Science Teaching Category	Summer 1		Summer 2		Summer 3		Summer 4		Summer 5	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1. The idea of teaching science is attractive to me; I understand science and I can teach it.	3.12	3.24	3.76	3.70	3.85	4.09	3.66	3.64	3.31	3.88
2. I do not like the thought of teaching science.	1.68	1.72	0.67	0.66	1.16	0.95	0.84		0.90	0.52
3. There are certain processes in science which children should know, i.e. children should learn how to do certain things.	4.30	4.24	4.05	4.00	4.53	4.67	4.55	4.14	4.59	4.34
4. There are certain facts in science that children should know.	4.03		3.50		2.79		2.48	2.67	2.65	2.31
5. Science teaching should be guiding or facilitating learning; the teacher becomes a resource person.	3.95	4.05	4.24	4.56	4.61	4.89	4.79	4.31	4.79	4.77
6. Science teaching should be a matter of telling children what they are to learn.	2.81		2.67		1.62	1.13	1.81	1.56	1.82	
7. In education and teaching, the needs of students and teachers should be more important than the subject matter.	3.40	3.52	4.22	4.60	4.39	4.20	4.15		4.16	4.17
8. In education and teaching, covering subject matter, i.e., science, should be more important than the needs of the students.	2.76		1.87	1.46	1.89	1.58	1.94	2.00	1.66	2.09

Note: * denotes statistically significant mean change p < .05.

Because the use of technology in project-based science was also a focus of Project INSITE, the pre-institute/post-institute questionnaire was also used to assess participants' attitudes toward computers. As described above, the computer attitudes scale yielded a score of 20 (negative) to 100 (positive). Table 2 summarizes the computer attitudes results broken down by each summer institute.

Table 2
Participants' Computer Attitudes, Pre-Institute and Post-Institute

Summer Institute	Pre-Institute Mean (SD)	Post-Institute Mean (SD)	t	p
1	85.28 (8.83)	86.04 (7.64)	1.60	0.12
2	85.07 (8.85)	87.54 (7.92)	2.47	0.02
3	88.48 (6.77)	88.88 (6.82)	0.54	0.59
4	84.42 (10.12)	86.51 (7.94)	1.60	0.12
5	85.06 (8.05)	86.18 (8.49)	1.24	0.22

The data in table 2 indicate that participants had positive attitudes toward computers both before and after the summer institute (where means above 80 denote an average response between agree and strongly agree on positively worded items). Post-institute computer attitudes means were slightly higher than pre-institute means after each summer institute. However, paired samples t-tests revealed a statistically significant ($p < .05$) change only after the second summer institute. Although little change was observed in participants' computer attitudes, use of technology was a key aspect of the institute. Participants reported becoming more familiar with various applications through the summer institute training, including word processors, presentation software, multimedia authoring software, and web page development software (Lehman, George, Rush, Buchanan, & Averill, 2000). In addition, technology was frequently cited by participants as a positive aspect of the project (see table 3).

Overall, participants tended to have positive opinions of the summer institutes. Through all four years of the project, participants' responses on a Summer Institute Evaluation Form showed consistent agreement that the science and technology content was useful, the institute instructors were effective and helpful, participants' knowledge of technology improved because of the institute, the hands-on activities were helpful and appropriate, and the institute helped participants gain knowledge and grow professionally (Lehman et al., 2000). Participants' responses to open-ended questions on the evaluation form indicated that they liked the opportunity to learn about and use technology, to collaborate with colleagues, and to learn about and develop a project-based science unit.

Qualitative Analysis of Project-Based Science Implementation

Participating teachers implemented project activities in their classrooms during the academic year following the summer institute. To address the guiding questions about curricular development efforts and project-based science in participating classrooms, a qualitative analysis was undertaken to examine how and to what extent teachers implemented the pedagogical approaches of project-based learning, introduced during the summer institute, into their classroom instruction. Findings are organized as assertions based on the evidence gathered.

