

Characteristics of Professional Development That Effect Change in Secondary Science Teachers' Classroom Practices

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Abstract: We studied the outcome of a professional development opportunity that consisted of 2-week-long resident institutes for teams consisting of a secondary science teacher and two students. The science content of the National Science Foundation (NSF)-funded professional development institute was monarch butterfly ecology. The first institute took place in Minnesota during the summer, and the second in Texas during the fall. Staff scientists provided intense instruction in inquiry, with numerous opportunities for participants to conduct short inquiry-based research projects. Careful attention was paid to introducing each step of the full inquiry process, from asking questions to presenting research findings. All participants conducted independent team full inquiry projects between the two institutes. Project findings show that the number of teachers providing opportunities for their students to conduct full inquiry increased significantly after their participation. A mixed-methodology analysis that included qualitative and quantitative data from numerous sources, and case studies of 20 teachers, revealed that the characteristics of the program that helped teachers successfully translate inquiry to their classrooms were: deep science content and process knowledge with numerous opportunities for practice; the requirement that teachers demonstrate competence in a tangible and assessable way; and providers with high expectations for learning and the capability to facilitate multifaceted inquiry experiences. © 2005 Wiley Periodicals, Inc. *J Res Sci Teach* 42: 668–690, 2005

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In science education research, the word “change” is often associated with a need to improve practice, content knowledge, and attitudes. The current impetus behind the push for change in science instructional practice was catapulted to center stage with the publication of the National Science Education Standards (National Research Council, 1996). The National Science Education Standards detailed instructional practices that are needed to improve the quality of science instruction and students’ academic achievement. Inquiry-based, student-centered classrooms are perceived as integral to cultivating the desired science teaching and learning culture that the National Science Education Standards recommend (Crawford, 2000). The National Science Education Standards encourage teachers to assume the role of facilitators, helping students learn to develop their own questions, design their own experiments, analyze and interpret an array of data, and draw conclusions. However, without teacher skills that include a deep level of scientific understanding, strong cooperative group management and organizational capability, and competencies in scientific inquiry, these activities could wreak havoc in the secondary science classroom. For teachers to fulfill the diverse and complex roles of teacher-facilitator, they need science learning experiences that will enable them to navigate this different terrain in secondary science teaching and learning, where scientific inquiry is the norm and not the exception. As Fullan (1996) argued: “You cannot improve student learning for all or most students without improving teacher learning for all or most teachers” (p. 41); teacher and student learning are inextricably linked.

Most science educators agree on the importance of providing teachers with experiences that allow them to do the same kind of scientific inquiry that is expected of their students. Darling-Hammond, and McLaughlin (1995) argued:

Teachers learn by doing, reading and reflecting (just as students do); by collaborating with other teachers; by looking closely at students and their work; and by sharing what they see To understand deeply, teachers must learn about, see, and experience successful learning-centered and learner-centered teaching. (p. 598)

Effective professional development opportunities must provide these kinds of experiences. Loucks-Horsley, Hewson, Love, and Stiles (1998) defined seven principles of effective science teachers’ professional development. These principles include a well-defined image of effective classroom learning and teaching, opportunities for teachers to build knowledge and skills, modeling the strategies teachers will use with students, building a learning community, supporting teachers as leaders, providing links to other parts of the education system, and providing for continuous assessment and improvement. Other researchers (Birman, Desimone, Porter, & Garet, 2000; Lieberman, 1995; Darling-Hammond & McLaughlin, 1995; Little, 1997) echoed similar principles of effective professional development.

The purpose of this study was to identify characteristics of professional development experiences that help teachers successfully translate full inquiry skills into their science teaching practices. Both science content and process were integral to the professional development opportunity that is the focus of the study. The content, monarch butterfly ecology research, provided a means to engage teachers and their students in meaningful, authentic (real-world work of scientists) inquiry. The processes of authentic inquiry were utilized throughout the program, providing practice in an array of complex integrated science process skills and research methodology.

According to the National Science Education Standards (National Research Council, 1996, p. 122, 145), when children or scientists inquire into the natural world they ask questions; plan investigations; and collect, organize, and analyze relevant data. The inquiry supplement to the

National Science Education Standards (National Research Council, 2000) focuses on essential features of inquiry. The learners: (1) are engaged by scientifically oriented questions; (2) give priority to evidence, which allows them to develop and evaluate explanations that address these questions; (3) formulate explanations from this evidence; (4) evaluate their explanations in light of alternatives, particularly those reflecting scientific understanding; and (5) communicate and justify their proposed explanations. Variations in the amount of learner and teacher direction in each of these features exist, which are sometimes referred to as a spectrum of “guided to full or open” inquiry. Full inquiry leads to more opportunities for cognitive development and scientific reasoning, but students should be provided with opportunities to participate in all levels of scientific inquiry as they study science (National Research Council, 2000). The professional development activities described here included all of the aforementioned features of inquiry at a level that is more similar to practices of scientists than is common in most teacher professional development, with a focus on the open end of the inquiry spectrum. Teacher and student participants conducted authentic real-world research and contributed to the knowledge base of monarch ecology. After the program, teachers practiced inquiry-based, real-world science with their students in the classroom and received support from the research scientists.

A program goal for teachers and their students was to practice science the way it is conducted by scientists; therefore, one of the desired outcomes was for students to be given the opportunity to conduct an authentic inquiry project of their choosing, addressing all of the previously stated components of the full inquiry process in a single project. This is not the only way for students to develop an understanding of or the abilities necessary to do full inquiry, but if students can carry out this constructive process, it is evidence that they possess these abilities. It is also one of the best ways for students to internalize science concepts and perceive their usefulness (Zemelman, Daniels, & Hyde, 1998). Although having students conduct an authentic inquiry study was the outcome addressed most thoroughly in the present study, teachers did report they infused more full inquiry practices into many aspects of their curriculum (see later), as advocated by the National Science Education Standards (National Research Council, 1996, 2000).

The research questions that guided this study were: (1) How did teachers translate inquiry-based experiences into their instructional practices? and (2) How effective were the professional development experiences in increasing teachers’ science content understanding? The program provided rich data on the experiences, processes, and learning that effected change in these secondary science teachers’ instructional practices.

Theoretical Framework

Ball (1996) cautioned that, although a number of ideas about teacher learning show up consistently in professional development literature, these ideas and beliefs are unevenly studied and may not warrant designation as knowledge. In other words, more research is needed before we accept conventional wisdom as research-based knowledge. Strong agreement exists among researchers that much of the professional development currently offered to teachers does not meet any definition of effective professional development; current practice is out of step with research (Birman et al., 2000; Lieberman, 1995; Loucks-Horsley et al., 1998). Lieberman (1995) said this well: “. . . what everyone appears to want for students—a wide array of learning opportunities that engage students in experiencing, creating, and solving real world problems, using their own experiences, and working with others—is for some reason denied to teachers when they are the learners” (p. 591).

