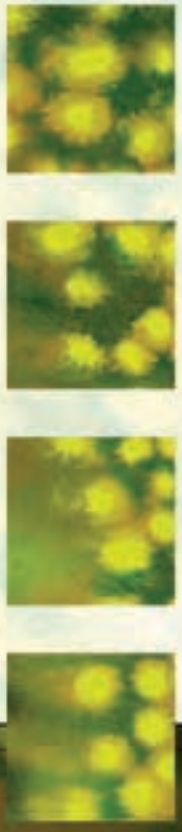
PRIORITIES *in* PRACTICE

The Essentials of Science, Grades K–6

Effective Curriculum, Instruction, and Assessment



Rick Allen

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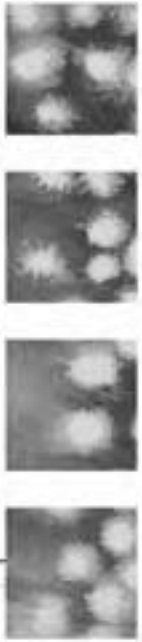

Effective Curriculum, Instruction, and Assessment

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- Preface v
1. Trends in Elementary Science Education 1
2. Planning a Curriculum of Essentials 18
3. Bringing the Curriculum to Life in the Classroom 33
4. Motivating Students in Science 64
5. Assessment for Learning 81
6. Implications for Professional Development 95
- Appendix A: Inquiry in Practice: Kindergarten 115
- Appendix B: Using Assessment to Deepen Students' Science Knowledge 121
- References 126
- Index 130

Preface

The Essentials of Science, Grades K–6 is intended to help elementary teachers and instructional leaders get a handle on the best ways to teach science to young children. Research shows that elementary teachers, who typically have the heavy responsibility of teaching multiple subjects, often believe that they don't have enough time to teach science, feel themselves inadequately trained for the task, or aren't particularly fond of the subject. It's with those difficulties in mind that I offer elementary educators some classroom examples of expert science teachers at work, along with practical information to help readers reflect on their own approaches to teaching science.

Although relying for the most part on classroom observations and interviews with award-winning elementary school science teachers and science education experts, this book also makes extensive use of widely available research examining the state of science education. To show that concern about science education crosses borders, I highlighted some studies that examine science education practices outside the United States. Promising research-based developments, including concept cartoons in the United Kingdom and lesson study in Japan, are already being used in the United States and other countries.

The Essentials of Science, Grades K–6 is divided into six chapters that seek to give readers a basic grasp of the following topics: trends in elementary science teaching, curriculum planning, best practices in the elementary science classroom, the engagement and motivation of students, ongoing assessment, and professional development.

As I gathered information for this book, I was continually reminded of the reality that science, rooted as it is in the certainties of the physical

world, is a process that necessarily unfolds over time. In school, science classes tend to work according to this linear model; there's a "beginning, middle, and end" to science investigations, no matter how hard teachers may fight the "cookbook" reductionism that threatens true scientific inquiry. Yet, in probing further, I came to understand that science cannot be defined in terms of a sequence. Science is recursive. It might be described as having a cyclical nature with a twist—spiraling upward, looking back on itself, and changing as necessary. Thus, scientists—and ideally, students in science class—continually look back on what they have observed, analyzed, and evaluated to see whether their conclusions still make sense or raise new questions to pursue.

These processes of wondering, questioning, predicting, observing, and data gathering can lead to one person's flash of insight, the "aha!" that cuts through the seeming tedium of the processes themselves. Such revelations can be as lofty as Einstein's equation of mass with energy or as humble as the realization that those painful burrs pricking through your jeans on the playground are in fact seeds.

The Essentials of Science, Grades K–6 would not have been possible without the generosity of the many science educators and researchers who agreed to share their knowledge, classroom practice, and insights for this book as an encouragement to their colleagues in schools here and abroad.

Trends in Elementary Science Education

Science is a wonderful thing, if one doesn't have to earn one's living at it.

—Albert Einstein

Many elementary school teachers, the proverbial jacks-of-all-trades, face a trio of issues when it comes to teaching science: they don't like science, they don't feel confident in their knowledge of science, and they don't know how to teach science effectively.

That's exactly what science education professor Alan Colburn tells his undergraduate education students at California State University, Long Beach. "People in general don't like science, and elementary school teachers are no different from the rest of the general public," explains Colburn.

Working under those circumstances, it's no wonder that teachers tend to treat science as an afterthought, say veteran science educators. Bobbie Sierzant, an elementary science teacher for 32 years, notes that "science is one of the first things to be let go of in an elementary school day because the teachers are so overwhelmed with language arts, math, and social studies and all the other duties they have. They'll keep on saying, 'I'll get to it, I'll get to it.' They realize science takes more time—but they never find that extra time."

A New Springtime for Science?

But there is hope. Colburn, who is training a new crop of science teachers and helping midcareer educators to advance their practice, promises to launch his students on the road to becoming exemplary science teachers. Such teachers, says the syllabus for his science class for prospective elementary teachers, "like science, have an accurate understanding of major science content and processes, feel confident in their ability to learn science, and teach science using an age-appropriate inquiry-based approach" (Colburn, 2005).

The question for elementary teachers who are already teaching science, however, is "How do I get there?" Now that the academic spotlight of No Child Left Behind (NCLB) is being trained on science education in the United States, these teachers might need to find answers to that question—fast.

NCLB is driving schools to take a closer look at how they teach science and to improve their practices accordingly. Science testing under NCLB is slated to begin in the 2007–2008 school year, prompting a flurry of activity among educators. State departments of education have been busily devising standards-based tests that will be administered annually within grade bands at the elementary, middle, and high school levels. And school administrators have looked up from their students' reading and math scores just long enough to realize that yet another test is on the horizon.

Additional concerns have joined in the push to improve science teaching. In many countries, public and private groups are demanding better science education at all levels because they see science and technology as the keys to economic advantage in the global village. Europe has recognized the importance of science and math education for economic success (Wellcome Trust, 2005), and even Asian nations, consistently high achievers in international comparisons of math and science, are not immune from worry. During the last decade, while U.S. reformers have looked to Asia as the "promised land" of education practice for high student achievement, reformers in East Asian countries have been experimenting with child-centered, constructivist practices, seeing them as the U.S. secret to economic success (Zhao, 2005).

Ironies in international education reform aside, one thing is clear: not since the years after Sputnik's launch in 1957, when U.S. schools dramatically increased the rigor of their science curricula, have U.S. public and private sectors voiced such interest in improving the quality of K–12 science education.

For example, a committee of leading scientists and business leaders working under the National Academy of Sciences recently recommended recruiting 10,000 science and math teachers annually by offering the nation's smartest students four-year college scholarships. The same group wants government and private grants to fund professional development for science and math teachers, including summer institutes, master's degree programs, and training programs for advanced placement and International Baccalaureate programs. This committee has even called for the convening of a national panel that would research and develop a "world-class standard" voluntary K–12 curriculum (Committee on Science, Engineering, and Public Policy, 2006).

Ultimately, improvements in science education—and educators' willingness to embrace change—will depend on how well schools, the government, and even the private sector provide teachers with the necessary resources and professional development to teach hands-on, inquiry-based science. Experts say the national science education standards developed by the National Research Council (NRC) in 1996 have not yet gained a strong foothold in the science teaching practices found in most U.S. schools. Nonetheless, science educators and education policymakers see the NCLB spotlight as one additional opportunity to ensure that science remains on everyone's academic radar screen.