Assertion One: Students in Participating Classrooms Were Engaged in Meaningful Investigations

In all twenty-three classrooms observed, the driving questions formulated during the summer institute served as a basis for meaningful classroom investigations. During the summer institute, teachers brainstormed a list of explorable topics within their school curricula, selected a topic, and formed six teams to develop appropriate driving questions. Each team chose a name to represent themselves and their topic; the six names were the Aquamorphs (A), Eco-Detectives (ED), Gems (G), La Nina (LN), Perpetual Inertia (PI), and Popcycles (P). The process of formulating a driving question was a thoughtful and time-consuming one. By the end of the summer institute, teachers had developed driving questions and project plans for classroom enactment that were feasible, worthwhile, contextualized, and meaningful. The driving questions were as follows:

- How do changes in our watershed affect the ecosystem? (A)
- How does water shape our earth? (G)
- How do forces change motion? (PI)
- How do the various components of an ecosystem interact? (ED)
- What are the causes and effects of populations? (P)
- What are the causes and effects of weather? (LN)

Implemented projects varied by the topics addressed, project duration, and the types of activities implemented. Typical projects spanned 4–6 weeks of class time, although specific project implementations varied. During classroom visits, activities suggested that children were engaged in self-directed investigations to address the driving questions. We saw evidence suggesting that teachers were fostering student motivation to learn science and enhancing students' cognitive engagement with science content. Projects were observed in various stages of enactment, which we classified as pre-activities, investigative activities, or presentations.

Pre-activities were defined as activities that introduced the students to the process

of doing "real" science, allowing them to "get their feet wet." Ideally, the driving question provided the backdrop for pre-activities, which included group-building activities, brainstorming sessions, introduction to technology and science equipment, preliminary investigations, and reflections. At one elementary school, two teachers, Joan and Molly (pseudonyms), were collaborating with their second and third graders beginning an investigation of a school-site wetland for the driving question, "How do changes in our watershed affect the ecosystem?" Joan and Molly divided the children into mixed groups of second and third graders. Each group had previously chosen a small parcel of land. They identified the native plants that lived in that parcel by comparing them with information they had found on the Internet and wrote down their findings in group journals. It was particularly meaningful that each group of children was responsible for a particular section of the wetland habitat. One group identified rice cut grass, fairy aster, and creeping spike rush in "their spot." One student commented, "I liked picking our spots in the wetland" (Ryan, second-grader). The feelings of ownership that were fostered in this activity helped to motivate the students. Further, the pre-activity allowed the students to become familiar with scientific processes, as well as scientific equipment and computer technology, in advance of the main investigation of the project.

In a majority of classrooms visited (13 out of 23), students were observed actively involved in different stages of the investigative process, including (a) generating and refining investigative questions, (b) planning "fair" investigations (where only one factor is varied at a time), and (c) interpreting evidence gleaned from the investigations. In these cases, it appeared that students were engaged in authentic science, thinking for themselves, working together, and gaining science process and content knowledge.

In one rural classroom, Beth, a sixth-grade teacher, had her students refine their list of investigative questions that had been generated in an earlier class meeting. The questions were derived from the driving question, "How does water shape the earth?" The teacher, using criteria suggested in the summer institute, asked the students to think about whether their investigative question (a) helped answer the driving question, (b) was testable, (c) could be answered in the time given and using available equipment, and (d) was unique. One group, dubbed the Soil Suds, generated possible questions, which (as recorded verbatim in the students' notebook) included "How dose aset rain go thrue and eat lime stone?" "How much rain dose it take to cause a mude slide?" "How tall could grass get in five days?" and "How much water can dirt or clay hold?" After discussing their questions and considering the criteria, the students narrowed their question to "How much water can dirt or clay hold?"

In an environmental education class at another school, students identified a question and worked on designing their experiments. One of these investigations involved large hissing cockroaches and the type of light they would prefer. The teacher, Ann, asked a series of prompting questions to focus the students on fair testing:

Ann: Go back to your procedure. How will you separate the lights?

Jason: We will use three chambers with holes between them so roaches can pass from chamber to chamber.

Ann: What do you think will happen?

Jason: If the bugs are given a choice between the different lights they will prefer the one that is most like their natural environment.

