Minds-On Science

Open-ended experiments cultivate childhood inquiry

By JANET RALOFF

Last year, Sherry Drilling asked each of her second-grade students to guess a mealworm's favorite color. To test those forecasts, each youngster placed a larva at the center of a color wheel and recorded which hue it wiggled toward. After repeating the experiment nine times, the children graphed the insects' responses and attempted to interpret the findings.

The project was part of a 3-week science segment at Takoma Park (Md.) Elementary School that focused an hour and a half each day on insects—what they are, how they communicate, the stages they pass through during their life cycle, and their diverse strategies for coping with a sometimes hostile environment.

After a few days of coached studies, Drilling encouraged the children to frame their own questions—Could a mealworm find its way out of a maze? Would it react to smelly substances? How would it respond to gentle prodding of its antennae? The children then devised and ran experiments to find answers.

This deeply involving, experiential investigation of insects embodies an approach to learning that has been dubbed minds-on science. It goes beyond mere hands-on activities—performing specific experiments under the guidance of a teacher or book. Instead, it engages the student in formulating original questions, brainstorming to find answers, and critically evaluating subsequent test results.

"I teach them that everybody is a scientist," Drilling says. Because science is driven by curiosity, she encourages questions—loads of them. By allowing students to chart the direction of their inquiries, she says, they not only become "discoverers" but also have fun.

Ann O'Meara of the Winsor School in Boston takes a similar tack with older students. "Without question," she says, "the best course I've ever taught is introductory physical science. Generally geared for eighth graders, it is totally self-discovery- and activity-based." Conducting an experiment daily, "these students really do come away knowing how to do and understand science."

While such programs can be found in some classrooms around the nation, they do not yet represent the norm, according to a blue-ribbon panel of educators and scientists assembled by the National Research Council in Washington, D.C. But in a new, 262-page report, "National Science Education Standards," the NRC panel argues that this type of science teaching should be available to all. The report offers a rough blueprint to help schools toward achieving it.

There have never been true national standards for science education, argues Richard D. Klausner, director of the National Cancer Institute in Bethesda, Md., and chair of the NRC committee that proposed such standards in December 1995.

There has always been a set of de facto standards for the older, university-bound students, he acknowledges—generally the specific knowledge or skills needed to perform well on college placement exams, especially the Advanced Placement (AP) tests and Scholastic Aptitude Tests (SATs). Textbooks, he notes, can serve as a second tier of de facto standards by creating a series of arbitrary bounds on the depth and breadth of a studied subject.

The existence of these informal standards prompted the NRC panel to recommend changes in curricula, tests, and other gauges of knowledge and skills to support the newer approach to science education, explains Karen Worth of Education Development Corp. in Newton, Mass.

A former first-grade teacher and now a curriculum developer and educator of elementary teachers, Worth served on Klausner's standards-writing panel. She argues that "there is nothing in the new standards that a really good teacher in the right environment is not doing already."

The message that the NRC panel took home from observing such teachers, Klausner says, is that classroom science should not focus on lectures, textbook study, and paper-and-pencil tests but should instead involve procedures "that actually look like the process of doing science—which we call inquiry."

The panel's new model for science education stresses collaboration and communication among students, problem solving, and individual evaluation. It downplays a drilling on vocabulary and formulation of hypotheses, he says, in favor of promoting questions and exploration, both "central to science."

Unfortunately, Worth points out, budgetary and other pressures, such as the need to succeed at "high-stakes tests like the SATs and APs," encourage the majority of teachers to continue using the older, less effective techniques.

"I watch my own kids in the Washington area who are just being asked to memorize parts of a cell or names of minerals," Klausner says. "And this is not how we do science." He would prefer to see students taught the functions that characterize a cell and then encouraged to investigate what structures the cell has developed to carry out such tasks.

Critical analysis of how and why things function—with the goal of being able to apply such knowledge to novel situations or questions—should be integrated throughout the curriculum, he argues, rather than "ghettoized" in courses labeled as science. Moreover, the new standards recommend that inquiry-based science remain an integral part of precollege education for every student, every year.

Many of these same recommendations have emerged elsewhere—notably from Project 2061, a program launched 10 years ago by the American Association for the Advancement of Science (AAAS) in Washington, D.C., the Carnegie Corporation of New York, and the Andrew W. Mellon Foundation in New York. In its 1990 book report, "Science for All Americans," Project 2061's call for "radical" and "systemic" reform of kindergarten through 12th-grade education recommended a minimal level of science literacy for all citizens. It then outlined changes that would be needed to achieve it.

Like the new NRC report, the AAAS tome argued that schools need "to teach less in order to teach it better." It also recommended placing a greater focus on understanding key concepts and principles, learning to think critically, recognizing the strengths and limitations of science, and building skills to harness knowledge and critical thinking for solving personal and social problems.

Project 2061 issued a 418-page follow-up 3 years later—"Benchmarks for Science Literacy"—in which it articulated those goals in more detail. Rather than compiling a uniform checklist of what should be learned in each grade at schools across the nation, it advocated "a reform strategy that will lead eventually to greater curriculum diversity than is common today." It encouraged teachers to focus their approach to a topic, much as Drilling made an in-depth exploration of mealworms the center of her school system's second-grade coverage of insects.