Why Standards Matter

The underlying goal of the NRC's *National Science Education Standards* (1996) is to create scientifically literate students. Although it's understood that not every student will grow up to be a scientist, scientific literacy is essential in a highly technological society in which the fruits of scientific research can have a major effect on such aspects of society as health care, food, transportation, and communication.

According to the standards, a scientifically literate individual can "ask, find, or determine answers to questions derived from curiosity about everyday experiences"; explain natural phenomena; and understand science news in the popular media. Further, as a boon to civic life, scientific literacy "implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed" (NRC, 1996, p. 22).

Leon Kass, past chair of the President's Council on Bioethics, says that such controversial scientific topics as cloning, genetic screening, and genetic engineering are "issues of enormous importance, not just for now but for the future." Students should understand science not just as knowledge for its own sake, but also as a means to become thoughtful citizens who can weigh in on scientific matters that directly affect society. "It's very important that young people come to understand that there are important moral concerns raised by genetics and biology," Kass says, pointing to just one branch of science. "It's never too early to introduce them to these questions" (Allen, 2002, p. 7).

A Need to Distill Standards

As senior program director in the education and human resources directorate at the National Science Foundation (NSF), Janice Earle evaluates the cutting-edge science education research programs that the NSF funds with taxpayer money allotted by the U.S. Congress.

Earle believes that despite the dissemination of *National Science Education Standards* and *Benchmarks for Science Literacy* (published by the American Association for the Advancement of Science in 1993), science education in the United States "has not taken the standards deep enough." Part of the problem is the standards themselves, which she describes as "tons of stuff" that's neither well connected across topics nor well articulated across grade levels. "Most states just took their own standards and added the national standards—it's accretion instead of distilling and refining. They've added, added, added, so now what they have is a cluttered landscape of stuff," Earle contends. She notes that "there's a lot of work

that remains to be done" to strengthen the standards, including making decisions about what knowledge is most essential for students to have.

The State of State Science Standards 2005, a recent study commissioned by the Thomas B. Fordham Institute in Washington, D.C., evaluated the state science standards for 49 states and for the District of Columbia. Only 19 states earned a top grade of *A* or *B* with "clear and rigorous standards." The standards for the 22 states that earned only a *D* or an *F* were characterized by excessive length, lack of coherence, an overemphasis on open-ended approaches to inquiry-based learning, inadequate content knowledge requirements, and insufficient attention to evolutionary theory (Gross et al., 2005).

Some standards-based curricula have created other problems as well, say the authors of the Fordham survey. They are particularly worried about state standards that create a false dichotomy between "rote" and "hands-on" learning. In a solid science curriculum, the accumulation of facts and concepts should go hand in hand with laboratory or field investigations. As the investigators note, the real problem lies "in determining reasonable demands on student memory. It is not at all a matter of 'just memorizing' versus 'doing' science. You can't just 'do' science, or any other intellectual work, without a minimum acquaintance with the facts" (Gross et al., 2005, p. 24).

Calling On the Cognitive Sciences

The next step in science education reform makes use of research within the cognitive sciences, which seek to uncover the mental processes of learning. According to this promising model, concepts, facts, and inquiry (in both its intellectual and hands-on aspects) play mutually supportive roles in learning science.

For example, one key research finding emphasizes the importance of understanding "domain-specific conceptual frameworks." Broadly, this means that the application of such concepts as *evidence* or *change* will look different within the context, or domain, of science than within the context of another subject, such as history. Within each domain, conceptual frameworks promote organization and understanding. In

science, for instance, the concept of the adaptation of species gives new meaning to what a student already knows about the characteristics of fish, birds, and mammals. The concept of adaptation, in turn, is fleshed out and enriched by the factual details of the species that students have studied (Donovan & Bransford, 2005).

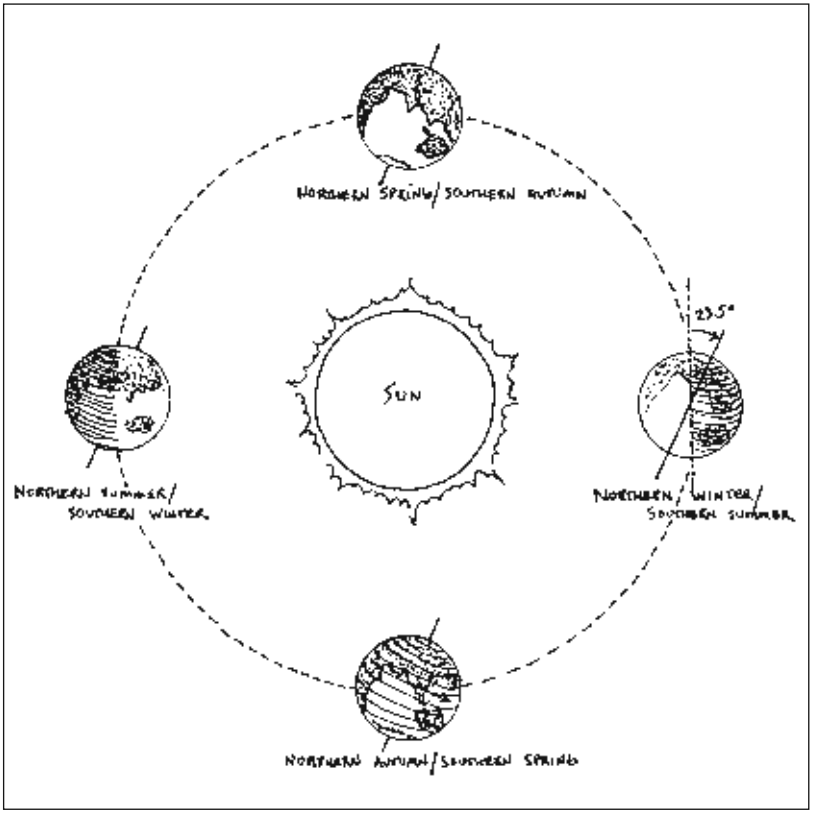
In *How Students Learn: Science in the Classroom*, Donovan and Bransford (2005) distill three principles from cognitive and developmental research that can help science teachers strengthen their classroom instruction and boost their students' learning:

- **Address preconceptions.** First, find out what students already know.
- **Know what it means to "do science."** Understand how constructing knowledge in this subject may differ from constructing knowledge in other subjects.
- **Use metacognitive strategies.** Help students reflect on their learning process.

Addressing Preconceptions

Students enter the classroom with their own ideas about how the world operates. These preconceptions may come from a variety of informal sources, including students' own observations. Some incomplete ideas persist as misconceptions into adulthood. One well-known study (Harvard-Smithsonian Center for Astrophysics, 1987) showed that a majority of randomly chosen Harvard University graduates, faculty, and alumni could not give correct explanations for either the change in seasons or the phases of the moon. One featured misconception held that the earth has a pronounced elliptical orbit that swings closer to the sun during summer and farther from the sun in winter. The study also showed that such fixed personal understandings are hard to root out, even after teachers provide correct information (see illustration on facing page).

Accordingly, teachers who understand the individual preconceptions that students bring to a science topic can address misunderstandings directly and thus better focus their lessons. In addition, teachers



The tilt of the earth's axis means that the angle of the sun's rays and the intensity of their energy vary during the planet's revolution around the sun. Typical depictions of the earth's orbit as a pronounced ellipse (to show three dimensions) can mislead students into thinking that the earth swings closer to the sun during summer and farther away during winter—a childhood preconception that can persist into adulthood. (Drawing: Rick Allen)

must be ready to address preconceptions that students hold about the science field itself and the procedures within it. For example, Donovan and Bransford (2005) point out that many students believe experiments are performed mainly to attain a certain outcome or that data correlation is itself sufficient to show a causal relationship.