Ann: Are the rest of you okay with Jason's hypothesis? Is it specific enough? (Field notes, 11/25)

As the discussion proceeded, Ann encouraged the students to think about the difference between the manipulated conditions (different color of lights) and the controlled conditions (food, air, intensity of light) in the experiment. The students spent time talking about this and other experiments they would be performing with the insects.

In a sixth-grade classroom investigating the driving question, "How do forces affect motion?" students selected their questions and generated fair testing situations. One group tested whether differently shaped cars traveled at different rates down plastic tracks. Outside, another group dropped water balloons from a ladder into a bucket of water to see how the dropping height affected the size of the splash, while a third group tested whether the angle at which a "stomp rocket" was projected affected the distance it flew. In these classrooms, students were asking their own questions, planning their investigations, collecting and interpreting data, and revising their experiments as needed. Teacher guidance was evident, but as a means of supporting students rather than doing the work for them.

The projects also provided opportunities for students to communicate with an audience about their findings via presentations. In a number of classrooms, students used PowerPoint to present the results of their investigations. In one of these classrooms, Kathy, a sixth-grade teacher, guided her students to create their presentations using a paper template before working in groups to put the information into the computer. In another participating classroom, the Project INSITE teacher-in-residence, Matt, assisted the classroom teacher, Tom, to help the students in his eighth-grade social studies class use Claris HomePage, a tool for developing web pages. After some instruction, the students were able to comfortably create links on web pages to report their group findings. In yet another case, middle-school students compiled their investigation results using HyperStudio, a multimedia authoring tool. The students made their presentations in the school library, a small room that housed a media system consisting of a computer attached to a television monitor. The students were excited about sharing their projects with their classmates, and this communication of results was a key element of the project-based science learning that took place.

Assertion Two: Artifacts Conveyed Understanding

One of the hallmarks of project-based science is the production of products or artifacts that address the investigative question, incorporate technology, and extend and amplify students' mental processes. These artifacts can be presented to and critiqued by others—students, teachers, parents, and community members—in formal presentations as described above, or in less formal settings embedded throughout the project. As a result of artifact development, learners were able to reflect on and revise their ideas, thereby enriching their knowledge.

Implementation of projects in the classrooms led to students' artifacts. Student artifacts took various forms: notebooks, journals, self-reflections and evaluations, written plans, model making, posters, and presentations. Typical of project-based science, the production of artifacts was embedded in the instruction and contextualized within the students' investigations. For instance, some teachers used pre-assessment concept maps or other types of graphic organizers to assess students' understanding before beginning investigations. Most teachers (18 of 23 observed) used student journals and reflections to document the progress of students as they undertook their investigations and secured information. Digital and analog photographs, as well as drawings taken by students and teachers, added depth and completeness to written accounts.

Some classrooms utilized model-building as a means of constructing understanding. Functional models of weather instruments, simple machines, and aircraft served as artifacts in participating classrooms. Students especially enjoyed the "hands-on" encounters with materials that this model-making provided. One student commented, "Well, our driving question was 'What kind of boat will hold the most coffee beans?' And we got to make the boats out of Styrofoam, and we got cardboard, poster board, foil, and mud. I really enjoyed making the mud boat and trying to make it float" (Tammy, survey). In nearly all participating classrooms (21 out of 23), a technology-based product (e.g., PowerPoint presentation, HyperStudio stack, or website) served as the culminating product of the project. Many teachers had students present their projects to a larger group, including other classrooms and parents, using the technology.

Teachers used portfolios as a means to document the projects that were developed in their classrooms. Portfolios included both student artifacts, such as those described above, as well as teachers' reflections and ideas as they enacted the project. Because of the breadth of classrooms represented, these portfolios were important documentation of the curricular targets addressed by the project-based science activities, the active investigations that occurred, and the collaborations initiated and sustained during the project.

Assertion Three: Collaboration Was an Important Element of Projects

Teachers incorporated collaboration into the enactment of their project-based science activities, particularly small-group collaboration within the classroom. Collaboration on a project often involved more than sharing work or dividing responsibilities. It required

exchanging ideas and negotiating meaning, or what Krajcik et al. (1999) defined as "a joint intellectual effort of students, peers, teachers, and community members to investigate a question or problem" (p. 131).

