Exemplary Science: Best Practices in Professional Development

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Implementing the Changes in Professional Development Envisioned by the National Science Education Standards:

Where Are We Nine Years Later?

Robert E. Yager, Editor
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Nine years have elapsed since the 1996 publication of the National Science Education Standards (NSES) (NRC 1996). The critical issues in science education now are these: How far have we progressed in putting the vision of the NSES into practice? What remains to be done? What new visions are worthy of new trials?

The four monographs in the NSTA Exemplary Science Monograph series seek to answer these questions. The monographs are *Exemplary Science: Best Practices in Professional Development* (the book you are reading), *Exemplary Science in Grades 9–12: Standards-Based Success Stories* (currently available); *Exemplary Science in Grades 5–8;* and *Exemplary Science in Grades PreK–4* (the latter two books are in development).

How These Essays Were Chosen

The series was conceived in 2001 by an advisory board of science educators, many of whom had participated in the development of the National Science Education Standards. The advisory board members (who are all active and involved NSTA members; see p. xv for their names) decided to seek exemplars of the NSES *More Emphasis* conditions as a way to evaluate progress toward the visions of the NSES. The *More Emphasis* conditions provide summaries of the NSES in science teaching, professional development, assessment, science content, and science education program and systems. (See Appendix 1 for the six *Less Emphasis/More Emphasis* lists.) The board sent information about the projected series to the NSTA leadership team and to all the NSTA affiliates, chapters, and associated groups. A call for papers on exemplary programs also appeared in all NSTA publications. In addition, more than a thousand letters inviting nominations were sent to leaders identified in the *2001–2002 NSTA Handbook* (NSTA 2001–2002), and personal letters were sent to leaders of all science education organizations.

After preliminary responses were received, the advisory board identified teachers and programs that it felt should be encouraged to prepare formal drafts for further review and evaluation. The goal was to identify 15 of the best situations in each of four areas—professional development and grades 9–12, 5–8, and PreK–4—where facets of the teaching, professional development, assessment, and content standards were being met in an exemplary manner.

The most important aspect of the selection process was the evidence the authors of each essay could provide regarding the effect of their programs on student learning. This aspect proved the most elusive. Most of us "know" when something is going well, but we are not well equipped to provide real evidence for this "knowing." Many exciting program descriptions were not among the final titles—simply because little or no evidence other than personal testimony was available in the materials forwarded. The 16 professional development models that make up this monograph were chosen by the NSTA advisory board as the best examples of models that fulfill the *More Emphasis* conditions of the Professional Development Standards; each has had a clear, positive impact on student science learning.

The History of the National Science Education Standards

Before discussing the contents of this book at greater length, I would like to offer a brief history of the National Science Education Standards.

Most educators credit the National Council of Teachers of Mathematics (NCTM) with initiating the many efforts to produce national standards for programs in U.S. schools. In 1986 (10 years before the publication of the National Science Education Standards), the board of directors of NCTM established a Commission on Standards for School Mathematics with the aim of improving the quality of school mathematics. An initial draft of these standards was developed during the summer of 1987, revised during the summer of 1988 after much discussion among NCTM members, and finally published as the *Curriculum and Evaluation Standards for School Mathematics* in 1989.

The NCTM standards did much for mathematics education by providing a consensus for what mathematics should be. The National Science Foundation (NSF) and other funding groups had not been involved in developing the math standards, but these groups quickly funded research and training to move schools and teachers in the direction of those standards. Having such a "national" statement regarding needed reforms resulted in funding from private and government foundations to produce school standards in other disciplines, including science.

NSF encouraged the science education community to develop standards modeled after the NCTM document (1989). Interestingly, both the American Association for the Advancement of Science (AAAS) and the National Science Teachers Association (NSTA) expressed interest in preparing science standards. Both organizations indicated that they each had made a significant start on such national standards—AAAS with its Project 2061 and NSTA with its Scope, Sequence, and Coordination project. Both of these national projects had support from NSF, private foundations, and industries. The compromise on this "competition" between AAAS and NSTA leaders led to the recommendation that the National Research Council (NRC) of the National Academy of Sciences be funded to develop the National Science Education Standards. With NSF funding provided in 1992, both NSTA and AAAS helped to select the science leaders who would prepare the NSES. Several early drafts were circulated among hundreds of people with invitations to comment, suggest, debate, and assist with a consensus document. A full-time director of consensus provided leadership and assistance as final drafts were assembled. Eventually, it took $7 million and four years of debate to produce the 262-page NSES publication in 1996.