"Doing" Science

Such misconceptions about the processes of science tend to occur when the processes become ends in themselves, divorced from core concepts of science. For students to learn how to "do" science, they need to understand the roles of observation, imagination, and reasoning.

Donovan and Bransford point out that research has shown that experts in a field acquire and retain knowledge differently from novices.

Experts add knowledge to their existing conceptual framework of "big ideas," which makes acquisition of new ideas or facts easier, and recall and application of knowledge more productive. Students, too, must "have a deep foundation of factual knowledge" to gain mastery in a scientific topic, which they must then link to a conceptual framework (Donovan & Bransford, 2005, p. 1).

Janice Earle finds promise in the reform efforts that highlight both scientific thinking and science's big ideas. She further notes that if science's domain-specific thinking is a way of reasoning based on evidence about the natural world, then schools need to give students opportunities to experience the natural world. "Cookbook labs" that involve step-by-step directions leading to certain outcomes don't satisfy the perennial call for inquiry-based learning in science. "Inquiry can be good, bad, or indifferent, just as curriculum or assessment can be good, bad, or indifferent," Earle asserts.

Using Metacognitive Strategies

The third principle for effective science instruction involves teaching students to use metacognitive strategies to monitor their own thinking. Such strategies can be as simple as having students compare outcomes of an experiment or leading a class discussion that exposes students to different viewpoints on a topic. With guidance and support from skilled teachers, students will reconsider and refine their own ideas.

A metacognitive strategy called *reflective assessment* involves giving students a framework, such as a rubric, for evaluating their inquiry. For example, students may rate their understanding of the main ideas, understanding of the inquiry process, systematicness, inventiveness, careful reasoning, application of the tools of research, teamwork, and communication skills. Donovan and Bransford found that when given a reflective framework for their thinking, academically disadvantaged students, in particular, made significant gains (2005).

Elementary science teachers can promote deep knowledge only if they give students chances to rethink how to observe and reason about the world, moving them from an everyday way of thinking to a scientific one (Magnusson & Palincsar, 2005). Such a shift is not easy, however.

It requires that teachers have a solid grounding in the topic so that they can help students use their reasoning abilities to question their prior understanding.

Inquiry in the Science Classroom

Age-Appropriate Inquiry

The standards set by the NRC call for K–12 students to both understand and be able to engage in scientific inquiry. For early elementary students, "full inquiry involves asking a simple question, completing an investigation, answering the question, and presenting the results to others" (1996, p. 122). For upper-elementary students and those entering middle school, inquiry calls for students to become more attuned to the role that evidence plays in forming their explanations.

Even young schoolchildren can engage in scientific inquiry, says Chris Ohana, field editor for *Science and Children* magazine and science education professor at Western Washington University. "I've seen really elegant things done by 1st and 2nd graders," notes Ohana, also a former schoolteacher. In one instance, two 2nd grade girls were not convinced that air was "something" rather than "nothing." So they took two balloons—one filled with air and one deflated—and weighed them on a well-calibrated balance. The students' experiment allowed them to understand that air has mass—that even though they cannot see air, it is in fact "something" rather than "nothing."

To encourage age-appropriate classroom inquiry, authors of the national standards take great pains to point out that the inquiry standard does not advocate a "scientific method." That's because inquiry can take many forms, such as "describing objects, events, and organisms; classifying them; and doing a fair test" that changes one variable at a time. Indeed, the commonly understood model of the scientific method can even distort the scientific understanding of "theory" and "law" (Colburn, 2003, p. 87).

The NRC's science education standards list abilities that elementary students need to effectively engage in inquiry in the classroom (1996). Students in grades K–4 should be able to

Is air "something" or "nothing"? These students weigh a balloon to find out. (Photo: Rick Allen)

• Ask a question about objects, organisms, and events in the environment.

• Plan and conduct a simple investigation.

• Employ simple equipment and tools to gather data and extend the senses.

• Use data to construct a reasonable explanation.

• Communicate investigations and explanations.

Students in grades 5–8 should be able to

• Identify questions that can be answered through scientific investigations.

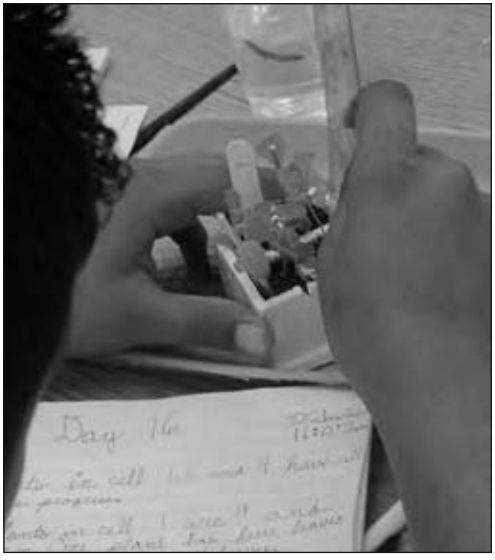
• Design and conduct a scientific investigation.

• Use appropriate tools and techniques to gather, analyze, and interpret data.

• Use evidence to develop descriptions, explanations, predictions, and models.

• Think critically and logically to relate evidence and explanations.

• Recognize and analyze alternative explanations and predictions.
• Communicate scientific procedures and explanations.
• Use mathematics in all aspects of scientific inquiry. (NRC, 1996, pp. 122–123, 145, 148)



Left: Scientific inquiry for students can involve using simple tools like magnifiers to extend the senses. (Photo courtesy of Valle Imperial Project in Science)

Right: Students' inquiry includes observing, gathering or quantifying data, and thinking and writing about their investigations. (Photo courtesy of Valle Imperial Project in Science)

Implementing the Inquiry Approach

Science education reformers have recommended inquiry as the preferred instructional method for elementary science classes because it directly engages students' thinking about a problem, usually in the form of a scientific investigation. The buzz phrase "hands-on, minds-on" science encapsulates the philosophy of many science educators who want to move classroom practice beyond the isolated use of science textbooks or predigested verification labs. (See "Inquiring Teachers Ought to Know: What Is Inquiry?" on page 12 for more information about the inquiry approach.)

Although science teaching varies in elementary schools, what often "counts" as science is reading from a science textbook or a science-related trade book, Alan Colburn points out. He explains that "those of us in the science ed biz tend to favor hands-on activities that are open-ended—something where you have to think and figure out a little bit for yourself and interpret data. You don't see a lot of that at any level." On the other hand, Colburn adds, hands-on, open-ended science is more common

Inquiring Teachers Ought to Know: What Is Inquiry?

Alan Colburn

Inquiry-based instruction encourages students to learn inductively through concrete experiences and observation rather than rote memorization, gaining problem-solving skills that will help them throughout life. In science, inquiry-based instruction is founded on several assumptions:

- Learning to think independently and scientifically is a worthy instructional goal.
- *Learning* to think independently means that students must actually *think* independently.
- Thinking is not a context-free activity. To gain a deep understanding of scientific concepts, learners must actively grapple with the content.

The inquiry approach represents a broad range of instructional possibilities. At one end of the spectrum, students make few independent decisions; at the other end, students make almost all the decisions. Science educators commonly refer to three different kinds of inquiry-based instruction: structured inquiry, guided inquiry, and open inquiry.

Structured inquiry. The teacher or lab manual might give students step-by-step instructions, but students must decide for themselves which observations are most important to record and must figure out, to some extent, the meaning of their data.

Guided inquiry. Students not only choose what data to record and interpret the meaning of those data but also design the procedure that will address the activity's main question.