The professional development opportunity described here addressed the previously stated issues by engaging teachers and students in authentic inquiry as they developed in-depth,

inquiry-based research skills. The program was designed within the context of research knowledge on the content of professional development, principles of how teachers learn, and the importance of supporting school structure. Based on the anticipated experience of the teachers selected for participation, the designers chose an action research approach, with time allocated during the institutes for curriculum development and for a “study group” approach to analyses of teachers’ classroom practices (Loucks-Horsley et al., 1998).

Choosing the content of professional development may be the most important decision when developing a professional development program. Content, in this study, is broadly defined to include subject-matter content and ways to teach that content, knowledge about students and how they learn, and pedagogical content knowledge. The science content, monarch butterfly ecology, proved to be an appropriate means for teachers to acquire diverse knowledge on insects, general ecological principles, processes, and authentic scientific inquiry.

It is important that teacher professional development carefully integrate science content knowledge and science process skills. Birman et al. (2000) reported that “the degree to which professional development focuses on content knowledge is directly related to teachers’ reported increases in knowledge and skills” (p. 30). Nelson and Hanegan (2003) found that teachers who had experienced intensive field science professional development reported overwhelmingly that their science content knowledge had improved. Garet, Porter, Desimone, Birman, and Yoon (2001) found that “activities that are content focused, but do not increase teachers’ knowledge and skills have a negative association with change in teachers’ practice” (p. 934). In addition, Cohen and Hill (2000) found that professional development grounded in academic content was more likely to affect instructional practices and student outcome. These studies and others (e.g., Basista & Mathews, 2002) suggested that increasing teachers’ science content knowledge and then having them apply that knowledge through actual experiences supports substantial teacher learning and positive change in the classroom.

Lieberman (1995) suggested that the ways teachers learn may be more like the way students learn than we have previously recognized. Loucks-Horsley et al. (1998) argued that it is “difficult if not impossible to teach in ways in which one has not learned” (p. 1), and that science and mathematics teachers “need to experience for themselves the science and mathematics learning they will want their students to do. Hearing about it in a vicarious manner is no substitute” (p. 13–14). Professional development opportunities should “contain follow-up experiences with multiple opportunities for interaction” (Luft, 2001, p. 552). Integral to this professional development was a supportive community of researchers who provided numerous opportunities for teacher learning alongside their students.

Teachers need supportive, collegial communities when inquiring into significant questions about subject matter, such as science and mathematics, as well as into questions concerning learning and pedagogy (Lieberman, 1995; Loucks-Horsley et al., 1998). The professional development activities reported here included daily structured time for collegial discussion and planning for teachers with their colleagues from the same school or school district, or their peers from other schools. The presence of students meant that teachers were able to try out and hone new practices as they were learning, and also that they saw that students were capable of carrying out complicated science and data analysis procedures.

Teams of teachers from the same school district were invited to participate in this program, and school district support was required. This helped to ensure a supportive structure when teachers returned to their schools. A growing body of research confirms that schools have “discovered the power of professional development when it is viewed as an integral part of the life of the school” (Lieberman, 1995, p. 1992). Coherence between professional development activities, school policies, and other professional experiences supports increased teacher learning

and improved classroom practice (Birman et al., 2000; Darling-Hammond & McLaughlin, 1995; Garet et al., 2001; Loucks-Horsley, Stiles, & Hewson, 1996).

This study extends our understanding of effective science professional development by elucidating several characteristics that effected change in teachers' instructional practices. The data presented in the following sections show that, in addition to providing teachers with rich content background and opportunities to practice the skills they experience during professional development, excellent professional development should: (1) provide "deep" science content and development of science process skills with numerous opportunities for teachers to practice using integrated science processes and research skills; (2) include teacher accountability requirements so that they demonstrate competency in a tangible and assessable way; and (3) include developers and providers that possess high expectations for teacher learning and are capable of facilitating multifaceted experiences.

Context of Study

This study was based on a 3-year project funded by a National Science Foundation grant to the Science Museum of Minnesota. Five groups of teachers and students participated in the ecology research institutes over a 3-year period: one group in year 1, and two each in years 2 and 3. Groups consisted of 8–10 teachers and 16–20 students. Each group attended a 1-week institute in Minnesota during the summer and a 1-week institute in Texas during the fall. This timing coincided with the breeding (Minnesota in the summer) and migration (Texas in the fall) stages of the monarch butterfly's annual cycle. Participants came in teams of either one teacher and two students, or two teachers and four students from the same school district. During the interim between the two institutes and after the second institute, participants conducted two kinds of research, a scientist-directed monarch monitoring project and a group-designed independent inquiry project (see details in what follows). Each team was visited by a project scientist twice, once as they were conducting their summer research and once during the academic year following their participation in their classrooms.

A total of 44 middle and high school teachers and 86 students completed participation in both 1-week institutes. All but one team were from Minnesota, Wisconsin, or Texas. Of the 44 teachers, 42 were Caucasian, 1 was African American, and 1 was Latin American. Twenty-one teachers had bachelor's degrees, 22 had master's degrees, and 1 had a dissertation. Among the 34 school districts represented in the study, 7 were urban, 12 suburban, 14 rural, and 1 suburban/rural. Teachers had a broad range of years of teaching experience: 2 teachers had taught 0–3 years; 8 for 3–6 years; 8 for 7–10 years; 7 for 11–15 years; 4 for 16–20 years; and 11 for over 20 years. Teachers self-selected student participants, with a request that they select girl–boy teams who demonstrated high academic potential, strong leadership qualities, and a willingness to share their experiences with others. Approximately, 25% of the student teams consisted of two girls, and 75% of the student teams consisted of a girl and a boy.

Participating districts were required to demonstrate a financial commitment to teacher travel (approximately \$300 per teacher), 50% of teachers' lodging at the institutes (\$280 per teacher), 50% of substitute costs during a week-long October institute in Texas, support for at least one class field trip to a teacher-selected field site, on-line capabilities, and support for project dissemination by teachers and students. All student costs were covered by the grant. Teacher and student participants received stipends for participation (\$1320 and \$500, respectively), and teachers could receive four graduate credits at a reduced rate from the University of Minnesota upon completion of the project.

Project Staff

Scientific staff included the project principal investigator (PI), a faculty member in the Department of Ecology, Evolution and Behavior (EEB) at the University of Minnesota; six EEB graduate students; an independent monarch scientist from Texas; two science educators from the Science Museum of Minnesota (SMM); and three secondary science teachers. Evaluators included a research associate and graduate student from the Center of Applied Research in Educational Improvement (CAREI). During the institutes, two senior scientists (the PI and Texas monarch scientist), three graduate students, one secondary science teacher (for all but the first group), and one SMM educator were present at all times. The PI and SMM staffs were part of the project planning team, and the additional scientist was chosen for his expertise on monarchs in Texas. The graduate students had been involved in other outreach and K–12 education projects with the PI and had expertise in insect ecology. The secondary teachers were selected from initial groups to help with later institutes.