There was never any intention that the Standards would indicate minimum competencies that would be required of all. Instead, the focus was on visions of how teaching, assessment, and content should be changed. Early on, programs and systems were added as follow-ups to teaching, assessment, and content.

The NSES volume begins with standards for improved teaching. That chapter is followed by chapters on professional development, assessment, science content, and science education program and systems. Content was placed in the document after the other three for fear that placing it first would invite a focus only on what should be taught—almost relegating teaching, staff development, and assessment to "add-on" roles. The major debates, however, centered on what should appear in the content chapter.

It is interesting to note that the early drafts of the National Science Education Standards did not include any mention of professional development. It was only when the final draft was about to be offered to the leadership in the National Academy of Sciences that a section on professional development was added. This addition came in response to the argument that such visions for the continued education of teachers would be needed if any significant use of the Standards, any improvement of existing teachers, and any improved ways of preparing teachers were to be realized. They were added as a way of ensuring that the science teaching standards would be central in the preparation of new teachers and the continuing education of all inservice teachers.

The Four NSES Goals for School Science

An exemplary professional development program must prepare teachers to implement the four NSES goals for school science, which are to educate students to be able to

Goal 1. experience the richness and excitement of knowing about and understanding the natural world;

Goal 2. use appropriate scientific processes and principles in making personal decisions;

Goal 3. engage intelligently in public discourse and debate about matters of scientific and technological concern; and

Goal 4. increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers (NRC 1996, p. 13).

Let us look at each of these goals and consider how far along we are to meeting them in today's science classrooms.

Goal 1. For many educators, the first goal is the most important since it ensures that every student will have a firsthand, personal experience with the whole scientific enterprise. This means exploring nature with the natural curiosity that all humans enjoy. It means asking questions, identifying the unknown, proceeding to knowing—even if what results is a personally constructed answer or explanation that might be wrong in terms of current science academy notions. What matters is that personal curiosity sparks an original question.

Unfortunately, science educators sometimes define science as the information found in textbooks for K–12 and college courses or the content outlined in state frameworks and standards. Such definitions omit most of what George Gaylord Simpson (1969) described as the essence of science. Simpson held that five activities define science:

1. *asking questions about the natural universe; i.e., being curious about the objects and events in nature;*
2. *trying to answer one's own questions; i.e., proposing possible explanations;*
3. *designing experiments to determine the validity of the explanation offered;*
4. *collecting evidence from observations of nature, mathematics calculations, and, whenever possible, experiments carried out to establish the validity of the original explanations;*
5. *communicating the evidence to others who must agree with the interpretation of the evidence in order for the explanation to become accepted by the broader community [of scientists].* (Simpson 1969, p. 81)

These five activities are rarely carried out in schools. Science students seldom determine their own questions for study; they are not expected to be curious; they rarely are asked to propose possible answers; they seldom are asked to design experiments; and they rarely share their results with others as evidence for the validity of their own explanations (Weiss et al. 2003).

Overall, one could argue that "real" science is seldom encountered or experienced in most science classrooms. The typical focus is almost wholly on what current scientists accept as explanations (Harms and Yager 1981; Weiss et al. 2003). Competent science students only need to remember what teachers or textbooks say. Most laboratories are but verification activities of what teachers and textbooks have indicated as truths about the natural world. There is seldom time for students to design experiments that could improve human existence.

Goals 2, 3, and 4. The other three goals from the Standards focus on experiences in school science that affect the daily lives of students, helping them to make better scientific and societal decisions and leading them to increased economic productivity. Regrettably, these three goals are rarely approached, realized, or assessed in typical classrooms by typical teachers. Information that would help in realizing these goals is not offered in texts, teacher preparation efforts, or programs for inservice teachers. If we want science concepts and skills to be used in making personal decisions, we are going to have to deal with ideas of how these goals can be achieved. In *Understanding by Design,* Wiggins and McTighe (1998) provide ideas about what needs to be done—in particular, what evidence we need to collect to be sure we have met Goal 2 (i.e., using appropriate scientific methods and principles for making personal decisions). We cannot stop with the idea that students seem to know certain concepts and can perform certain skills. We need to expect evidence for learning to include practice with the concepts and skills in actually making decisions in daily living.

Regarding Goal 3, educators must focus on involving students in public discourse and debate in school, as well as in the outside community. Where do they actually use what is in the curriculum and what teachers teach? A whole new way of viewing content, instruction, and assessment is needed if this goal is to be realized. Goal 4 may be the most difficult to achieve and to assess. In some ways it is further from daily life and the immediate community than the other goals. It focuses on future economic productivity, possible career choices, and the use of concepts and processes that are often given short shrift in today's science classroom.