Open inquiry. Students make almost all the decisions. In the quintessential open inquiry activity, a student thinks of a question

to investigate, considers how to investigate the question and what data to collect, and decides how to interpret those data.

Implementation

Teachers may face challenges in implementing inquiry-based teaching practices, largely because many students are not used to figuring out so much on their own. Teachers can make the transition by implementing changes gradually. For example, a teacher accustomed to students performing verification lab activities could remove any ready-made data tables, conduct a preliminary classroom discussion to point students in the right direction, and, after the experiment, ask students to share information about the variety and significance of the data they collected. Or if an activity's directions tell students to pour 10 milliliters of liquid in a test tube, the teacher can instead direct the students to pour "a little" liquid in the tube. Students will inevitably place a variety of volumes in their test tubes. Consequently, results may vary—prompting great possibilities for class discussion on how and why the results varied as they did.

Assessment

Formative assessment of student understanding helps teachers decide when it's time to move on to more open-ended activities and when it's time to backtrack and scaffold student understanding. Teachers' assessments in inquiry-based classrooms must stress scientific reasoning and critical thinking in addition to content knowledge. A teacher could assess students' abilities to

- **Generate open-ended, researchable queries.** Extend the experiment by having students develop further questions to investigate after interpreting their data.
- **Devise scientific procedures.** Have students come up with a procedure to address a question and situation similar to the question already investigated.

• **Interpret data.** Provide students with sample data from a given scenario and ask them to analyze the data's meaning and implications.

Source: Adapted from "Inquiring Scientists Want to Know," by A. Colburn, 2004, *Educational Leadership, 62*(1), pp. 63–66. Copyright © 2004 by Association for Supervision and Curriculum Development.

at the elementary school level than at the secondary level, where the emphasis is on learning content: "Really good elementary school science will be a hands-on kind of activity, because at that level, the emphasis is on learning to like science."

But in reality, inquiry "hasn't really infiltrated the classroom in a major way," observes Chris Ohana. Because inquiry is sophisticated and complicated, it's hard to pull off in the classroom while also covering the curriculum, she notes.

Kit-based curriculum series—like Full Option Science System (FOSS) and Science and Technology for Children (STC)—are popular, says Ohana, but they are "essentially cookbook lessons" that tell students what to do yet fail to provide insight into how science is constructed. "Their strength is that the kits motivate kids, and the hands-on experience makes science more memorable. Some kits will help kids develop inquiry skills—some are strong—but some are dogs," she concludes.

To ensure that kits promote inquiry-based teaching rather than merely entertain requires that teachers receive training in inquiry-based approaches. "Inquiry-based science is difficult to teach sometimes, even though teachers like it and want to teach it," says Alan Colburn. "It's not something that any of us were raised with, so it represents a new set of skills. The approach could also be new to students—or principals and parents—who may not be comfortable with it," so it's easy for teachers to "go back to the old ways," he adds.

Professional development is one way in which teachers can gain theoretical and practical knowledge about implementing the inquiry approach, as well as other innovative instructional practices. Many states

and schools are already using NCLB funds targeted at the preparation, training, and recruitment of highly qualified teachers to help teachers better engage in such practices.

Preparing for NCLB Science Testing

Slated to begin in 2007–2008, NCLB science testing is the next piece of the science education reform puzzle. As state education officials feverishly work on designing the annual assessments, the big question on everyone's mind is, Can such state science testing be approached as business as usual?

Most educators agree that standardized tests have a limited capacity to convey what students know. The shortcomings of a 60-minute paper-and-pencil exam become even more apparent when it comes to science, researchers say.

"Critical aspects of science—inquiry, for example—cannot be well measured or well assessed on a single, time-limited test," says Meryl Bertenthal, coeditor of *Systems for State Science Assessment*. That report, the culmination of a two-year $1.8 million National Research Council study, offers state education departments suggestions to help them reassess K–12 science testing under NCLB.

Science education researchers, like Bertenthal, have high hopes that upcoming tests will at least mark the beginning of change in how schools assess science—and ultimately influence curriculum and instruction. Whittling down and streamlining the science standards could only help the cause of learning science, the report concludes: "A potentially positive outcome of a reorganization in state standards from discrete topics to big ideas is a shift from breadth of coverage to depth of coverage around a relatively small set of foundational principles" (Wilson & Bertenthal, 2005, p. 3).

Classroom-Level Assessments

To test inquiry—that central component of good science teaching—*Systems for State Science Assessment* asks states to consider creating a system of multiple tests that assess students' abilities to frame appropriate

questions for investigation, make predictions, and evaluate claims based on evidence. One such test might be a classroom assessment that teachers could conduct over a longer stretch of time than a class period.

"Teachers could observe students doing an inquiry and evaluate their work as they continue it," Meryl Bertenthal says. "So much science requires revision and rethinking. You're gathering evidence to see what that tells you, then trying to synthesize and pull things together. That's really hard to capture on a multiple-choice test." She notes that "right now there's no ready mechanism for recording these kinds of assessments into the scores reported as part of NCLB." Nonetheless, Bertenthal says, although standardized classroom-level assessments may be hard to implement in the short term, states should make them part of a system of multiple science assessments.

Aligning Tests with Standards

According to NCLB, state assessments must be aligned with learning standards. This requirement compels states to take a hard look at how they select and organize those standards.

Typically, state science standards overwhelm educators with a welter of topic-based information to teach—mostly disconnected facts, formulas, and procedures. The study committee behind *Systems for State Science Assessment* wants this to change, suggesting that standards—and therefore instruction and testing—should help students focus on big ideas in science (Wilson & Bertenthal, 2005).

Big ideas, in turn, are often best understood within the context of a "learning progression" of other big ideas. For example, to eventually understand the concepts of matter and atomic molecular theory, a student at the elementary school level should first understand that the physical world around her consists of material that can be described, measured, and classified according to its properties. Next, the student learns that such matter can be transformed—but not created or destroyed—by chemical and physical processes, such as decay or erosion (or, closer to home, chewing her food).

At the secondary level, the student builds on these earlier notions, moving her understanding to the molecular level. She learns that matter consists of atoms bound together into molecules, which determine the properties of the material; that such properties can alter due to both changes and underlying continuity in the atoms and molecules; and, finally, that the properties of atomic and molecular transformations are distinguished from the physical changes that occur (Wilson & Bertenthal, 2005). This learning progression takes into account the development of a student's thinking as it moves from the concrete to the general to the abstract, an important capacity for understanding atomic-molecular theory (Smith, Wiser, Anderson, Krajcik, & Coppola, 2004).

Although *Benchmarks for Science Literacy* has mapped out learning progressions for major science concepts, further research is necessary to determine the age-appropriate introduction of material recommended by standards documents (Smith et al., 2004). States also need to solve the potential problem of the disconnect between the "cognitive demands" of the standards and the reality of the actual test, says Meryl Bertenthal. "In science, a lot of standards ask that students be able to analyze, understand, conduct, *do* things," she points out, but standardized tests tend to take the low cognitive road of "identifying, defining, and calculating."

It's unlikely that most states will iron out all these issues in the early rounds of state science testing, but as testing continues and "states have time to think about it," the recommendations of *Systems for State Science Assessment* will have more influence and be more useful, says Bertenthal.

Reflections ◆ ◆ ◆

In this chapter, we learned that various forces both from within education (such as NCLB) and from without (such as global competition) are combining to give a new push to K–12 science education reform. Through the practice of inquiry-based science, a reform promoted by *National Science Education Standards,* even young students can learn about the authentic enterprise of science: reasoning based on evidence from the natural world.