Professional Development Institutes

The institutes took place at residential facilities with large meeting rooms, breakout locations, and natural areas for ecology research. Students, teachers, and staff were lodged in dormitory-style rooms, and spent about 10 hours a day on project activities. During the first week, each day focused on an ecology topic (e.g., interspecific interactions or biodiversity), a science process (see later), and a study system (e.g., the milkweed community or monarch butterflies). Most days started with a short presentation on the ecology topic and science inquiry processes, followed by an activity that reinforced the presentation and was suitable for classroom use. For about an hour in the morning and most of the afternoon and evening, small groups that included teachers, students, and at least one staff scientist conducted a short field research project (see later). There were breaks for recreational activities on most afternoons, and a teacher/staff session at the end of the day while students had free time. During these sessions, teachers discussed inquiry teaching and classroom implementation, and reflected on how daily activities fit into key features of inquiry learning. During the final 2 days of week 1, small groups that included teachers, students, and scientists spent approximately 4 hours planning independent team inquiry research projects (see later). The second week was similar, with the exception that 2 days were devoted to analyzing and presenting the independent team inquiry projects. Other activities took advantage of local attractions, such as a cave, restored prairie, and monarch roosting sites. Additional activities took place between and after the summer and fall institutes.

Inquiry-based research activities fell into three categories: short research projects conducted during the institutes; the Monarch Larva Monitoring Project; and independent team inquiry projects.

Short research projects. On 4 days during the summer and 3 days during the fall institute, six- to eight-person teams of participants and scientists worked together to conduct short research projects. None of the projects were of a “cookbook nature”; although scientists chose a broad topic, such as herbivory, the details of the experimental question and methods were chosen by participants in a consensus approach with mentoring, but not leading, by the scientists. Each of these projects focused on a single science process skill (observation, questioning, hypothesis formation, experimental methods, data analysis, and communication of results) in a sequential building format, as follows: for their first project, participants focused on making observations and asking testable questions and, for the second, making observations, asking questions, and developing hypotheses, and so on. These steps included details rarely taught to nonscientists,

including the concepts of null and alternative hypotheses, statistical significance, and sample size. Each step was addressed in every project, but scientists gave more input into steps yet to be presented. Projects addressed an array of ecological concepts, including interspecific interactions, census-taking techniques, animal behavior, and migration. Each evening, teams gave short presentations of their results in a forum similar to that at a scientific meeting.

Examples of team-generated questions addressed in these projects include: “What kinds of plants do butterflies prefer as nectar sources?” “Does the presence of galls on goldenrod plants affect plant height?” and “How are milkweed weevils distributed in a prairie field?” Although the focus of the workshop was monarch butterflies, most projects addressed broader ecological topics.

Monarch Larva Monitoring Project (MLMP). The MLMP is an ongoing, NSF-funded citizen science project directed by the project PI in which volunteers (including, but not limited to, teachers) from throughout the USA and southern Canada collect systematic data on the distribution and abundance of monarch eggs and larvae. Teams learned about the goals and methods of the project, and practiced the technique during the first institute. All teams were required to monitor a site near their schools during the interim between their two institutes. Because the project has been designed to work well in urban and suburban areas, all teams, regardless of their school location, could find a site to monitor. Project staff helped those who initially had trouble finding a site. Over 25% of the teachers have continued to participate in this project, even though it requires a substantial summer time commitment.

Independent team inquiry-based projects. On the penultimate day of the first week, research teams consisting of two or three teachers, their students, and one or two scientists were self-selected. These teams used a consensus approach to choose a research question based on interests of the teachers and students that had emerged over the week of the professional development institute. They then designed an experiment—including details of sample size, methodology, and procurement of materials—that could be conducted before the second institute. These plans were presented to and critiqued by the entire group. Teams conducted the research during the summer, with frequent communication with their scientist mentors (via phone, e-mail, and a site visit). During the second institute, they analyzed their results (using simple statistical tests, including t tests and χ^2 analyses, which were taught to the entire group), and made presentations to the entire group. Students and teachers took this process very seriously, practicing their presentations and working to assure that their conclusions were accurate and interesting. After the end of the second institute, teams were required to prepare a write-up of their research for the project’s website (www.monarchlab.org). Reports were formatted similar to journal publications, and project staff evaluated several drafts before final acceptance. These reports are of a caliber similar to those in an undergraduate setting or at a state or national high school science fair.

The relative amounts and kinds of input by teachers and students in the design and implementation of the projects varied. Scientists acted as facilitators, trying to encourage all participants to have an equal say in the planning, but this did not always happen. After observing the former phenomenon in the first group, during the first teacher/staff meeting, project staff emphasized the goal of teacher professional development and the importance of teacher participation in all steps of the research process. Even after this change, a few teachers still seemed to view the institutes as for their students, and not themselves.

Recruitment

In Minnesota, recruitment efforts included brochures distributed at Minnesota Science Teachers Association (MnSTA) meetings, including: a direct mailing to MnSTA biology/life

science members; announcements in MnSTA and Monarchs in the Classroom (www.monarchlab.org) newsletters; and announcements at other programs. In Texas, the workshop was announced in the Science Teachers Association of Texas (STAT) newsletter and on their web page. A flyer was e-mailed to two teacher listservs through the Texas Statewide Systemic Initiative. Flyers were also sent electronically to the Journey North (www.learner.org) Texas e-mail list. For group 1, flyers were mailed to all members of the Texas Biology Teachers Association (TABT), as well as to all members of the Texas Association of Environmental Educators (TAEE). Additional applications were sent to teachers who requested them for early workshops but did not submit them.

Recruitment efforts focused on teachers with leadership qualities who were willing to experience and use full inquiry in their classrooms. None of the sessions had more teacher application submissions than could be accepted, so no applicants were turned away.

Methods

Data Collection

A mixed methodology was used to identify the degree to which teacher content knowledge and use of inquiry increased. The Qual-Quan method (Gay & Airasian, 2003), in which the qualitative phase occurs first, followed by a quantitative analysis of data, provided structure for the analysis. Several sources provided information on teachers' use of inquiry-based practices. First, teachers completed an initial written survey of their current use of inquiry-based projects and field experiences. In this survey, teachers were asked to describe, in detail, any inquiry projects that they did in their classrooms (Appendix A). An identical written survey was completed several months after their participation.

Second, copious field notes were kept of project staff conversations with teachers during the institutes, classroom visits, interviews of project staff, and observation of institute activities. Notes during the institutes were taken by the PI or an evaluator; when an evaluator was present the conversations were taped. The PI did not facilitate the conversations, so she was free to record everything that was said. Taped interviews with project staff were conducted after the institutes. Although there is concern about staff members providing these kinds of data (Merriam, 1990), no individual's job depended on the outcome of the evaluation, and much of the note-taking and conversation occurred in the context of formative evaluation, because the staff wanted to learn as much as they could to improve the project. The evaluators also compared staff accounts with those given by participants.