Professional Development and the Standards

Professional development is about ensuring that teachers continue to grow and improve. Professional development forces us to look at the acts of teaching and to discuss the effects of these acts on student learning. We have to be sure that learning does result and that it is learning with understanding and potential use—not merely an indication of students' ability to remember, repeat, and recite.

Professional development programs must not only help teachers meet the 14 *More Emphasis* conditions of the Professional Development Standards, but they must also assist teachers to implement the 9 *More Emphasis* conditions of the Science Teaching Standards and the 7 *More Emphasis* conditions of the Assessment in Science Education Standards (see Appendix 1 for these *More Emphasis* conditions).

Professional Development Challenges and Solutions

Professional development providers need to be familiar with how content strands are organized across K–12 curriculums and how major concepts and processes are seen and used in concert. Professional development initiatives must focus on science as inquiry and on how science teaching also can result in inquiries about teaching. If we focus too acutely on a single scientific discipline, and exclude concepts from other disciplines, problems result.

Another serious issue is that schools too often spend funds on general workshops with leaders from general education backgrounds. The workshops are presented to all teachers in a building or district, without regard to the likely impact of implementation on teaching, curriculum, or student learning. In addition, staff development efforts often present an abundance of suggestions for reform—too many to be carried out over a relatively short period of time.

Furthermore, professional development programs are often structured solely as a summer workshop or institute. Even those lasting over multiple weeks focus only on "more science study," with little attention paid to how new information and insights can be used successfully to promote more and better student plans. Recent evidence suggests that work with inservice teachers should be extended to plans for actual changes to be tried during the following academic year. Teachers should have opportunities to practice "evidence collecting" to determine the impact of what they have learned in the summer workshop or institute on their students (Weiss et al. 2003). Evidence suggests that inservice work is more effective the longer it is sustained—over three, four, or even more sequential years.

Among issues on the college level is the fact that although 50 semester hours of course work in science certainly indicates a strong background in traditional science, it is no indication of someone's ability to teach. And too often, science methods courses are taught in the same way that science is taught: Instructors define terms, provide lists of ways to teach, offer their own ideas, and expect students to take notes and repeat what they say for tests. This approach is no better than what typically happens in science classrooms and laboratories. We have learned more about how people learn in the last decade (see, e.g., Bransford, Brown, and Cocking 1999) than can be considered in a single, three-semester-hour methods course.

Conclusion

The 16 exemplars described in this monograph provide very creative ideas with all kinds of evidence that progress is being made toward carrying out the visions of the NSES. They each illustrate important contexts for assisting with the preparation of new science teachers and for assessing the continual growth and development of inservice teachers. Staff development should always be planned so that teachers become enthusiastic about the NSES and are ready to implement their visions.

About the Editor

Robert E. Yager was an active contributor to the development of the National Science Education Standards. He has devoted his life to teaching, writing, and advocating on behalf of science education worldwide. Having started his career as a high school science teacher, he has been a professor of science education at the University of Iowa since 1956. He has also served as president of seven national organizations, including NSTA, and been involved in teacher education in Japan, Korea, Taiwan, and Europe. Among his many publications are several NSTA books, including *Focus on Excellence* and *What Research Says to the Science Teacher.* Yager earned a bachelor's degree in biology from the University of Northern Iowa and master's and doctoral degrees in plant physiology from the University of Iowa.

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A Collaborative Endeavor to Teach the Nature of Scientific Inquiry:

There's More to Science Than Meets The "I"

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Setting

Built in 1959, in Bloomington, Indiana, Arlington Heights Elementary School is one of the oldest of the 14 elementary schools in the Monroe County Community Schools Corporation. The school serves about 300 students in grades K–6, the majority of whom are white. Approximately 29% qualify for free or reduced lunches. Arlington's faculty includes classroom teachers, resource/inclusion teachers, and certified instructors for music, art, and physical education. The school has an ongoing partnership with Indiana University (IU) and hosts a number of preservice teachers for their early field experiences and for student teaching. With the recent adoption of the Indiana Academic Standards for Science and the upcoming inclusion of science on statewide assessments, the school identified professional development in science as a need the university could address.