2 Planning a Curriculum of Essentials

I'm astounded by people who want to "know" the universe when it's hard enough to find your way around Chinatown.

—Woody Allen

In Chapter 1, we learned that state science standards tend to be too long, too detailed, and too unwieldy. No wonder educators fear the prospect of being responsible for teaching each one, down to the last detail! According to science education experts, districts need to take a commonsense, less-is-more approach to using such standards to organize their curricula.

"There's another way of looking at the standards if you look at them at the national level—at *Benchmarks for Science Literacy* or *National Science Education Standards*—they really propose much less than the attempted curriculum [of many states] in terms of the number of topics, concepts, and skills to master," contends George Nelson.

Nelson ought to know. A former astronaut and founding director of Project 2061, a science education reform group that has been calling for greater rigor and coherence in K–12 science teaching, he's now leading a regional research-based science education reform project in Washington State called the North Cascades and Olympic Science Partnership (NCOSP).

As Nelson describes a typical standards-based unit on the cell, a student gets "a big picture of this flat thing that's supposed to be a cell. It has 20 different little gizmos inside—and the student has to memorize

terms like *endoplasmic reticulum*, *golgi bodies*, *nucleus*, and all the other pieces that are there."

In contrast, *National Science Education Standards* and *Benchmarks for Science Literacy* just explain "that the cell is the basic unit of life and carries out all the same functions that life does and that there are a lot of subunits in the cell that carry out these functions," Nelson notes. These functions help the cell fulfill its need for food, water, and air—the same needs of all living organisms. Nelson points out that the national standards "don't say anything about their names. So learning the names of all these parts of the cell—which is often the main learning goal now—is irrelevant. What's important is how life works."

This kind of standards-based teaching tends to obscure a subject's central concept, says Nelson: "Another big idea is that *plants make their own food*. That's what photosynthesis does. Yet students learn all about photosynthesis and the chemical reactions that take place, but never come away with the idea that plants make their own food—which is the important piece about photosynthesis."

Nelson suggests that for deeper understanding, it's more worthwhile for students to spend their time on mastering larger concepts instead of the "easier-to-test trivia kinds of things": "You can think of standards as giving you permission to teach less, better—to say, 'We don't have to cover all this mind-numbing trivia that's in the current materials. Our tests don't have to be about vocabulary words and algorithms.' Instead, tests can be about conceptual understanding and about the nature of science—the nature of the enterprise—and still satisfy the requirements of the standards and the [NCLB-driven] tests. Standards really give you freedom to make 'less is more' a reality."

Many state science education officials believe that NCLB-mandated testing will give states the incentive to reassess and revise their own science standards while helping K–12 teachers to align their teaching to these standards. But that outcome remains to be seen.

"If the teacher focuses too much on the facts that are within those standards and fails to deal with the nature of science and the attitudes and dispositions needed for science, it will move science teaching in the wrong direction," warns Brett Moulding, state science education specialist for

Utah. "Especially at the secondary level," he notes, "state assessments will cut across many branches of science, so teachers must help students to understand major concepts—for example, the laws for the conservation of mass." At the elementary level, teachers need to help students understand that general concepts such as *change* and *constancy* undergird many science topics, from weather, to the rock cycle, to the changing states of liquid, solid, and gas.

In an effort to promote deeper learning of major concepts, many states and districts are adopting a curriculum approach known as *backward design*.

Importance of Backward Design

In their book *Understanding by Design* (2005), Grant Wiggins and Jay McTighe make the case that backward design can correct the excesses of what they call the "twin sins" of traditional curriculum design. The first sin encompasses activity-oriented curricula that offer engaging, "hands-on" experiences that lack an explicit focus on important ideas. Teachers committing the second sin—"coverage"—make a heroic attempt to march students through a curriculum or a textbook within a prescribed period of time, focusing mostly on memorizing facts.

In contrast to these approaches, backward design "begins with the end in mind, and designs toward that end" (Wiggins & McTighe, 2005, p. 338). Backward design consists of three stages:

- **Identify desired results.** Review teaching goals, content standards, and curriculum expectations. Then prioritize these by focusing on what students ought to know, understand, and be able to do within the framework of "big ideas."
- **Determine acceptable evidence of achieving desired results.** Evidence can include summative assessments, such as end-of-teaching tests and culminating tasks, and formative assessments, such as quizzes, performance tasks, projects, observations, and student self-assessments.
- **Plan learning experiences and instruction.** Make appropriate choices about teaching methods, lesson sequence, and resource materials

with the dual aims of guiding students to perform effectively (stage 2) and achieving the desired results (stage 1).

Backward design theory is influencing the development of new science curricula in the IQWST (Investigating and Questioning our World through Science and Technology) project. A collaborative led by the University of Michigan and Northwestern University (in partnership with other universities and Project 2061 of the American Association for the Advancement of Science), IQWST is currently piloting curricula for students in grades 6–8 in the Chicago and Detroit public schools, as well as in the independent Greenhills School in Ann Arbor, Michigan.

In IQWST, backward design—known as *learning goals–driven design* within the project—steers teachers to first ask, "What do I want my students to know?" says Joseph Krajcik, a University of Michigan science education professor who helps lead the project. Krajcik's group advocates that those writing curriculum start with a standard and then "decompose and expand or articulate" it. Decomposing the standards begins when curriculum writers ask three questions:

- What prior knowledge do students need to understand the standard?
- What preconceptions do students have about the standard?
- What sequence of concepts do students need to understand the standard?

For example, a 7th grade IQWST unit called "How Can I Make New Stuff from Old Stuff?" asks students to understand the nature of chemical reactions with the following descriptive standard:

> **Standard:** Students will understand that substances interact to form new substances and that the elements composing them combine in new ways. In such recombinations, the properties of the new combination may differ from the old.

The curriculum writer would first "decompose" the standard by determining what other learning it requires. For example, to understand a chemical reaction, students need to know the meaning of the terms *substance, interact, element, composing,* and *recombination*.

Next, to develop the learning performances that will indicate a student's grasp of the standard, "we typically cross a content standard with a practice, such as scientific explanation," Krajcik notes, because "we want kids to write scientific explanations that say, when they see a phenomenon, why it is indeed a chemical reaction, and also be able to say *how* they know." The following learning performance ties the standard of understanding chemical reactions to the practice of scientific explanation:

> **Learning Performance:** Students construct a scientific explanation by *stating a claim* (i.e., whether a chemical reaction occurred); *showing evidence* (i.e., in the form of properties before and after the reaction); and *explaining the reasoning* (i.e., tying the claim and evidence together to show that the new properties are evidence of a recombination of the old substances).

Learning performances may also require evidence of lower-level cognition, such as *defining* or *describing,* but the emphasis in the IQWST curriculum is to link standards to such higher-order practices as modeling, analyzing data, and representing knowledge in different ways, Krajcik says.

Anatomy of a Kit-Based Curriculum

Virginia is one of a handful of states that got high marks for their science standards from a recent comprehensive study sponsored by the Thomas B. Fordham Institute. Virginia's Standards of Learning (SOL) "can be read with profit—even, in places, with pleasure—by a literate layperson. It was written to be read, and not just by state or school employees who *must* read it," reports *The State of State Science Standards 2005* (Gross et al., 2005).

Fairfax County Public Schools, home to a diverse student population of 160,000, is one Virginia school district that strives to align local science curriculum with Virginia's well-organized standards. At the K–6 level, Fairfax uses 21 science kits designed and field-tested by teachers in the district. Each grade typically uses four kits in a year, one for each nine-week quarter. Each kit cycles through the 5Es learning model—engage, explore, explain, elaborate, and evaluate. Examples of such kits include a 2nd grade kit that provides toy cars, LEGO Dacta blocks, and magnets that students use to build devices that demonstrate the nature of motion and magnetism; a 5th grade kit has students activate yeast to show how organisms grow under the right conditions.