During enactment of the projects in the classrooms, collaboration took many forms. The predominant forms of collaboration observed were teacher-student facilitation (observed in 19 of 23 classrooms) and within-class small-group collaboration (observed in 21 of 23 classrooms). Often teachers actively worked to create collaborative environments, for example by establishing student groups. Teachers in these situations tended to act as facilitators, collaborating with the students by helping them think of questions, design investigative plans, analyze data, procure materials for their investigations, or provide instruction to master a particular skill, such as using a balance, microscope, PowerPoint, or the Internet. For example, in one classroom, where fourth graders were investigating the question, "What are the causes and effects of weather?" the teacher led a discussion in which she had each group work together for about twenty minutes to answer the following questions: How are data reflecting your hypothesis? What do you think about this? Why do you think it may be different? What might be some of the causes? (field notes, 11/3).

In addition to teacher-student collaboration, small groups of students directed project activities at almost all sites. In the fourth-grade classroom cited above, the students shared the preliminary results of their investigations and conducted a tour of the school showing the sites of investigations. All of the individual students were familiar with the groups' project plan and comfortable sharing information. However, students expressed mixed feelings about working with other students. Student comments included the following: "One of my group members didn't do much work" (Laurie, fifth-grader); "Sometimes people wouldn't cooperate, and we had to sort of push them to do something" (Justin, seventh-grader); "I learned that it might not be that easy to do a project like this by yourself" (Ashely, seventh-grader); "I liked working in groups more; it let you share your ideas" (Mario, sixth-grader); and "We work as a team and if you mess up your whole company will have to pay" (Austin, sixth-grader).

Collaboration also occurred across classes within particular schools. This was the case, for example, when two or more teachers from the same school had participated in the Project INSITE summer institute and worked together during the academic year. In five participating school communities, a Project INSITE participant utilized a school-based project site, such as an ecosystem or wetland, and this motivated other classrooms to get involved in the investigations and learn about project-based science. Those schools where collaboration occurred among a group of teachers, such as most or all of the members of the science department staff, seemed to have the greatest impact on students' learning and engagement. Perhaps the least common form of collaboration was among participants from different schools. Although some classrooms communicated via email and chat

rooms or posted websites to inform other Project INSITE classrooms of their progress in answering the driving question, sustained collaboration among teachers or students from different school sites was uncommon, although it had been a goal of the project.

Teacher collaboration was most effective when teachers were at the same school, working on the same driving question. For instance, two fifth-grade teachers who were members of the Perpetual Inertia group were able to team-teach and structure collaborative activities easily within their classrooms. One teacher addressed the science aspects of the question, "How do forces affect motion?" while the other teacher emphasized the forces in the U.S. Constitution that affect the "motion" of democracy in our country. Another group of middle-school teachers addressing the same driving question collaborated to plan a unit that integrated math, science, and language arts. Some teachers from different schools attempted to initiate and maintain collaboration via email or chat rooms. However, these attempts largely failed. The teachers attributed this failure to problems such as lack of technology, inexperience with project-based science, or unresponsiveness of other group members.

However, in several cases, teachers successfully integrated community resources into their projects. Several teachers invited guest speakers from local universities or businesses to visit with the children and share information regarding their area of expertise. Field trips were another way that teachers incorporated community resources. Many teachers were fortunate to have outdoor labs or other types of exploratory sites to visit that were close to school grounds, while other teachers scheduled lengthier field trips at distant sites that proved to be valuable parts of the children's learning experiences. Beth, a sixth-grade teacher and member of the GEMS group, took her class on a field trip to a cave as part of their investigation of the driving question, "How does water shape our earth?"

Most teachers involved in Project INSITE also collaborated with the project's teacher-in-residence, Matt. Some teachers collaborated with Matt to help them plan their lessons. Other teachers invited Matt into their classrooms to help students formulate questions and plan investigations. Matt also taught students in several classrooms to create web pages and PowerPoint presentations. Many teachers used Matt as a "sounding board" for their frustrations as well as successes in enacting problem-based science in their classroom. Those teachers who used Matt's expertise were positive about the support he provided.