Professional Development Program

The professional development program created in response to this need, Learning Science by Inquiry, focuses on helping teachers promote scientific literacy. The vision of science education outlined by the National Science Education Standards (NSES) (NRC 1996) includes the development of scientifically literate students who can experience the richness and excitement of learning about the natural world and also apply what they learn about science to a wide range of personal and social decision-making processes. Central to this goal is an understanding of the nature of science—that is, the values and assumptions inherent in the construction of scientific knowledge (Lederman 1992).

The National Science Education Standards indicate that effective professional development should provide long-term, sustained support, collegial work with both peers and staff developers, and a variety of activities. We developed the Learning Science by Inquiry program specifically to target the content standards of inquiry, subject matter related to the nature of science, and understanding the role of prior knowledge in assessment. We planned professional development activities to meet the NSES Teaching and Professional Development *More Emphasis* conditions (NRC 1996, pp. 52, 72) that include teachers as members of a collegial community and teachers as both reflective practitioners and producers of knowledge about teaching; we also

Table 1. Targeted *More Emphasis* Conditions From the National Science Education Standards Aligned With Professional Development Activities in the Learning Science by Inquiry Program.

***More Emphasis* Conditions**	**Learning Science by Inquiry Professional Development Activities**
Professional Development Standards	
• Long-term, coherent plans	• 18-month-long program
• Variety of professional development activities	• Many activities: monthly workshops, collaboration with facilitators and peers, on-site support
• Staff developers as facilitators, consultants, and planners	• Staff developers plan program in consultation with school administration and teachers, facilitate teacher progress
Content and Inquiry Standards and Assessment Standards	
• Implementing inquiry as instructional strategies, abilities, and ideas learned	• Teachers participate in inquiry and observe inquiry instruction in their own elementary classrooms
• Learning subject matter disciplines in the context of inquiry, technology, science in personal and social perspectives, and history and nature of science	• Teachers focus on inquiry and the nature of science in the context of elementary science content
• Assessing to know what students do understand	• Teachers learn assessment tools for becoming aware of their students' prior science content knowledge—student science journals, KWL charts, observation/inference charts, student observation records
Professional Development Standards and Teaching Standards	
• Collegial and collaborative learning/ teacher as a member of a collegial professional community	• Teachers work with each other to enhance the science program by sharing ideas, providing feedback, presenting their work at state science teacher conferences
• Teacher as intellectual, reflective practitioner/ producer of knowledge about teaching/ source and facilitator of change	• Teachers create change in their instruction, in students' knowledge; teachers reflect on their practices together, with facilitators, and individually
• Selecting and adapting curricula	• Teachers adapt existing curricula to focus on inquiry and the nature of science

helped program participants select and adapt curricula. The features that have been critical to the success of our program include sustained efforts over multiple academic years, collaboratively developed workshops, and on-site support for teachers. Workshops provide time for teachers to learn new information, discuss their current practices, and develop goals for their teaching. The alignment of each of these aspects with the NSES *More Emphasis* conditions that were used in designing the program are outlined in Table 1 and discussed in detail in the sections that follow.

Teachers in the Program

Of the 14 classroom teachers at Arlington Heights Elementary School, 6 participated in the program. We focus on 3 teachers in this paper: Kathy, Andrea, and Melissa. None of these teachers had specialized science training or any particular affinity for science; however, each recognized science as her weakest instructional area and expressed a desire to improve as her primary motivation for joining the program. We are showcasing these particular teachers because they represent the grade levels of participants in the program, and their results are typical for all teachers in the program.

Kathy, who has taught kindergarten for 29 years, teaches morning and afternoon classes of 18 students each. Andrea has five years of experience at the first-grade level and currently teaches 18 students in a self-contained classroom; she is also responsible for teaching science to all first-grade classes. Melissa is a new sixth-grade teacher, and her first year as part of this program was the first year she was responsible for teaching science. She teaches 36 students in a self-contained classroom.

Unique Features of the Program

The structure of the program, which was based on and reflects the *Changing Emphases* outlined in the NSES, was important to the success of the teachers as they implemented changes and developed their understanding of the nature of science and of scientific inquiry. The following sections will describe the program's unique features.

Monthly Workshops

Teachers attended a series of monthly half-day workshops during the school years. Based on conversations with faculty, during which needs and concerns were identified, the IU teacher educators designated topics for the initial year of the program (January–May). In the following year of the program (August–May), we selected workshop topics in cooperation with the teacher participants. (Workshop topics are listed in Table 2.) The involvement of qualified instructors who have used techniques successfully with students is critical to the success of professional development efforts (Loucks-Horsley, Hewson, and Love 1998). Guest speakers with appropriate levels of expertise were employed to lead workshops 1, 5, and 8. The IU teacher educators, who were former elementary teachers, facilitated the remainder of the workshops. Guest speakers and program staff used classroom vignettes and anecdotes from their own classroom experiences with teaching inquiry and the nature of science to help teacher participants visualize the strategies being presented.