Third, project staff evaluated the completion and quality of the monarch monitoring data and team-generated research projects. Fourth, case studies were developed on 20 teachers. Criteria for inclusion in a case study were location and grade level, with teachers selected to assure representation across the spectrum of participants from each of the five institutes. Twelve case study teachers were from Minnesota, two were from Wisconsin, and six were from Texas. Seven teachers were from high schools, nine from middle or junior high schools, and four from middle through high school. Case studies included information gleaned during the phone interviews and the sources described earlier. All case study teachers were interviewed twice each year after their participation, until the project ended: the first group for 3 years; the second and third groups for 2 years; and the fourth and fifth groups for 1 year. Writing of the case studies was completed during summer 2001. The evaluator sent each individual a copy of their case study for review, asking them to check for accuracy of the facts and for plausibility of the conclusions as recommended by Merriam (1990). Teachers made a few suggestions for additions, which were incorporated. All

participants, including case study teachers, were given an opportunity to review all the case studies (pseudonyms were used) as well as the summative project report on the evaluator's web site (Freeman & Jeanpierre, 2001).

To assess gain in content knowledge, a pre-assessment of teacher content knowledge of monarch biology and research techniques was conducted at the beginning of the first institute (see Appendix B). This provided baseline data on teachers' knowledge of monarch biology and ecology. An identical post-assessment was given at the completion of the second institute to allow a comparison of change in teachers' knowledge. The assessment was written by the PI and ecology graduate students.

Quantitative statistics included a χ^2 test on the proportion of teachers that were giving students the opportunity to conduct inquiry-based projects before and after their participation, and a *t* test on change in teachers' content knowledge. Prior to the professional development, project evaluators categorized teachers into three categories, based on their description of inquiry projects. The pre-institute descriptions included: (1) *Doing inquiry*: teachers' descriptions of classroom practices revealed that they used inquiry during science instruction. Teachers had to give examples of activities that included all steps of the inquiry process (observing, questioning, developing hypotheses, conducting experiments, analyzing data, and presenting findings) during interviews or in written summaries of their classroom practices. (2) *Almost doing inquiry*: teachers gave examples of inquiry practices, but the consistency of applications of inquiry steps varied; they did all parts of the inquiry process, but in different projects, or covered all but one or two steps in the same project. (3) *Not doing inquiry*: teachers did not include detailed examples of consistent inquiry practices, or examples in which they used at least three of the steps of the inquiry process in their classroom activities. The same categories were used post-institute.

These categories were chosen based on the goals of the project, and the recognition that inquiry, as defined earlier, is an excellent way to teach both science content and inquiry-based processes (e.g., National Research Council, 1996, 2000). Students who only participate in intensive hands-on activities learn little about the concepts or the nature of experimentation; instead, they need sustained opportunities that require them to learn how to ask questions, analyze unfamiliar problems, decide what strategies to apply, learn to recognize the benefits and limitations of experimental approaches, and learn to make decisions about when to persist in completing an investigation and when it makes sense to try a different approach (Schauble, Glaser, Duschl, Schulze, & John, 1995). It is this approach that was advocated in the institutes, and assessed in the evaluation.

Formative evaluation occurred throughout the project, and much of the information used in the formative evaluation also became part of the summative evaluation. Evaluators attended several of the institutes and met with staff throughout the project, and many small modifications meant that the experiences of the five groups were not identical. Examples of changes include: the stipend payment schedule was changed to provide incentive to finish the required team research project in a timely manner; the amount of time between the two institutes was increased to provide more time for monitoring and team projects; more social time for students; more regular staff/teacher meetings were added; and more explicit information was provided about the roles of teachers as both students and teachers during the institutes. Although the experience of the groups changed slightly, this summary of findings does not take into account the group in which a teacher participated. The relatively small sample size and other uncontrolled differences between groups (such as weather, group dynamics, and monarch population dynamics) meant that it is impossible to assign any differences between groups to particular factors, including changes made in response to the formative evaluation.

Data Analysis

The assertions that follow were validated through triangulation of findings using multiple data sources, including the pre- and post-assessment of teachers' content knowledge, field notes, classroom and professional development observations, telephone interviews, and written survey data. The 20 rich descriptive case studies were completed by analyzing all qualitative data sources for emergent themes and patterns. Upon completion of all data analysis, teachers were placed into one of three identified categories: doing inquiry; almost doing inquiry; or not doing inquiry.

The case studies included both individual institute and across-institute analyses of all 20 case study teacher participants. Using the qualitative program NUD*IST NVIVO, researchers completed a variety of coding processes. The analysts performed both line-by-line coding and various lengths of text segment coding. In addition, the NVIVO program was used to gather text segments from the 20 case studies, which were then put into a report for each category code (quality of professional development) and product (authentic team research project and classroom inquiry). These reports were analyzed to determine the main themes and patterns that emerged within each of these category codes across institutes. This analysis led to the identification of the key characteristics of successful professional development institutes presented in what follows.

This interpretation of case study is situated in the perspectives of Creswell (1998) and Yin (1984). The case study is an exploration of a bounded system over time that includes data collection involving multiple sources of content-rich information (Creswell, 1998). In this study, the sources of information included all of the aforementioned sources. The foci of the case studies are the teachers, and the way in which their professional development experiences impacted their classroom practices. Yin (1984) observed that a case study examines a phenomenon within its real-life context and, in this study, it was teachers' classrooms.

Results

Incorporation of Inquiry-Based Teaching Into the Classroom: Part 1. Case Studies

The following representative case studies illustrate how teachers in each of three categories (using, almost using, and not using inquiry) utilized knowledge gained during the professional development opportunity. Their understanding of inquiry was not assessed, just their use of full inquiry in the classroom.

Donald Anderson: Using inquiry. Donald had taught science for 26 years when he applied to the monarch project. Prior to the project, Donald did some inquiry-based teaching, but had never had his students carry out all of the steps on a single project; he was thus classified as almost using inquiry prior to his participation.

Before participating in the project, Donald used 70 acres of land near his suburban high school to provide students opportunities to do field projects, many in partnership with outside agencies such as the Hennepin Conservation District, Wildlife Science Center, and U.S. Fish and Wildlife. With these partners' expertise and resources, Donald's students helped plant 300 native Minnesota trees and shrubs on the edge of the forest, wild rice in a run-off pond, and over 2000 plugs of native plants in the prairie near the school.

After the project, Donald increased his understanding of how to effectively implement inquiry-based teaching:

It has really jelled and really come together. As I built my knowledge base on how to have students do research, I have become more confident. I've been able to have students do experiments with many topics in biology and environmental science. (Donald, December 2000)

Donald's comment illustrated his belief that he is more capable of carrying out inquiry in the way advocated by the National Science Education Standards (1996). In Donald's biology classes, the first student-generated inquiry of the year utilized monarch butterflies. Students recorded observations, brainstormed questions, selected a question to pursue, and formed a classwide hypothesis to test. In each class, they collected and analyzed data and wrote and presented reports of their findings. After the monarch study, students decided on questions and procedures for doing an insect diversity study on the prairie and a pond study. Donald found that, by the end of the term, students were prepared to carry out the individual research project that was required by graduation standards: "They know how to set it up. If I lectured them about the scientific method and then asked them to do it, I know from past experience that it wouldn't work" (Donald, June 1999).