Qualitative Analysis Summary

This qualitative analysis documented features of project-based instruction as it was enacted in participating teachers' classrooms. The findings suggest that participants' curricular units reflected the goals of the project, and the implementations of these projects in participants' classrooms were true to the vision of project-based science. Teachers designed

classroom units focused around a driving question, and in the classrooms student groups planned and undertook investigations, utilized technology and community resources, and presented their findings. Various artifacts documented this intellectual collaboration.

Teachers and students participating in Project INSITE appeared to benefit from project-based science in several ways. First, because students and teachers were pursuing authentic questions, they found the work interesting and motivating. Second, teachers, students, and project staff, including the teacher-in-residence, perceived that much learning took place. Teachers and students both thought that students learned about science content, and teachers gained confidence in student-centered pedagogical techniques. Third, both teachers and students developed a greater understanding of the process of science. Teacher and student participants developed the ability to ask good questions, plan and design investigations, and make conclusions about everyday problems. Fourth, participants learned to work with each other and with their community to solve problems. Finally, projects encouraged both group and individual accountability in the production of artifacts, and it led to the development of technological skills of both teachers and students. One fifth grader expressed his own feelings about project-based science by writing:

> I really liked how Project INSITE let us do almost everything hands-on. I liked that we got to choose our own projects. I also liked testing how long it took the balloons to touch the ceiling. I think this is a better way to teach science because the material is more likely to get implanted in your brain than if you're studying from a textbook. We got a chance to get along with our classmates and hear their ideas. It must have taken a smart person to come up with a cool science project idea like Project INSITE! (Brian, survey)

Teachers' and Students' Perceptions of Project-Based Science Activities

In addition to the qualitative analysis of classroom activities, evaluation of the academic year implementation of project-based science activities incorporated questionnaires of participants' perceptions of the projects and students' reactions to project activities to address the guiding questions related to participants' and students' perceptions of the projects. Participating teachers' perceptions about the project were gathered via open-ended questionnaires that were administered at the end of the summer institute (to establish a baseline) and again at follow-up meetings during the academic year. Student reactions were collected after the completion of project activities in the participating classrooms.

Items on the participating teacher questionnaires asked participants about their feelings concerning project-based science, use of technology, perceived advantages and disadvantages, and perceived impact on students. Participants' comments in response to

these items often reflected greater confidence and feelings of success after implementation of projects in the classroom. For example, a first-year participant commented,

> Last summer on the last day of training I didn't think there was any way I would be able to get sixth graders into project based science. It has taken about ten weeks to get through the obvious getting to know middle school for the students. During this period we've done several mini-projects which served as background information. Much to my amazement the students have, for the most part, been wildly enthusiastic about everything we've done. (Participant questionnaire)

A second-year participant commented, "Project-based science has changed my entire teaching style. It has empowered me to try things I've never before considered. It has definitely empowered my students!" (participant questionnaire).

Participants were asked to identify project benefits, both for their students and for themselves, as well as advantages and disadvantages of project-based science. Common themes that were expressed in these comments across all the years of the project, and the frequency of comments addressing these themes, are summarized in table 3.

Specific comments from participants addressed many of these themes. A first-year participant noted, "It has made me more of a believer in the power of student engagement through the use of inquiry based instruction and technology, both of which are natural motivators" (participant questionnaire). A third-year participant suggested, "Students have a better grasp of the complexity of research. Students feel more confident in their science and technology skills. Students enjoyed facilitating younger students in project-based science" (participant questionnaire). A second-year participant commented, "The driving questions really helped me change my focus from teacher-initiated to student-driven. I think any time our students can take more responsibility for their learning then we are better teachers" (participant questionnaire).

Teachers' comments also addressed the disadvantages or limitations of this method. As noted in table 3, time issues were the most frequently cited disadvantage. A first-year participant commented, "I have observed the increased interest of students during project time, but I am still 'nervous' about the decrease in base knowledge that results because of time constraints when involved in projects—am working on this mindset" (participant questionnaire). Issues with technology were also frequently noted, although these declined over the term of the project. A fourth-year participant noted, "There were times that the appropriate technology was not available or not operating at the time" (participant questionnaire).