Table 2. Monthly Professional Development Workshops

	Workshop Topic	Month/Year of Workshop
1.	An Introduction to the Nature of Science (NOS)	January 2002
2.	Conducting Scientific Inquiry	February 2002
3.	Assessing Inquiry Learning	March 2002
4.	Strategies for Adapting Curricula to Be Inquiry Based	April 2002
5.	Looking at Where Inquiry and NOS Fit Our Curricula	May 2002
6.	Goal-Setting for New School Year	August 2002
7.	Modifying Existing Curricula/Collaborative Planning	September 2002
8.	Using Children's Literature to Teach NOS Elements	October 2002
9.	Modifying Existing Curricula/ Collaborative Planning	November 2002
10.	Presentation at HASTI (Hoosier Association of Science Teachers, Inc.) Conference	February 2003
11.	Accessing Materials Inexpensively	March 2003
12.	Debriefing/ Reflecting on Goals and Successes	May 2003

The workshop series was designed with the assumption that teachers benefit from inquiry experiences grounded in the same pedagogical principles they are expected to implement with their own students and that a change in teachers' conception of the nature of science teaching and learning happens over an extended period of time, not through "one-shot" workshops (Loucks-Horsley, Hewson, and Love 1998; NRC 1996). An introductory workshop included opportunities for teachers to reflect on aspects of scientific inquiry such as those in the National Science Teachers Association (NSTA) position statement on the nature of science (NSTA 2000), which emphasizes the importance of certain concepts—for example, that scientific knowledge is simultaneously reliable and tentative, relies on empirical evidence, is influenced by both existing scientific knowledge and the sociocultural context of the scientist, and does not rely on a universal, step-by-step scientific method for investigating phenomena. The nature of science is also emphasized in NSES Content Standard G, focusing on science as a human endeavor (K–8) and the nature of science (5–8). This introductory workshop provided a framework through which teachers could reflect on the view of science apparent in the workshop activities that followed. Having teachers participate in inquiry science has been shown to help them conceptualize inquiry learning and implement it (Kielborn and Gilmer 1999). Our second workshop involved teachers in a guided inquiry investigation of antacids to determine which was "best."

Teachers wanted to be sure that their change in instruction improved their students' learning; thus, the third workshop focused on assessment strategies. We helped teachers understand the role of prior knowledge in inquiry and also develop strategies for assessing students' ideas before, during, and after instruction. Class discussions and science journals were used to track students' ideas over time and identify their changing understandings.

Because teachers' existing curricula did not recognize the importance of teaching science as inquiry, a necessary step was supporting teachers in adapting their materials for classroom use. As teachers participated in the program, they were better able to critique curricula in terms of the activities included and the images of scientific inquiry portrayed. Two workshops were devoted to adapting curricula. Teachers revised the focus of their lessons to accurately and explicitly discuss aspects of the nature of science.

With the initial curriculum adaptation completed, teachers at the goal-setting workshop raised new topics, such as how to effectively integrate science instruction across the curriculum; ways to access necessary materials for teaching science; and an expressed desire to share their successes with other teachers. These questions formed the basis for future workshops. In the spring of 2003, teachers presented their work at the state conference of the Hoosier Association of Science Teachers, Inc. (an NSTA affiliate), and at the end of the 17-month period we held a final session to reflect on successes and future instructional goals.

Collaborative design of both the professional development topics and on-site support was based on the NSES Professional Development *More Emphasis* condition wherein staff developers serve as facilitators, consultants, and planners, rather than as educators. We also addressed the NSES Professional Development *More Emphasis* condition of viewing teachers as members of a collegial professional community. By focusing on inquiry and the nature of science, our program reflected the changing emphases on content and inquiry, shifting from a view of "content as the standard of understanding" to "content as the context for understanding the science community" (Sullenger 1999, p. 25). Our program placed more emphasis on implementing inquiry as an array of instructional strategies, abilities, and ideas to be learned and on learning subject matter disciplines in the context of inquiry, technology, science in personal and social perspectives, and the history and nature of science.