By creating its own kits, teacher manuals, and student guides rather than relying on commercial science kits, Fairfax can tailor its curriculum materials to state standards. Yet using a kit-based curriculum does present a variety of challenges, according to school officials. Parents and principals have occasionally voiced discomfort about the lack of grade-level textbooks, which are a regular feature of science classes in the district's secondary schools, says Stephanie Roche, Fairfax County's elementary-level science coordinator.

Curriculum specialists also believe that teachers could better use science kits to focus on key content issues. "Hands-on investigation is a very effective way for students to understand big concepts," Roche says. Yet without reflection, students "may not see the connections to the big idea." She adds that "science specialists in the county decided that teachers need to give kids time to reflect. Now we're trying to encourage teachers to do that."

Fairfax elementary students typically use "interactive notebooks" to reflect during science class. Students use the right-hand page for class notes or vocabulary terms and the opposite page for their reflections. These reflections can take a variety of forms. An older student might write about how understanding electricity or the water cycle will affect how he uses those resources in the future. Students might also draw pictures of what they learn or even cut out magazine pictures to illustrate a concept. For example, students can show how energy is transformed by cutting out photos of different household appliances and writing

captions that describe where the transformation takes place. Teachers might also ask students to write about the questions that were raised in their minds and what they would like to learn more about. A teacher's review of all the notebooks can help gauge student understanding and areas needing reteaching. But these notebooks mostly benefit students.

"The beauty of interactive notebooks is that the students keep them over the years. The 5th graders can use their 4th grade books to review before an SOL test, for example—it brings up their prior knowledge in a personal way," Roche says.

The district is also trying to meet teachers' requests for more science resources. In the coming year, 6th graders will be using a science textbook as a supplementary resource. "I don't want teachers to use the textbook from beginning to end," Roche insists; rather, teachers ought to "pick and choose" what students should read to enrich their understanding of a concept. "Teachers felt that they needed a strong resource—not that they didn't have them," Roche observes, referring to the science trade books, Windows on Science videodiscs, and relevant Web sites already in use. But she admits that students could benefit from the detailed information that textbooks provide because "by 6th grade, the concepts in science are getting more abstract." District curriculum specialists also believe that textbook use will provide an appropriate transition to middle school.

To facilitate this new approach, the teacher's manual for a new 6th grade weather unit kit will include references to relevant parts of the textbook. Technology will also be an integral part of this unit. Each Fairfax County elementary school has a license to WeatherBug Achieve, a Web site where students can monitor real-time weather—not only in the 35 district schools that have their own weather stations, but also through participating schools across the country. "Twenty years ago it was difficult to get a lot of weather data [in a school], but now we have so much that we can really get students to understand, analyze, and use the data," in science class and beyond, Roche says. For example, one elementary school has an internal TV program with a weather feature that enables

students to become weather forecasters by making predictions on the basis of real data.

Teacher involvement, Roche suggests, makes Fairfax's science curriculum highly effective. Teacher volunteers pilot the kits in the field, work with science specialists to write the curriculum, and train other teachers. "When teachers are involved with designing the lessons from beginning to end, then they understand the complexity of the lesson and know its most important aspects," Roche observes. That knowledge benefits not only colleagues but also the students they will be teaching.

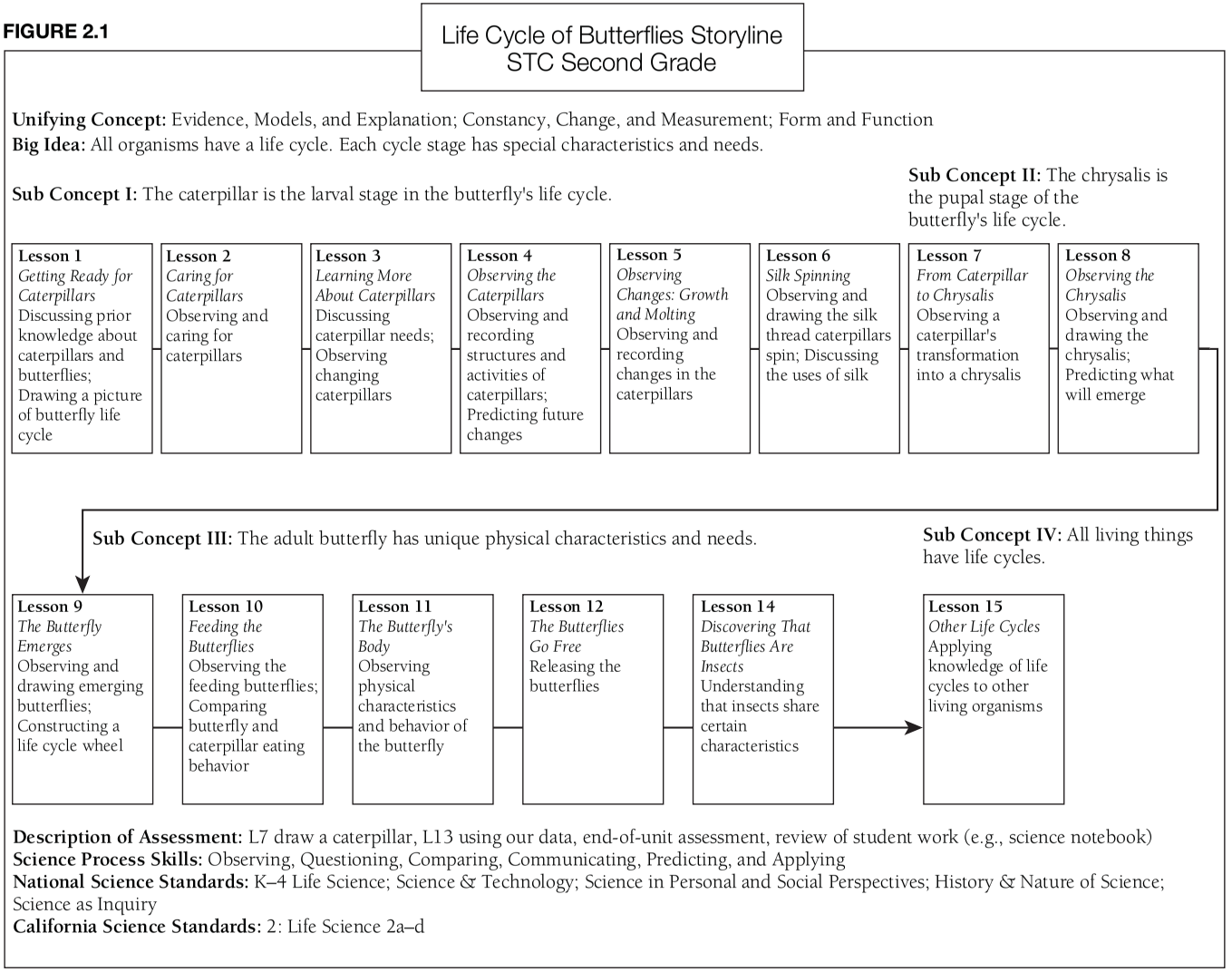
Storylines: Reading Between the Lines of Big Ideas

Writing storylines is a strategy some districts use to make state and local curriculum goals explicit, especially when using kit-based curricula. To clarify a typical science kit module's content goals in relation to California's science standards, El Centro Elementary School District has reconfigured the commercial curricula it uses into graphic organizers called *storylines*. Typically, storylines first point out big ideas, such as the 4th grade–level concept "Electricity and magnetism are part of a single force." Then the storyline weaves a coherent connection among a unit's lessons, often grouping them by subconcepts. Finally, each storyline is linked to state and national science standards and science process skills.