To summarize, participating teachers reported many perceived student benefits, including high levels of student motivation, learning about science and technology, development of collaborative learning skills, and students' ownership of their learning. For themselves, the teachers cited the benefits of learning a new instructional method,

learning to use technology, learning the role of a facilitator, collaboration with colleagues, as well as general enjoyment or satisfaction. Disadvantages of project-based science included that it was time-consuming, can be subject to problems with technology and access to materials, may interfere with coverage of the regular curriculum, and may in-volve classroom management difficulties, including student group dynamics. In general, participants seemed to view the advantages as outweighing the disadvantages.

Table 3
Project Benefits and Disadvantages Frequently Cited by Participating Teachers (n=132)

Commonly Cited Benefits and Disadvantages	Frequency
Student benefits	
Interest/enthusiasm/motivation	34
Ownership/responsibility for own learning	32
Learning about technology	28
Collaboration/cooperative learning skills	25
Learning science/scientific processes	18
Improved thinking/problem-solving skills	12
Teacher benefits	
Learning new teaching methods/teaching better	51
Learning more/better use technology	29
Becoming more of a facilitator/learner-centered	18
teaching	15
Teaching enjoyment/personal satisfaction	5
Seeing students' success	4
Collaboration with others	4
Learning more about science	4
Improved personal confidence	
Disadvantages	
Not enough time/time-consuming	68
Problems with technology/access to technology	32
Classroom management problems	20
Lack of sufficient materials and supplies	16
Difficulties with group dynamics	13
Problems covering content/interferes with regu-	12
lar curriculum	8
Poor collaboration/support of team members	

In addition to the qualitative data reported above, a student reaction form was de-veloped and used to gather students' opinions about the project in the last three years of implementation. As noted above, the instrument contained eight Likert-type items (with scores ranging from 1 for strongly disagree to 5 for strongly agree), five semantic

differential items (with scores ranging from 1 for agreement with the first term to 5 for agreement with the second term), and five open-ended questions. The student reaction form was administered by teachers to students in participating classes after the conclusion of project activities. A summary of the mean scores from this instrument for the three years it was used is given in table 4; open-ended responses are summarized below.

Table 4
Summary of Responses to the Student Reaction Forms

Evaluation Item	1997–98 Mean (n=869)	1998–99 Mean (n=883)	1999 Mean (n=728)
Likert-type Items			
1. In this project, I feel like I learned a lot of science.	3.86	3.77	3.86
2. In this project, I feel like I learned new things about using technology.	3.65	3.71	3.50
3. I would rather work by myself than work in groups.	2.02	1.96	2.21
4. I did not like the hands-on activities during the project.	1.74	1.92	1.68
5. Compared to what we usually do in school, I like this project better.	4.06	4.05	3.92
6. I do not really like studying science in school.	2.51	2.36	2.28
7. This project is okay, but it does not really relate to me and my life.	2.79	2.94	2.89
8. Because of this project, I am more confident in my ability to do science.	3.40	3.44	3.51
Semantic Differential Items			
9. Exciting............Boring	2.38	2.38	2.26
Too Easy...........Challenging	3.53	3.48	3.48
Fun....................No Fun	2.17	2.09	1.99
Waste ....Worthwhile	3.88	3.82	3.97
Worst...............Best	3.65	3.62	3.75

Note: Likert-type item means could range from 1.00 (strongly disagree) to 5.00 (strongly agree). Semantic differential item means could range from 1.00 (agreement with first term) to 5.00 (agreement with the second term). For both item types, means of 3.00 indicated undecided or neutral.

The data in table 4 indicate that students agreed that they learned about science (item 3) and technology (item 4). They disagreed that they preferred working by themselves (item 5) and that they did not like the hands-on activities (item 6). Students clearly liked the Project INSITE activities in comparison to their usual class activities (item 7). They liked studying science in school (as indicated by disagreement with item 8). They disagreed, but only slightly, that the project did not relate to them personally (item 9); since this item approached neutrality, it suggests students were not always convinced of the personal relevance of project activities. They agreed that the project made them more confident in their ability to do science (item 10). The semantic differential items (items 11–15) showed that students tended to view the project as exciting, easy, fun, worthwhile, and the best.