On-Site Support

One of the benefits of the on-site mentoring visits (designed in light of the NSES *More Emphasis* recommendation for a variety of professional development experiences) was the ability to tailor professional development to the individual teacher's changing needs over the duration of the program. While some concerns were common to all teachers in the program, individuals encountered unique challenges in implementing inquiry in their respective classrooms. Program staff engaged in (a) modeling inquiry-based instruction in the teachers' classrooms; (b) providing instructional support by co-teaching inquiry-based lessons; (c) observing and providing feedback to teachers on their instruction; and (d) assisting teachers in adapting curricula, accessing materials, and designing assessments for use in their classrooms. We will illustrate the effectiveness of the program on three participants' instruction and knowledge of science in the vignettes that follow.

Kathy's Story: Building on Her Strengths

After 29 years of teaching kindergarten, Kathy retains her enthusiasm and love for teaching, as well as the desire to improve her practice. Though she favors teaching reading and language arts, recognition of science as her weakest area of instruction motivated her to join the program. She views science at the primary level as building a foundation for future science learning. In addition to using her science textbook, she tries to locate activities related to her students' interests. However, she notes it is difficult to find science materials that are developmentally appropriate for her kindergarten students. As a result of the program, she believes her science instruction has changed for the better, particularly in her ability to adapt science lessons to focus on inquiry and to emphasize the nature of science to her students while building on their prior knowledge.

Though initially Kathy held a view of science as "truth," through ensuing discussions with colleagues, together with reflection on her own ideas, she came to understand the role of creativity and subjectivity in science as the way in which existing theories and scientists' own prior knowledge and experience influence the production of scientific knowledge. Kathy also now understands the way in which those findings are tentative, or subject to change with new evidence or interpretation. One of the activities designed to help participants reach these understandings was a reading and discussion of *Earthmobiles as Explained by Professor Xargle* (Willis 1991). This book discusses transportation on Earth from the viewpoint of aliens. The inferences made by the alien professor, while consistent with his observations, seem comical to readers, whose own perspectives are informed by their experiences with transportation. By recognizing that interpretation of data could vary based on the researcher's perspective, the creative aspect of meaning-making became clear to the participants. As Kathy explains, "Scientists use their creativity to interpret the meaning of data collected and to form opinions regarding the results of experiments."

As the Standards indicate, one of the important understandings about scientific inquiry students should grasp is that scientists develop explanations using observations (evidence) and what they already know about the world. Kathy has helped her own kindergarten students understand this idea, as well as other aspects of the nature of science, including the distinction between observation and inference. Workshop 8 focused on ways to emphasize the nature of science through children's literature. Using the technique modeled by the children's literature workshop facilitator, Kathy used the book *Seven Blind Mice* (Young 1992) to illustrate that the white mouse is better able to identify the "something" in the book both because she collects more data *and* because the inferences made by the other mice give her prior knowledge. Kathy asked her students to relate how the white mouse made her inference as to how scientists go about their work and how their background knowledge influences those inferences. Asking students to discuss how the activity of the mice in the story was "like what scientists do" is an appropriate way to explicitly relate science activities to the nature of science for kindergartners. NSES Content Standard G, History and Nature of Science, indicates that K–4 students simply should recognize science

Kathy uses the book *Seven Blind Mice* to introduce observation, inference, and subjectivity to her class.

as a human endeavor. As suggested by the facilitator of Workshop 5, Kathy did not use the word *empirical* with her kindergartners but rather emphasized *data* and *evidence* as ways that scientists both learn and make explanations about the world.

Though she had frequently used literature with her classes, this was her first use of literature to emphasize aspects of the nature of science to her students. The internalization of ideas presented throughout the professional development was apparent in her subsequent teaching approaches, where again she often related her new ideas about teaching science, building on her strengths in language arts instruction. Though she already brought with her a wealth of knowledge for teaching kindergarteners, Kathy made tremendous strides in teaching science as inquiry and in emphasizing the nature of science in her science lessons.

Andrea's Story: Assessment Practices for Inquiry and the Nature of Science

Andrea has taught first grade for five years. As a primary teacher, her first and foremost goal for science teaching is encouraging curiosity and enthusiasm for science in her students. Her assessment practices in science reflect this goal and include affective as well as cognitive outcomes. From her participation in the program, Andrea recognizes the subjective aspect of science and acknowledges the impossibility of a science without bias. She realizes that scientific knowledge can change with new evidence, or the interpretation of old evidence, and she can accurately describe the distinctions between observation and inference and between theory and law, indicating that her content knowledge of the nature of science is now in line with NSES Content Standard G, History and Nature of Science.