Donald used inquiry in his class as often as he could. Instead of lecturing about seed germination, this is what he did:

All the students are working with the same thing—germinating popcorn. The observations that we had were of the actual popcorn seed itself. We did seed anatomy, looking at colored plates out of a botany book, and read a small article from a plant physiology book that had to do with germination, scarification, and the anatomy and function of the seed Then we generated questions. One of the questions that they wanted to focus on was, "what is the relationship between scarification and germination?" Then they decided they all wanted to produce their own treatment. So some people boiled their [seeds] in water before they germinated; many soaked them in solutions other than water. They know that there are inhibitors in the seed coat; they read about that. From those different treatments, they formed hypotheses. I helped them realize that when we do all these alternative hypotheses, we need to include the null hypothesis. That if none of the treatments cause any effect, [the null] would be the hypothesis we would then select. We set up a control group. I'm doing this with a lower track biology group and they know the parts of an experiment, and, basically, they've really driven it. (Donald, January 2001)

At this point, inquiry learning in Donald's classroom more fully demonstrated the nature of science. Students were investigating a variety of their own questions, developing hypotheses and experimental designs, carrying out research, and presenting their results in written and oral forums. Donald was influential in getting other biology teachers in his department to adopt the insect diversity field study to meet the field study requirement of the graduation standards.

Lucille Forester: Almost using inquiry. Lucille had taught biology in a suburban junior high for 5 years. She welcomed the opportunity to participate in the institute, because she believed that her college education did not adequately prepare her to use inquiry-based instruction.

During the first year after participating in the institutes, all of Lucille's students studied monarchs. They did measurements and kept journals of their observations. In addition, they tagged and released monarchs. All of her students participated in a schoolwide science fair in which they could showcase what they learned during the monarch unit. She also used parts of the scientific process with an ecology conservation unit to wrap up the school year. A main focus of this unit was to study various habitats of living things. Lucille emphasized the observation step of the research process with students: "I have all kids do mostly observations and journaling" (Lucille, January 2000).

Lucille has changed her teaching practices. Prior to the monarch training institute, she used a lot of commercially generated laboratory activities and teacher-directed lessons. She has incorporated more inquiry-based instruction by revising some of her "cookbook" laboratory activities: "On a few of them now, I give them some materials and have them generate questions and try to figure it out without me giving the step-by-step instructions" (Lucille, January 2000).

Lucille asked herself whether there was a way to “tweak some of the [units] to make them more inquiry-based, more hands-on for the kids, less teacher directed.” She feels that every year, she’s gotten a little bit better at facilitating inquiry experiences. She found that she uses “fewer and fewer notes, fewer and fewer worksheets, and more hands-on activities” each year rather than standing up there and writing on the overhead. In addition, Lucille found that she used the textbook even less than before:

I don’t teach out of the text very much, but I use it even less since I started with the monarch stuff. I find that the topics that are very sterile in the textbook are covered very effectively through their hands-on explorations with the monarchs. (Lucille, January 2000)

However, Lucille was not utilizing the whole scientific process in a single inquiry project, as recommended in the institutes and by the National Science Education Standards. One constraint keeping Lucille from doing more with inquiry was time: “Time is an issue. We must take time from the regular curriculum to teach science standards components.” This comment suggests that Lucille did not feel that using inquiry would allow her to successfully meet the requirements of the Minnesota State Standards and the requirements of the district’s curriculum. Although this analysis did not include details of district support for changed classroom practices, it is possible that Lucille and other teachers who would like to incorporate inquiry into their classrooms need additional support from their school or district administration.

By the second year after participating in the project Lucille had expanded her use of inquiry in the classroom. She summarized her more student-centered teaching approach:

I’m trying to do a student-generated, inquiry project at least every quarter. They have some questions that they have to come up with on their own, and they decide how to carry out all the steps. This year we had at least one additional project like that, so I’ve been able to increase that. (Lucille, February 2001)

Lucille’s classroom practices demonstrated constant movement toward incorporating more and more inquiry practices into her classroom instruction as evidenced by starting with “cookbook experiments and incorporating at least one full inquiry experience, each year,” for her students.

Bernice Zachary: Not using inquiry. Bernice Zachary taught seventh grade in a suburban middle school. She has a bachelor of science degree in medical technology and has taught for 24 years. She found that working with monarchs in her classroom presented difficulties, especially getting sufficient milkweed. She did not implement all the steps of full inquiry or incorporate the techniques presented in the professional development sessions into other research topics.

Bernice was not sure she was going to have her students raise monarchs in the coming year. She said:

It was so much work for me that it wore me out. I don’t have the availability of the milkweed so that my kids can go out and get the milkweed . . . But the kids loved it. One student told me “my favorite thing was working with the butterflies.” (Bernice, February 2000)

Bernice saw the value of providing her students with full inquiry experiences, but she was struggling with issues of access to needed materials and the amount of work involved in carrying out this form of instruction.

A project staff member visited Bernice's class to help her students choose a research question related to the monarchs they were rearing. Bernice reported that her students thought it was fun and that she would try it herself next year. However, the students were not given the opportunity to set up an experiment to answer their question, and it seemed unlikely that Bernice would have them do full inquiry in the future. She did set as a goal for the coming year to spend a little more time outside with her students, and planned to work with them on observations and coming up with questions.

Although Bernice's students had not participated in full inquiry, as defined by the project, they had experienced at least parts of an authentic real-world scientific inquiry. When students respond positively to handling organisms and making observations, they may provide the needed push for some teachers who are wavering between the amount of work required to do inquiry and the desirable outcome of increased student interest. Discussions with Bernice indicated that she saw the goal of her participation in the project as incorporating the study of monarchs into her classroom curriculum, not the process of inquiry. Her goal during the institutes was providing a good learning experience for the two students who accompanied her, not her own professional development. Because she was in an early group, it may be that this goal was not made clear enough to her.

Summary of case studies. The aforementioned teachers implemented inquiry at different levels. Donald's increased confidence in his ability to effectively "do" inquiry-based teaching resulted in an expansion of inquiry teaching and learning to other science units and the addition of a field-based study, which was adopted by his school's biology team to address a component of the science graduation standards. Lucille increased her use of inquiry by changing her "cookbook" labs, incorporating more inquiry experiences over time. Bernice completed the inquiry-based project that was required for her participation and utilized some of the subject and inquiry content of the professional development institute, but had not fully incorporated the inquiry process into her classroom by the end of the study. However, it is clear that Bernice and other teachers in the "not using inquiry" category did increase the amount of specific inquiry processes they used in the classroom; Bernice gave her students more opportunities to make observations and ask questions, and other case study teachers in this group were carrying out similar activities, many related to monarch ecology.

Bernice's difficulty in finding the time for inquiry is a fairly common barrier to implementation. Although full inquiry clearly takes time, several of the teachers involved in this project not only incorporated inquiry practices into their classrooms, but also provided authentic research opportunities to students outside of the regular classroom. This was illustrated by the experience of one teacher who was selected to help teach a workshop during the summer following her own participation:

So when I got back from helping teach at one of the monarch monitoring institutes, I took a group of 12 students and worked with them every week on a monitoring project doing field biology out at a meadow site and then had each develop their own research project. (Diane, June 1999)

Given the tools provided in a learning opportunity such as this, some teachers are clearly able to provide incredible experiences for their students.