In response to open-ended items, students reported liking the hands-on activities, group work, and use of technology. A second-year project student commented, "I liked doing a project where it was completely up to your group on how you wanted to do it. There was room for fun and creativity" (student reaction form). Their most common dislikes were group work or group members, having to write, having to do research, and not having enough time. One third-year project student commented, "I liked everything we did. Everything was fun. My least favorite thing could be that a few times my group didn't get along because someone didn't get their way" (student reaction form). Their overwhelming first choice as the favorite part of the activity was the hands-on activities and experiments; other favorites were use of technology, getting to make things, and working in groups. When asked to name something they had learned, most students named something related to science content.

Conclusions and Lessons Learned

The evaluation of Project INSITE suggests that it was mostly successful in preparing teachers to implement project-based science activities in their classrooms. The key professional development component of the project, the annual summer institute, helped to promote somewhat more learner-centered attitudes toward science teaching among participating teachers while also giving them the opportunity to learn how to integrate technology in support of project-based science. During the summer institutes, the use of a project-based science modeling activity was able to convey, in a relatively short period of time, the nature of project-based science to teachers, many of whom had never been exposed to this method before. This approach is consistent with the recommendations of Hitchcock and Mylona (2000), who suggested that faculty development for PBL must first help faculty members understand the nature of PBL and experience the PBL process for themselves. Facilitators, many of whom had been participants in previous years of the project, helped to guide the project-based science experience for participants and model the sorts of approaches the teachers could employ in their own classrooms. Previous

work in problem-centered learning has shown that the role of the facilitator is critically important (Hmelo-Silver, 2004). In this project, facilitators helped introduce participating teachers to project-based science, and the teachers themselves became facilitators when helping their students conduct project investigations. The teacher-in-residence extended facilitation through the academic year by supporting the teachers and helping them to implement their projects. In the end, participating teachers implemented project-based science curriculum units that were anchored in national science standards, long-term in duration, and interdisciplinary, and used technology as a tool integral to the process. These units affected classroom instruction for thousands of students.

While there was considerable variation in the projects themselves, there were many clear instances of successes. Observations in participating classrooms confirmed that students pursued authentic questions that they found interesting and motivating, learned science processes and content as well as how to use technology, collaborated with each other and with members of their community to solve problems, and demonstrated individual and group accountability through the production of artifacts and presentation products. This is consistent with other accounts of project-based science (Schneider et al., 2002).

Participating teachers' reactions to the project activities revealed that they felt that their students became more interested and motivated because of project-based science, learned about technology, developed personal responsibility for learning, acquired collaborative learning skills, and, of course, learned science and scientific processes. These findings are consistent with literature on problem-centered instructional methods (Hmelo-Silver, 2004; Schneider et al., 2002; Torp & Sage, 2002). Participating teachers felt the projects were of personal benefit because they helped them learn new ways to teach, become more facilitative rather than directive in the classroom, learn to use technology in teaching, and gain more enjoyment from teaching.

Student reactions to the projects were generally positive as well. The students felt that they learned science, learned how to use technology, and became more confident about their ability to do science because of project participation. They indicated a clear preference for the project-based science activities when compared to usual schoolwork. Students reported liking the hands-on activities/experimentation, working in groups, and using technology. The words they most often used to describe their projects were "fun" and "exciting."

Many, if not all, of these outcomes are consistent with the vision of reform efforts in science education that is advocated nationally (National Research Council, 1996; Rutherford & Ahlgren, 1991). Thus, Project INSITE was successful in meeting its aims and promoting an approach to science education that is consistent with calls for inquiry-based and collaborative learning practices. The professional development approach utilized in Project INSITE—a summer institute focused on an authentic problem-centered experience, use of experienced facilitators, integration of appropriate technology and pedagogy

training, and support of project implementation with a teacher-in-residence—represents an approach that could be replicated in other settings to help teachers acquire the knowledge and skills to utilize problem-centered and inquiry-based methods in the classroom.

References

American Association for the Advancement of Science. (1993). Benchmarks for science literacy. New York: Oxford University Press.

Andersen, R. E., Hansen, T. P., Johnson, D. C., & Klassen, D. L. (1979). Minnesota computer literacy and awareness assessment. St. Paul, MN: Minnesota Educational Computing Consortium.