Andrea has readily incorporated new assessment techniques into her teaching practice, including assessment of students' understandings of the nature of science elements. During a lesson in which students would eventually observe signs of life on their playground, Andrea first held a class discussion. She asked students to predict the kinds of life they might see. She then asked them whether they would see all the life forms that lived on the playground during their investigation. She encouraged the students to think about the evidence they would see that different life forms were on the playground, in the absence of directly observing them (e.g., bird droppings, animal tracks). Andrea recorded student responses on chart paper prior to their investigation. Students brought their science journals to the playground, where they recorded observations and listed inferences—and evidence—about what lived on the playground.

Andrea monitors students as they record observations and inferences in their student science journals.

During the lesson debriefing, Andrea asked students to share their observations of the kinds of life on the playground, along with the evidence they had for the existence of that life. She helped them recognize that they did not have to directly observe the animal, but could find evidence that would lead them to infer that the life existed. During this lesson, Andrea was successful in assessing students' understandings of the distinction between observation and inference, together with the empirical nature of science, by using two modeled strategies—individual student journals and whole-class charting of observations and inferences. In her current teaching approach, Andrea always asks her students to relate what they are doing to scientists' work by asking, "How is what you are doing like what scientists do in their work?" This question again focuses specifically on NSES Content Standard G, History and Nature of Science—science as a human endeavor—for grades K–4. Andrea is able to assess students' content knowledge of science as well as their understandings of inquiry and the nature of science, employing the methods of assessment she uses as a result of participation in the professional development program.

Melissa's Story: Shifting from "Cookbook" Science Activities to Inquiry

Melissa teaches in a sixth-grade self-contained classroom. As a relatively new teacher, she is enthusiastic and eager to develop a repertoire of science teaching ideas and strategies. She initially tended to rely on the adopted text series to plan science lessons, but she found this approach insufficient for accomplishing her goals. Many of the "cookbook" science activities in the series required little more to complete than skill in following directions. As the Standards indicate, "when a textbook does not engage students with a question, but begins by assigning an experiment, an essential element of inquiry is missing" (NRC 2000, p. 28). Melissa wants her students to go beyond the experiments outlined in the textbook and to formulate their own questions and devise ways to answer those questions.

While many of Melissa's views of the nature of science were aligned with those outlined by the Standards, the activities of her text series did not provide her students with opportunities to develop these understandings themselves. For example, Melissa understands the subjective nature of science, stating, "Scientists' backgrounds influence how they interpret data." Similarly, she is able to describe the tentative nature of science and how theories can change with new evidence. She recognizes that no universal "scientific method" adequately characterizes scientific investigations. Her text's prescribed step-by-step activities fail to capture the complexity of science and can direct students' attention to one right answer and one way of finding out that answer, rather than helping them develop the ability to think critically and logically (NSES Content Standard A, Science as Inquiry). Interactions among the teachers in the program as they grappled with these ideas, and with how to teach these ideas to their students, helped all the teachers reconceptualize the scientific method as "science as inquiry with multiple methods."

For Melissa, helping her students to generate and refine questions—and to develop experiments of their own to answer those questions—was an important step in helping them take ownership of the task and develop their abilities to conduct scientific inquiry, which she found was recommended by NSES Content Standard G, History and Nature of Science (grades 5–8). A successful strategy for implementing inquiry for Melissa has been to use the "cookbook" activities to serve as a springboard for students' inquiries. This strategy was developed collaboratively by teachers during one of the curriculum adaptation sessions of the program. After her students have completed the experiment in the textbook, Melissa asks them to brainstorm variables that might affect the outcome of the experiment, formulate a testable question, and design inquiries to test the effects of those variables.

Once students collect data, Melissa helps them develop explanations for the evidence. At Melissa's invitation, the program director taught a model lesson to her students that focused on the skills of observation and inference using students' own interpretations of a presented scenario. The students were given an organizer to categorize their responses as "observation" or "inference." Understanding this distinction helps students evaluate the explanations proposed by classmates in determining which inferences are valid, given the observations they made, a step also recommended by Content Standard G (grades 5–8). Melissa continued to use this organizer to reinforce students' conceptions of this distinction during investigations of other topics.


Melissa works with a team of students to brainstorm ways their experiences at the Challenger Center relate to the work of scientists.