Incorporation of Inquiry Into the Classroom: Part 2. Quantitative Summary

The incorporation of inquiry into the classroom can also be illustrated by comparing numbers of teachers using inquiry before and after their participation in this project (Table 1). The numbers of teachers in each category are significantly different before and after participation ($\chi^2 = 25.48$,

Table 1
Teachers' use of inquiry-based instruction (IBI) before and after participation

Before	Number	After	Number
Not doing IBI	21	Not doing IBI	9
		Almost doing IBI	3
		Doing IBI	9
Almost doing IBI	14	Not doing IBI	0
		Almost doing IBI	0
		Doing IBI	14
Doing IBI	8	Not doing IBI	0
		Almost doing IBI	0
		Doing IBI	8

Note that one teacher's use of IBI could not be determined based on the assessment tools used.

$p = 0.001$), and of those who were not doing inquiry before the institutes ($n = 21$, 49%), 57% moved into the almost-doing or doing inquiry categories (12 of 21). Of those who were almost doing inquiry before the institutes, 100% were doing inquiry after them (14 of 14). Perhaps not surprisingly, teachers who were not doing inquiry before the institute were least likely to change, although almost all of them incorporated science content from the professional development institute into their classrooms.

Improvement in Content Understanding

The content assessment for teachers included a combination of knowledge-level and higher-order thinking skills questions (see Appendix B). Question 1 is a knowledge-level question; participants had to know that August monarchs migrated and July monarchs did not. Questions 2–4 are examples of higher-order questions. For example, to get the full amount of points for question 2, teachers were expected to include the following in their answer: Estimate milkweed density using some kind of random sampling process (i.e., walking a transect and counting the number of plants in randomly chosen meter square areas), then use the average number of plants/meter to estimate overall density. Another possible answer would be to describe the point quadrant method of measuring plant density. Once an estimate of the number of plants in the field is obtained, it is possible to estimate the number of larvae by randomly sampling plants and seeing if they have larvae on them. The percentage of sampled plants occupied by larvae multiplied by the total number of plants in the field is an estimate of the total number of larvae in the field.

The posttest results indicated that teachers' understanding of monarch ecology and research techniques increased significantly. The mean score (for teachers who took both tests) on the pretest was 9.0 (53%, $n = 23$, $SE = 0.482$) and the mean on the posttest was 12.8 (76%, $n = 23$, $SE = 4.38$). This difference is significant (paired $t = 5.34$, $df = 22$, $p < 0.001$).

To achieve a deep understanding of the content presented, teachers were immersed into monarch ecology during the professional development institutes. In addition to presentations by project staff on the biology content, they had numerous opportunities to pose their own questions, investigate the answers, and use the field-based techniques.

Key Characteristics of Effective Professional Development

Teachers consistently raved about the content of this project. Three teachers' comments are representative: "It has been an outstanding experience. It's been the most successful National

Science Foundation Project that I've worked with, and I've done a few" (October 1999). "This is my eighteenth year of teaching high school biology and environmental science, and I can truthfully say that the educational experiences gained by both me and my students through our monarch migration and larval monitoring research far exceed any previous learning experiences we have ever had" (January 2000). "This is absolutely the best I have ever attended; the [monarch institute] was outstanding" (February 2001).

Our analysis of the project illuminated *three characteristics of effective science professional development* that led to the aforementioned comments and change in teachers' classroom practices: (1) "deep" science content and development of science process skills with numerous opportunities for teachers to practice using integrated science processes and research skills; (2) clear accountability requirements of teachers, where they demonstrate competency in a tangible and assessable way (i.e., a product of their learning is produced, which is accessed at specified standard of acceptability); and (3) developers and providers of professional development experiences with high expectations for teacher learning who can facilitate multifaceted experiences that allow teachers to demonstrate their learning. What follows is a more detailed analysis of the extent to which teachers implemented inquiry-based practices as a result of these characteristics.

Deep science content and process knowledge with numerous opportunities for practice. The importance of content in effective professional development is well documented (Cohen & Hill, 1998; Kennedy, 1999; Loucks-Horsley et al., 1998). For this project, the defined content focus was for teachers to attain deep understanding of field ecology, using the monarch as a focal organism. Gain in content knowledge can be measured by the pre- and post-assessments that most teachers completed (one entire group did not do the pretest because a storm delayed the start of the workshop; other individual teachers were involved with other things when the pretest was given, which had to be before any content was covered). This gain in content knowledge demonstrated that teachers learned the science content expected of them.

Even more elucidating were the comments teachers had about their science content knowledge gains. Teachers across institutes and in an array of contexts gave examples of using their understanding of monarch ecology during case study interviews. The confidence teachers gained in their knowledge was demonstrated by their comfort in sharing it. In addition to continuing with the ongoing inquiry-based research, five teachers brought student presenters to a monarch population dynamics meeting in May 2001. These teachers were selected by project staff because of the quality of their research and its connection to the subject of the meeting. Scientists from all over the world attended the meeting, which included both paper and poster presentations. These teachers obviously felt comfortable enough about the level of their understanding of monarchs to attend and enjoy such an event with their students. Another participant instituted a "Monarchs for Parents" class to answer parents' questions each year. She has also helped other teachers in her district initiate monarch studies with their students. Yet another participant had a variety of opportunities to share monarchs:

In the last few months my students and I have been asked to informally share our research and the techniques of the monitoring program with staff and children at the River Legacy Nature Center, the Arlington Master Composters, and the Arlington Garden Club. In addition, I have been asked to prepare an in-service on monarch monitoring and ecology for area teachers. Other venues could certainly include Girl Scout and Boy Scout troops, school ecology clubs, senior citizen groups, and the University of Texas at Arlington Entomology Department. (Marianne, June 2000)

The attainment of content knowledge can be linked to the numerous opportunities teachers had to use the content in inquiry-based processes during the institutes. One teacher attested to the rigor of the professional development experience as follows:

We did so many mini-research projects, with migratory habitat, monitoring [the stopover sites during migration], conducting censuses, studying sex differences in the behavior of the monarchs in the tents . . . We would divide up into four teams, you'd collect data, and come back, share data, make transparencies, maybe do a statistical analysis, and then present your results to the big group. We had to do this six to eight times . . . You really got kind of good at it. (Diane, June 1999)

Other comments attested to the importance of practicing the methods being taught:

One teacher commented: "Instead of being told how to use inquiry learning, we were taught by inquiry learning. By experiencing the process several different times, the techniques become second nature to me." Yet another teacher was more explicit about the comparison between this professional development experience and others:

Not surprisingly, I learn in the same way my students learn, by doing. [This workshop was] one of the best things that had ever happened to my teaching . . . So many workshops I go to are pretty worthless. I sit there and I might glean one of two good things from them, but I'm sitting there for hours and hours, going, "uh, I paid for this?" But this one was non-stop learning. . . (Ronald, January 2000)

Require teachers to demonstrate competence in a tangible and assessable way. Teacher participants were required to conduct authentic (real-world research) in their communities, thus putting their learning into action.

Teacher–student–scientist teams selected and designed research projects on monarch ecology. These projects involved the teachers and students in all stages of full inquiry: from generating their own questions to reporting their findings. The project report was a tangible product that emerged from the teachers' and students' participation, and project staff made it clear before and during their work that a high-quality report was expected.