For example, the big idea in the Life Cycle of Butterflies storyline for 2nd grade is "All organisms have a life cycle; each cycle stage has special characteristics and needs." Subconcepts include understanding that the caterpillar is the larval stage, the chrysalis is the pupal stage, and the "adult butterfly has unique physical characteristics." During the unit's 15 lessons, student activities focus on observing the various stages of the butterfly's life cycle and applying this learning to understanding insects and other organisms (see Figure 2.1, p. 26).

Nonetheless, bowing to the fact that teachers still face a time crunch —even with a well-ordered curriculum—El Centro is revising its storylines so that teachers will know which lessons they can drop and still

FIGURE 2.1



Source: "Life Cycle of Butterflies Storyline." Copyright © 2000 by Valle Imperial Project in Science. Reprinted with permission.

meet the California science standards for that grade level, says El Centro's science coordinator, Elizabeth Molina-De La Torre.

The revised curriculum is driven by the principle of *scaffolded inquiry,* which outlines a sequence of content goals and activities in the context of the district's use of commercial science kits, science notebooks, and the California standards (see Chapter 5, pp. 87–93).

El Centro superintendent Michael Klentschy says such scaffolded inquiry gives students a series of coherent activities that lead them—"almost in staircase fashion"—to the big ideas in science. "This is a more effective way of teaching for understanding," Klentschy says.

A group of 4th grade students, for example, would have some leeway in deciding how to combine their share of batteries, bulbs, and wires in a unit on building series and parallel electrical circuits, but their investigation is guided by the structure of the science notebook process, which involves a good deal of support from the teacher. Although scaffolded inquiry might fall under the rubric of guided inquiry, Klentschy notes that "it's kind of a cross between guided and open—maybe we could call it 'guided-plus.'" He points out that in a standards-based world, it's imprudent to allow students to do "pure inquiry," which can get reduced to "kids floating around doing a series of unrelated activities based upon what they want to do."

Rhode Island's East Bay Educational Collaborative, which serves eight school districts, has also found that using storylines with kits helps teachers keep crucial science concepts and their links to one another always in view, even as students advance through the grades.

Science resource specialist Ron De Fronzo ensures that every elementary teacher who attends training on how to use science kits gets a complete K–6 set of storylines tied to 20 kits: "I point out to them that the kit is organized around one or two big ideas in science that they need to be very purposeful about—they should constantly be bringing the students back to the big idea."

De Fronzo recently revised all storylines to align them with Rhode Island's state science testing program. Storylines now highlight lesson links to the state test's assessment targets and grade span expectations, so teachers will know that they're covering what will be tested. He points

out that teachers who have seen the revised storylines with the new state information have embraced them "as a source of relief" from the pressures of not knowing whether they were emphasizing the right topics in their science lessons.

For example, De Fronzo describes a kit used for a 3rd grade unit on sound that was unpopular with teachers. The concepts were too difficult for 3rd graders, the activities were too abstract, and teachers couldn't see how the unit aligned with content from either previous or subsequent grades. But after Rhode Island's new testing program revealed a strong emphasis on the concept of energy and how it can be stored, transferred, and transformed, teachers started viewing sound from an energy perspective. Suddenly it became much clearer to them that the 3rd grade unit on sound had strong connections to both the K–2 units on forces and motion and the 4th grade unit on electric circuits. The sound unit finally had a place in the curriculum.

De Fronzo notes that "the new storyline we've written for the sound kit clearly shifts the emphasis from sound as simply a matter of vibrating objects to sound as one of many forms of energy which can change to other forms. When the sound unit is organized under the big idea of energy, it readily connects not only to the motion of vibrating objects but also to how other forms of energy, such as electricity, can be transformed into sound—in radio, for example."

Curriculum Reform: Professional Development Is Key

Professional development can stimulate standards-based curriculum reform because it leads teachers to a better appreciation of the conceptual connections among grade levels, say educators who have experienced powerful professional development.

"In the trenches, it is so easy for teachers to not even know what other grades are teaching, much less understand its importance," laments Washington State 5th grade teacher Marj Hendricks. She has seen prior district reform efforts spring up only to wither before any real change occurred.

Efforts at science curriculum reform in Lynden School District 504 in Washington began all the way back in 1992 with a backward design plan that began with "what should all 12th grade graduates know and be able to do in science," says Hendricks, who was involved in the original plan.

In the hopes of moving out of the "inch-deep, mile-wide" curriculum syndrome, Lynden's earlier reform managed to ditch coverage-heavy textbooks in favor of three or four main units per grade with accompanying Full Option Science System (FOSS) kits. But because of staff turnover, the streamlining and articulation of the science curriculum lost steam, so "our scope and sequence was almost nonexistent in science," Hendricks says. "Until this year, we have been rather weak in accountability for what is being taught, so science instruction has been strong in some classes while nonexistent in others."

Change has begun again because of Lynden's involvement in the North Cascades and Olympic Science Partnership (NCOSP), a K–16 project that aims to train educators to teach science deeply at all levels. In anticipation of NCLB-mandated testing, curriculum adoption has gotten a just-in-time boost through this professional development model. A team of district educators, including Hendricks, are now using what they've learned about aligning instruction with content standards and grade-level expectations to influence a newly invigorated curriculum adoption process.

Science teachers are once again conversing about the state of science and using *Benchmarks for Science Literacy* and *Atlas of Science Literacy* (copublished by Project 2061, an initiative of the American Association for the Advancement of Science, and the National Science Teachers Association) to guide their understanding of what students should know and be able to do in the various fields of science at different grade levels, Hendricks says. "Without the NCOSP grant, I doubt we would have even been aware of the Project 2061 work," comments Hendricks, referring to that group's *Benchmarks* and *Atlas* publications.

As a Teacher On Special Assignment (TOSA) through the NCOSP project, Hendricks received training in science curriculum and instructional practices, which she then brought to other schools in her district.

She emphasized the value of curriculum alignment, pointing out that just getting kindergartners to focus on observation skills helps ensure that they will be well prepared for science by the time they reach 5th grade.

A streamlined and well-articulated curriculum could also offer "awesome" opportunities for professional development across grade levels, Hendricks points out. Through the NCOSP project, Lynden School District 504 is already reaping the benefits of this K–16 professional development model that involves teachers in shaping and delivering the training (see Chapter 6, p. 103).

Hallmarks of a High-Quality Curriculum

According to differentiated instruction expert Carol Ann Tomlinson, schools need curricula that prepare students to live in a fast-paced society that values such high-level skills as problem solving, ethical decision making, and self-initiative. This imperative is even greater for teachers of math and science, the subjects Tomlinson calls "the gatekeepers of opportunity" (2004, p. 4). A successful curriculum both engages students and promotes deep understanding. Curriculum that engages students

- Is fresh and surprising to the student.
- Seems "real" and purposeful to the student.
- Connects with the student's life and focuses on products that matter to the student.
- Allows choice.
- Requires active learning.
- Is pleasurable or satisfying to the student.
- Taps personal interest.
- Allows the student to make a contribution to something beyond self.
- Challenges the student while providing support to achieve success.