Bratt, H. M. (1973). A comparative study to determine the effects of two methods of elementary science instruction on the attitudes of prospective elementary teachers. Unpublished doctoral dissertation, Purdue University, West Lafayette, Indiana.

Brown, J. S., Collins, A., & Duguid, P. (1991). Situated cognition and the culture of learning. In M. Yazdani & R. Lawler (Eds.), Artificial intelligence and education, volume 2 (pp. 245-289). Norwoord, NJ: Ablex Publishing.

Buchanan, P., Rush, M. J., Krockover, G. H., & Lehman, J. D. (1993). Project INSITE: Developing telecommunications skills for teachers and students. Journal of Computers in Mathematics and Science Teaching, 12(3/4), 245-260.

Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. Educational Researcher, 23(7), 13-20.

Cognition and Technology Group at Vanderbilt. (1997). The Jasper project: Lessons in curriculum, instruction, assessment, and professional development. Mahwah, NJ: Lawrence Erlbaum Associates.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. Educational Researcher, 23(7), 5-12.

Goetz, J. P., & LeCompte, M. D. (1984). Ethnography and qualitative design in educational research. New York: Academic Press.

Hitchcock, M. A. & Mylona, Z. E. (2000). Teaching faculty to conduct problem-based learning. Teaching and Learning in Medicine, 12(1), 52-57.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? Educational Psychology Review, 16(3), 235-266.

Kirkpatrick, D. (1979). Techniques for evaluating training programs. Training and Development Journal, 33(6), 78-92.

Kozma, R. B. (1991). Learning with media. Review of Educational Research, 61(2), 179-211.

Krajcik, J. S., Czerniak, C. M., & Berger, C. (1999). Teaching children science: A project-based approach. Burr Ridge, IL: McGraw-Hill.

Lehman, J. D., George, M., Rush, M., Buchanan, P., & Averill, M. (2000). Preparing teachers to use project-based science: Lessons from a four-year project. Paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Moreno, N. P. (1999). K–12 science education reform: A primer for scientists. BioScience, 49(7), 569-576.

National Research Council. (1996). National science education standards. Washington, D. C.: National Academy Press.

Rutherford, F. J. & Ahlgren, A. (1991). Science for all Americans. New York: Oxford University Press.

Savery, J. R. & Duffy, T. M. (2001). Problem based learning: An instructional model and its constructivist framework. CLRT Technical Report No. 16-01. Bloomington, IN: Indiana University Center for Research on Learning and Technology.

Schneider, R. M., Krajcik, J., Marx, R. W., & Soloway, E. (2002). Performance of students in project-based science classrooms on a national measure of science achievement. Journal of Research in Science Teaching, 39(5), 410-422.

Singer, J., Marx, R. W., Krajcik, J., & Chambers, J. C. (2000). Constructing extended inquiry projects: Curriculum materials for science education reform. Educational Psychologist, 35(3), 165-178.

Stratford, S. J. & Finkel, E. A. (1995). The impact of scienceware and foundations on students' attitudes towards science and science classes. Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.

Stufflebeam, D. L. (1983). The CIPP model for program evaluation. In G. F. Madaus, M. Scriven, & D. L. Stufflebeam (Eds.), Evaluation models. Boston: Kluwer-Nijhoff.

Torp, L. & Sage, S. (2002). Problems as possibilities: Problem-based learning for K-16 education, 2nd ed. Alexandria, VA: Association for Supervision and Curriculum Development.

James D. Lehman is head of the Department of Curriculum & Instruction in the College of Education, Purdue University. Email: lehman@purdue.edu

Melissa George is a teacher at Tecumseh Middle School, Lafayette School Corporation, Lafayette, Indiana.

Peggy Buchanan is director of curriculum of the Zionsville Community Schools in Zionsville, Indiana.

Michael Rush is an educational consultant at INTEConsulting, Inc., Lafayette, Indiana.

Correspondence concerning this article should be addressed to James D. Lehman, College of Education, Purdue University, Beering Hall, Room 6134, 100 N. University St., West Lafayette, IN 47907-2098.