The project website (www.monarchlab.org) contains an impressive array of team-generated research projects. A few examples of project titles include: "How will the addition of specific nutrients affect the size and survivorship of monarch butterflies?" "Will not eating the chorion affect the growth of monarch larva?" "The effect of humidity on the egg development and survivorship of the monarch butterfly" "Does acid rain affect the weight of adult monarchs?" The level of sophistication in these projects mirrored real-world scientific research. Teams studied complex questions, used advanced research techniques, were guided by specialized experts, and produced high-quality research projects. In fact, one of the team projects was subsequently published in a book on monarch biology (Borland et al., 2004). Teachers' comments indicate that the level of research involved in producing the team reports was an intense learning experience that required hard work but produced a product for which they were very proud. One teacher commented: "My student teams did an excellent job. They were very motivated, and met after school to complete their project and turned in everything by January."

Project staff gave teacher–student teams substantial feedback on the progress of their research projects and papers, thoroughly critiquing the projects prior to posting them to the website. One team made revisions four times before their paper was accepted:

It was a very interesting process for my girls, especially. That was such a growing experience for them. They thought, "Okay, we wrote the paper; we turned it in; we're

through,” because that’s how it works in school. And no, [the staff] kept sending it back. And they would kind of get discouraged; I would tell them; hey look at how much less we have to do this time. But they were so proud when it did get posted. It was a big deal. (Darlene, June 2001)

It is evident that this teacher and her students soon realized the depth of the analysis and quality of presentation results that were required of them in this team research project.

Other aspects of the research project provided challenges for some participants. During one of her first interviews, one teacher commented on the difficulty of data entry and reporting. The only challenging task mentioned during a later interview was the technical challenge of incorporating pictures into their team report. She was positive that in time they would meet this challenge, as they had met other project requirements, such as data entry and writing the report.

Completing the team-generated research to the point of publication served to solidify teachers’ understanding and comfort level in carrying out inquiry-based learning. Participants’ comments further demonstrated the value of practicing for themselves what they had learned:

[This format] makes you go home and [practice] what you did. A lot of times you will go to a workshop and then go home and you don’t practice it, and it’s not yours until you have. The team-generated research project was probably one of the biggest learning experiences I had. It helped me realize how tough it is to design an experiment, how hard it is to think about everything, and how important it is to have a couple of trial runs and practice. I feel that I am much more equipped to teach students how to do research projects than I ever was before. (Dorothy, July 1999)

The importance of completing a project of this magnitude was not immediately apparent to some teachers, as illustrated by one teacher’s comments on her initial and then later reaction to team-generated inquiry-based research projects:

At first, team-generated research projects did not seem like a valuable part of the experience. But when we took our data to the second institute we realized, wow, we really did prove something. We just felt so good about it. (Dorothy, July 1999)

This component of effective professional development, requiring teachers to show evidence of their learning in a meaningful and evaluative way was crucial to fostering teachers’ comfort levels with and subsequent use of inquiry-based instruction.

Providers with high expectations for learning and capability to facilitate multifaceted experiences. Project staff had high expectations for the teachers, and asked them to do things that many teachers initially thought that they, let alone their students, could not handle. These expectations and experiences encompassed both science content and process, such as recognizing monarch parasitism and doing statistical analysis.

Teachers were expected to increase their content knowledge beyond the surface level. To complete the level of research expected for this project, they needed to be immersed in monarch ecology content, and utilize library and hands-on research techniques. This project included the often missing component of inquiry done in schools: studying reviewed research reports. Chinn and Malhotra (2002) argued that “. . . reading expert research reports play almost no role at all in simple forms of school science. At most, students conduct their own research and make some reports to each other” (p. 186). By contrast, in this project, teachers and students were expected to review and use published research reports that were pertinent to their team-generated topic. After the projects were completed, the written reports were critiqued and redone until they met the

research scientists' expectations. However, this did not occur in a vacuum; scientists provided support during all steps of the project. One participant commented: "A project scientist came out and was a big help. She helped us understand variables and making testable questions."

Participation in the monarch monitoring program provided another research experience, and included the expectations that teacher–student teams would understand the process and findings of the citizen science project. Teams first practiced monarch monitoring under the supervision of the scientists during the institutes, then collected weekly data at their home locales using consistent methods that allowed comparisons of relative monarch numbers within and between sites over broad temporal and geographical scales. Techniques that teachers and students used included assessing the abundance and quality of larval host plants, recording the presence and abundance of other invertebrates on the plants, assessing larval densities using census methods, and providing detailed descriptions of their monitoring site.

Throughout the project, staff scientists made it clear that this work was important. Participants were confident that their data would provide information on monarch ecology that would add to the scientific knowledge base on this species. A teacher stated:

I refer to that very valuable field experience working with the researchers quite often. . . I tell [students] that we did some real research which we felt was valuable to the University of Minnesota. . . It is exciting to know that the data we are collecting is adding meaningful information to the scientific community's understanding of monarch biology. (Ronald, July 1999)

Teachers were proud of their contribution to monarch monitoring research. In addition, sustained follow-up and reporting of project findings continued to reinforce the importance of this work, including an annual newsletter, publications in scientific literature, and a project website (www.mlmp.org).

The importance of high expectations was mirrored in teachers' expectations for students following the institutes. Teachers provided a myriad of comments that illustrated the relationship between staff expectations for them and their own expectations for students: "I can honestly tell you that there were a lot of things I thought were out of reach, and just too overwhelming to do. I have seen that kids are capable, sometimes, of a lot more than we think they are." Another teacher commented "I began to see how the students can learn. And I began to see how far you could push them." Yet another teacher had a similar thought, "I can put a lot more on the students than I thought. I can demand a lot more than I had been demanding." After the student–teacher teams had completed their team inquiry projects, they were very positive about students' research capabilities. Then teachers' expectations of their own performance as it related to students' performance was linked. One teacher stated:

I expect more of students because I know that I taught it better, and so when they turn in lab reports, they get it back sometimes because I expect more. I know more about it now, how to teach it, what a good conclusion is and what good data is. So it makes the students better scientists. (Daniel, February 2000)

In sum, professional developers had high expectations, which they communicated to the teacher–student teams. Each team produced an inquiry project that met high-quality expectations. Teachers and their students were required to produce work that they would be proud to present and have published at the University of Minnesota's Monarch Website or possibly in journal publications.

Conclusions and Implications

This professional development program was designed to facilitate change in teachers' use of inquiry-based practices in their own classrooms, using previously described criteria. Scientists, teachers, and students formed a learning community, with opportunities for teachers to develop collegial relationships with their peers and scientists, thus creating links across regional and institutional boundaries. A key job of this learning community was to create workable plans for implementation of inquiry processes, thus addressing McCarty's (2001) recommendation that professional development for teachers "must not only assure that teachers come to understand the nature of science through actual research experience in the field, but help them to build new and personal visions of what it means to practice science in the contexts of their own classrooms" (p. 5).