The new NRC document draws heavily on those earlier AAAS reports, notes F. James Rutherford, director of Project 2061. But where his program focuses on the development of standards for content across the spectrum of science-related disciplines, including math and technology, the NRC's panel restricts itself to the natural sciences.

Moreover, Rutherford points out, Klausner's group broadened its purview well beyond subject content to include such issues as the need for teachers themselves to receive subsidized continuing education. But anyone adopting the principles and recommendations in 2061's benchmarks "will be satisfying the spirit of [NRC's] national standards," Rutherford adds, because "there is an of overlap of 90 to 95 percent" between them.

That said, interpreting what the benchmarks or the science standards advocate in terms of specific classroom, curriculum, or administrative changes leaves much to the imagination. Without question, the new science standards "are very vague," observes Pamela J. Akiri, a biology teacher at the Ethel Walker School in Simsbury, Conn.

For instance, content standards for the life sciences state only that by the time students leave fourth grade they will have studied characteristics of an organism, life cycles of organisms, and organisms in environments. Earth and space science standards for high school students are similarly general, requiring knowledge of such broad topics as energy in the Earth system, geochemical cycles, the origin and evolution of Earth, and the origin and evolution of the universe.

In fact, Worth says, the standards' authors intended such generalities to provide only a guiding "philosophy—a kind of vision." While "they describe the nature of what ought to be going on [in classrooms]," such as assessing what students know instead of testing them to find out what they don't know "the standards are not a teachers' guide," she points out.

Gerald Wheeler, the new president of the Arlington, Va.–based National Science Teachers Association, shares Worth's view on that last point, noting that the new standards certainly don't answer the question: "What should I do differently in my class next Tuesday morning?"

But that's where NSTA plans to step in. "We're positioning ourselves in this issue as the implementer of their ideas," Wheeler told SCIENCE NEWS. In March, his group plans to unveil a series of three volumes known as pathways. Geared for elementary, middle, and secondary grades, the pathways are being developed to provide teachers with concrete interpretations of the new science standards. Wheeler's goal is that the standards "have a presence in every single school building in the United States"—all 110,000 of them.

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— R. Klausner

In addition, he's developing an accompanying set of World Wide Web home pages for the Internet "so that teachers can get on-line and chat about these standards and engage in dialogues with other teachers and the experts." He hopes this will bring teachers out of isolation and "alert them that there's a contact to whom they can direct questions about the standards."

Figuring prominently in the new standards are discussions about the importance of depth versus breadth of knowledge and about the most influential sources of knowledge. In the old school, teachers lectured on a topic, imparting information gleaned from experimentation by others, explains Wendy Saul, a science education analyst at the University of Maryland, Baltimore County. More recently, data on teaching have come to "suggest that people don't learn science by absorbing stuff that has been poured onto them [via lectures] but rather by constructing meaning out of experiences that the teacher provides," she says. "The new science standards are very much of that school."

Indeed, the standards recommend a fundamental shift in teachers' expectations about experimentation, Saul argues. In the early post-Sputnik era, when hands-on science was first getting a big push, educators argued that a primary benefit of experimentation was to illustrate established scientific principles. Working with batteries and circuits, say, would drive home the meaning of volts and amps. With the evolving minds-on emphasis, Saul says, educators are now looking at such experimentation as a way to kindle testable questions. Are there ways to make a lightbulb burn more or less brightly? If I hooked things up differently, would the bulb still light? Will different power sources affect light output or bulb life?

For most large public school systems, implementing such minds-on programs will require nothing short of an administrative revolution, Akiri believes. "People will do what they're assessed on—and that includes teachers, not just students," she says.

As long as school systems evaluate teachers on their ability to cover a certain number of chapters in specified texts or on how well their students perform on multiple-choice achievement tests, teachers will neither pace their teaching to the speed at which their students are learning nor risk omitting a topic that will be on the test so students can pursue other concepts in greater depth.

O'Meara concurs, noting that minds-on learning emphasizes experiences over the facts that achievement tests tend to measure. In that eighth-grade class she taught, she reports that "although the students didn't learn a great deal of facts, it was the most successful course I ever taught." She argues, "kids forget most of the facts we give them. So what we really hope they will retain is an ability to think critically, work through problems logically, and make connections with the real world." That, she maintains, is what her course taught.

Such experiences may prove especially hard to engineer in poor, inner-city schools, Akiri argues. "I've taught in them, and what I'm teaching now [in an independent, girls' school] would be impossible there," she maintains. "That's not because teachers wouldn't like to do what I'm doing, but because you can't maintain discipline for more than half the class period."

Compounding the problem, she says, are overcrowded classrooms—which don't lend themselves to in-depth discussions—and the frequent truancies in many poor schools. Akiri structures her lessons and experiments to build cumulatively from one week to the next. "So if you come in halfway through the year or have many absences, you're lost."

Worth argues that too little time, overcrowding, and lack of resources or adequate teacher training "are political problems" that can be remedied when the United States musters the will to demand adequate resources for educating the next generation. She suspects that the NRC standards, because they have been issued "by the premier science organization in the country," may finally offer education reformers like herself the clout to begin mustering that will. □