Melissa's efforts to help students understand the nature of science have focused on helping them connect their experiences in science class to the experiences of scientists. On one occasion, she took her class on a field trip to the NASA Challenger Center in Indianapolis. As part of their simulated mission work at the center, the students engaged in pre-mission activities and on-site science inquiries in the context of a mock Challenger mission. In the field trip debriefing lesson, Melissa asked students from each science team to record examples of how what they did during their mission was like what scientists do. She used categories collaboratively generated by the teachers for use in their classrooms (make a plan, investigate, predict, consider personal perspectives, infer, observe, create, collect data, classify, analyze, interpret, organize, ask questions, research). By sharing their experiences in a mock scientific exploration, communicating the science content they learned, and reflecting on how their experiences compare to the ways scientists go about their work, Melissa's students have developed a much richer understanding and appreciation of the scientific endeavor.

Evidence for Success

Teachers in our program made important changes in their views of the nature of science, their instructional practices, and their abilities to adapt curricula to emphasize inquiry and the nature of science. We tracked the effectiveness of the professional development program in helping the teachers accomplish these changes. Data collection and interpretation helped us plan additional professional development workshops and on-site support. Thus, the design of the professional development program was modified to meet teachers' needs as the data were collected and analyzed (Bogdan and Biklen 1998). Data for tracking the teachers' success included

- field notes written by program personnel at each workshop;
- videotaped sessions of teachers and program personnel teaching inquiry lessons;
- transcripts of interviews of teachers as they watched videotapes of their inquiry lessons;
- teacher responses to the Views of Nature of Science questionnaire (VNOS-B) pre and post, to determine changes in conceptions of the nature of science;
- teacher responses to the Views of Scientific Inquiry questionnaire (VOSI);
- e-mail and verbal communications between the program personnel and teachers regarding successes and difficulties associated with inquiry teaching; and
- teachers' descriptions of their lesson adaptations as they prepared them for a presentation at the state science teachers' conference.

To analyze the data, a comparison was made between the pre- and post-VNOS-B and VOSI questionnaires to track teachers' understandings of the nature of science elements and of scientific inquiry. Classroom observations, video-simulated interviews, e-mail and verbal communications, descriptions of lesson adaptations—we used these methods to note changes in instruction and to evaluate the success of the program.

Summary

Teachers participated in a long-term professional development program, designed in accordance with the National Science Education Standards, that enabled them to experience science as inquiry, to confront and change their own ideas about the nature of science, and to develop strategies for teaching science as inquiry while emphasizing the nature of science to their own students. A key feature of the professional development that enabled the teachers to change their science teaching was providing them with time, in terms of both the length of time of the program (17 months) and release time to explore, learn, and discuss changes in their teaching. This element has been identified as critical to the success of professional development programs (Loucks-Horsley, Hewson, and Love 1998; NRC 1996). The success of these teachers shows the importance of the *More Emphasis* conditions of long-term and coherent professional development (NRC 1996, p. 72).

Another key feature was collaboration between program staff and teachers at the local school, as well as among the teachers themselves. Teachers' interests and ideas guided the design of workshop sessions, during which they worked together to make changes to their teaching approaches. As Loucks-Horsley, Hewson, and Love (1998) emphasized, "Reflection by an individual on his or her own practice can be enhanced by another's observations and perceptions" (p. 127). The NSES Professional Development *More Emphasis* conditions calling for collegial collaboration and for the teacher as creator of knowledge about teaching were vital for this program.

A final key feature was the individual, on-site teaching support provided to the teachers by the program staff, who taught model lessons and gave feedback and suggestions to teachers as they tried new instructional strategies. Because members of the program staff were former elementary teachers, the participants found them to be "credible peers" (Bandura 1997) and reliable sources for collaborative professional development, particularly for the on-site classroom support. The ability to have individualized support for unique classroom challenges was invaluable to the teachers. The NSES Professional Development *More Emphasis* condition calling for a variety of professional development experiences was relevant in this regard—the workshops served as a way to discuss the new ideas and strategies, while the on-site supports aided teachers in adjusting instruction methods.

It is evident from classroom observations and teacher responses in interviews and on questionnaires that all facets of the professional development contributed to teachers' abilities to make substantive changes in their teaching. Their teaching became inquiry focused, and the teachers now explicitly teach about the nature of science to their students, which illustrates how the Content and Inquiry *More Emphasis* conditions influenced their work. They have also become more skilled in assessing what students understand about content, inquiry, and the nature of science through class charts, student journals, and teachers' observation of students, which shows how the Assessment *More Emphasis* conditions shaped their work. Finally, they have become better at identifying and responding to individual students' understandings, adapting curricula, conducting ongoing student assessment, and working together to enhance the science program, which illustrates the importance of the Teaching *More Emphasis* conditions on their work.

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