Teachers need to become confident with the content and processes they are to facilitate with their students. The importance of professional development providing teachers with rich content and numerous opportunities to experience the learning that they are expected to facilitate with students may serve to assist them in translating inquiry practices to their own classrooms. A number of researchers (Birman et al., 2000; Darling-Hammond & McLaughlin, 1995; Garet, Porter, Desimone, Birman, & Yoon, 2001; Loucks-Horsley et al., 1998) have echoed how important it is that professional development experiences provide teachers with rich content and opportunities to practice what they are learning.

Just as teachers' expectations are key to student learning, high expectations of teachers during this professional development gave them the incentive to fulfill the requirements with high-quality work. The importance of high expectations of adults is stressed by Weiss and Hartle (1997), who argued that raising expectations is a well-demonstrated method for improving staff performance results. In addition, professional development providers must be able to facilitate a variety of experiences for teacher learning. Fullan and Miles (1992) argued that, if a practice is to be implemented successfully, it should become a natural part of the teachers' repertoire of professional skills. With the focus on inquiry-based learning and teaching as the framework for the program, teachers had numerous opportunities to practice and observe inquiry teaching and learning.

Many of the interviews and other data sources made it clear that, although teachers were not accustomed to the amount of work required in this project, they benefited from its intensity. The university credit and stipend may have served as a necessary incentive to complete the work, but our analysis did not reveal what encouraged teachers to complete the professional development institute requirements. However, it was clear that teachers were proud of their accomplishments and their hard work facilitated the achievement of the expected learning goals of this project.

This program sought to help teachers incorporate inquiry, not as an add-on, but as an integral part of their classroom practices. At the heart of inquiry is orchestrating learning such that students are encouraged to ask questions and reflect upon their own learning in meaningful ways. Therefore, teachers must have opportunities to experience inquiry, not as a rote instructional approach to science teaching, but it should become a part of the way they think about and plan for science instruction. Dewey (1910) referred to inquiry as "a habit of mind"; that is, he viewed inquiry as a way of thinking.

Bernice represents a group of nine teachers that were "not using inquiry" even after their participation. She was undecided as to the extent she would use monarchs in her classroom, although she saw their value in increased student interest. However, like the other teachers in this category, Bernice was using more inquiry-based activities in her classroom after the professional development. Although we did not do detailed analyses of the reasons these nine teachers did not

incorporate full inquiry into their teaching practices, Bernice's case is an interesting one. She had a previous career as a medical technologist, so teaching represents a career change. In a case study of three novice career-change teachers, Greenwood (2003) reported that: "these career-change teachers' practices as described by Science Teaching Orientation, relate more closely to the individual's *conception of science* than to his/her belief or conception of teaching science" (p. 230). It is possible that different strategies should be used for teachers who have had other careers, with detailed attention paid to their perceptions about science pedagogy and teaching as well as science. Bernice was also among the teachers who taught the longest (24 years), and it may be more difficult for some veteran teachers to change their practices. Although they often do not have the challenges many novice teachers face, they may be more resistant to change.

Recommendations for Professional Development and Further Research

The program met national goals of science professional development, and we recommend many of the components just described. The focus on a single study system that is inherently interesting to both teachers and students was important, as were the intensity of the training; the inclusion of multiple forms of real-world research; and opportunity for constant interactions among scientists, teachers, and students. However, there are some caveats to this recommendation. The timing of the institutes was difficult for many teachers; the week during the fall meant that substitutes were needed for teachers. Although this allowed participants to experience an integral part of the monarch life cycle, we would not recommend scheduling this much time during the academic year.

A more complicated problem is reaching teachers who for some reason or another are resistant to change. Before their participation, 21 of the 43 teachers were "not using inquiry" according to our criteria, and 9 of these 21 were still in this category after their professional development participation. More success in facilitating change was documented in the classrooms of teachers who were "almost using inquiry" before the project; all 14 of these moved into the "using inquiry" category. More research is needed to define strategies that will reach teachers "not using inquiry," and how factors such as previous careers and years of teaching experience affect teachers' responses to professional development. It will be important to define how to convince teachers of the value of "full inquiry" and that they are qualified to implement it. Tobin, Tippins, and Gallard (1994) reported evidence of a strong connection between teachers' beliefs about teaching and learning and their actions, and it is likely that teachers who are not using inquiry at all will require restructured belief systems about valuable teaching and learning outcomes. Luft (2001) added that professional development programs should attend to the diverse behaviors and beliefs of its participants. Our professional development may not have provided that for the nine teachers that remained in the "not using inquiry" category.

In addition, student participation was integral to the professional development. Having students work alongside scientists and teachers provided the added bonus that teachers could observe students' reactions to this learning structure, although there were costs associated with the inclusion of students, which is the subject of a forthcoming article (Jeanpierre, Oberhauser, & Freeman, unpublished manuscript).

Professional development literature stresses the need to take learners from where they are and to provide them with ongoing support as they incorporate changes in their classroom practices. Our formal evaluation of this group ended 2 years after their participation, and continued contact with them depends on their own initiative. Unfortunately, this means that most of our contact is with the most motivated teachers; further research should focus on structuring long-term postprofessional development support for the teachers who need it most.

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Appendix A

Pre- and post-survey on teachers' use of active inquiry research in class:

1. Do you use inquiry (i.e., students are involved in formulating questions and/or designing research protocol, collecting and interpreting data, and reporting results) in your classroom?

Circle one: Yes/No. If yes, please answer questions 2, 3, and 4.

2. How often (e.g., once every year, twice a year, whenever a student shows interest) do your students do inquiry projects?
3. What proportion of your students are involved in these projects?
4. List below inquiry projects you have used with students in your classes.

Follow the format below—you need not write the words in parentheses. Be as brief as possible. If you have more inquiry projects than you can list on this page, you may continue on the back of page 3.

Sample:

- a. (Brief summary of inquiry project.)
- b. (Teacher's role.)
- c. (Students' role.)
- d. (How comfortable you are using this activity—use scale?: very comfortable, comfortable, uncomfortable, or very uncomfortable.)
- e. (How often you have used this activity?)
- f. (Indicate inherent problems with this activity.)

Appendix B

Monarchs' Monitoring Sample Pre-Assessment Questions

1. Identify the stages of the life cycle of a monarch that begins life as an egg in Minnesota in (a) early August or (b) early July.
2. You have been asked to estimate the number of monarch larvae in a nature reserve near your home. This reserve contains one large field with a lot of milkweed plants. There are too many milkweed plants to check all of them; in fact, you don't even have time to count all of the milkweed plants. What could you do?
3. You wonder if female or male monarchs are larger. You measure the wings of five males and five females. The males' wings are 0.54 mm, 0.49 mm, 0.47 mm, 0.53 mm, and 0.54 mm long. The females' wings are 0.53 mm, 0.54 mm, 0.44 mm, 0.53 mm, and 0.56

- mm long. What can you conclude (without using a calculator)? What else could you do to answer this question?
4. You observe ants, aphids, and a monarch caterpillar on a milkweed plant. (a) Describe at least two ways that these insects might be interacting with each other and with the plant. (b) What question could you ask about the interaction between any of these organisms? (c) How could you answer this question? (summarize your process).

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