Curriculum that promotes understanding

- Focuses on the essential knowledge, understanding, and skills that a professional in that field would value.
- Allows the student to see its coherence—that it is organized, unified, and sensible.
- Addresses student misconceptions.
- Deals with profound ideas that endure across years of student learning.
- Enables the student to use what he or she learns in important ways.
- Requires cognition and metacognition.
- Causes students to grapple with significant problems.
- Helps students to raise useful questions.
- Requires that students generate rather than reproduce knowledge.

Although even the best teachers won't hit all of these indicators in every lesson, teachers should work toward fulfilling them "consistently and persistently" (Tomlinson, 2004, p. 4).

Ultimately, a well-organized, high-quality elementary science curriculum provides students with a solid understanding of important concepts, familiarity with science processes, and an appreciation for the scientific enterprise. After two years of fairly intensive professional development, teachers in Washington's Lynden School District 504 are getting a glimpse of the effect that strong curriculum paired with sound instruction have on student learning.

For example, in 2006, Lynden 5th graders held a "Science Investigation Conference" rather than a science fair for which each student was responsible for conducting a science experiment. Teachers who had been trained in experiment design through the use of inquiry boards—a practice that uncovers the logical process behind changing a variable during an experiment (see Chapter 6, pp. 101–103)—passed this powerful strategy on to their students. In addition to performing their own

experiments, each student was required to evaluate two other investigations, using appropriate scientific terms.

"This was so much better than our science fairs of the past that often were more projects and demonstrations than experiments," Hendricks says. "I was amazed. My Hispanic students, my special education students—all students—were successful and are much more familiar with setting up and conducting an experiment than ever in the past."

Reflections ◆ ◆ ◆

When devising a science curriculum, schools should focus on getting all students to understand the big ideas for the topics studied. Curriculum designers can use backward design to align assessment and instruction with those big ideas. Because big ideas often rest on other big ideas and prior knowledge, outlining a progression of required prior understanding can also help teachers keep moving toward an important concept without getting bogged down by secondary factoids that may divert students from essential learning.

Bringing the Curriculum to Life in the Classroom

3

Men love to wonder, and that is the seed of science.

—Ralph Waldo Emerson

In a standards-based world, elementary science teachers have their work cut out for them. Not only must a teacher's content knowledge include the main branches of science—life sciences, physical sciences, and earth and space science—but the teacher must also have a grasp of scientific inquiry to make class investigations meaningful.

In districts that pursue hands-on science—an essential component of standards-based science inquiry—science kits have become more commonplace. The advantages are obvious: kits supply the materials for experiments and outline the procedures for the teacher.

The use of kits with prepackaged materials can ease classroom management issues in science classes. (Photo courtesy of Terry Wilson)

"At the elementary level, we're more generalists, especially in the content areas. The kits help us become content experts. This in turn helps the students to inquire more effectively," says Connecticut teacher Terry Wilson. Nonetheless, she believes that kits are just one facet of good science instruction. Curriculum, not kits, should drive instruction, Wilson says.

Bob Chaplin, who, like Wilson, is a recipient of the 2004 Presidential Award for Excellence in Mathematics and Science Teaching, agrees that teachers must use a variety of instructional practices to teach science effectively, echoing critics who fear that an overemphasis on open-ended discovery practices might leave students content-deprived.

"There has to be a balance in the approach to teaching science in the elementary school—this would include textbooks to read for content, individual learning stations, kits for hands-on experiences, technical writing, and field experiences. What determines the mix has to be directly related to the unit being taught," says Chaplin.

For example, during a unit on simple machines, students build models from LEGOs. These models show students "how a simple machine, such as gears, can make work easier, and they gain concrete engineering experience," says Chaplin. As they construct their models, students also write journal entries to document their thinking, thus helping to develop their working vocabulary for simple machines.

In contrast, for a unit called "You Are the Expert Zoologist," students complete much of the project on the Internet, researching a mammal, a reptile, a fish, an amphibian, or a bird. They gather information about an animal's range and biome (a major ecological community type, such as rain forest or tundra), habitat, life span, appearance and adaptations, diet, and breeding. Students select and summarize the information and attach it to models that they have constructed of their chosen animals. A student's model can be anything from a realistic six-foot-long stuffed cloth sculpture of a minke whale to a simple cardboard-and-poster-paint lizard.

Teachers of these units promote learning by varying the means with which they deliver instruction, and the projects are effective because

they capitalize and build on students' diverse strengths in reading, writing, conducting research, and engaging in hands-on experiences.

The following examples demonstrate how experienced, enthusiastic, and award-winning educators are successfully teaching science in their elementary school classrooms. They prove that the seemingly impossible feat of finding a place for standards-based science in a crowded elementary curriculum is not only possible, but also possible to do well.

Starting Out: Attitude and Basic Goals

Among the teachers interviewed for this book, some came to a love of science early in life, as children, college students, or science professionals in industry. Others developed and nurtured the "science bug" only after they were faced with a sea of students and realized how much more they had to learn.

Fifth grade science teacher Bobbie Sierzant advises elementary teachers who feel inadequately trained in science to move beyond the fear of teaching the subject by joining forces with students. "When kids start asking 'Why is the sky blue?', teachers may feel that they can't give students a thorough or age-appropriate answer, so they feel threatened and decide that they don't like teaching science," says Sierzant. Instead, she suggests, tell students, "'I don't know, but let's find out.' Children will respect that."

Terry Wilson, who teaches 5th grade at Myrtle H. Stevens Elementary School in Rocky Hill, Connecticut, urges elementary teachers to "express your own enthusiasm for science—it's contagious!" She also suggests relating curriculum content and investigations to the world that students understand. For example, the study of motion and force offers a chance to talk about amusement park rides, and learning about floods brings to mind local rivers and swollen backyard creeks. Wilson notes that "most kids are enthusiastic about science because it is hands-on. In the past, it was rare for kids to conduct their own experiments." She recommends that teachers take advantage of this shift in practice.

Pita Martinez-McDonald, who came to truly enjoy science after mid-career professional development, wants her 5th graders "to love science

and make it their favorite course." She wants students to understand that science is more than "doing" an investigation, as enjoyable as that might be. Science also includes gathering and analyzing data, writing, and making connections between experiments and ideas. Not every student is convinced that science goes beyond investigation, but Martinez-McDonald has ambassadors for science in her class who wholeheartedly tell their classmates, "This *is* science!" even as they crunch data.

Teachers, no strangers to going the extra mile for students, should also be open to students' initiatives or inconvenient questions, say educators. An open attitude encourages students' spirit of open inquiry. Sierzant recalls that when one student brought in an unknown seed and asked her for some soil to grow it at school, she spent a free period on an already busy day tracking down potting soil and a container for the student. "It's so important for us to stop when children ask us to do something for them—or else they will stop asking us," she says. "They're often really just simple things." By going out of his or her way in small ways, a teacher acknowledges and affirms students' interests and thinking.

If thinking is to flow freely in a science class, teachers also need to show students how to respect one another's ideas. Building understanding and trust in the classroom takes time, says 4th grade teacher Tanya Siwik. Early in the school year, she tells her students that if a classmate is sharing ideas that strike them as strange, students must quickly decide, Is my classmate trying to be funny? Or is he or she dead serious? If it's the latter, then the class must respect that and receive the idea seriously.

Inquiry in Practice: Preparing the Ground

Science education professor Alan Colburn views inquiry-based instruction as a happy medium between the two extremes of cookbook science and discovery learning (Colburn, 2004). At the cookbook end of the spectrum, students follow a "recipe" to duplicate an experiment and arrive at a foreseen outcome. On the discovery side of the spectrum, students receive lab materials, minimal teacher guidance, and plenty of encouragement to discover concepts by themselves and enjoy the experiment (Lawlor, n.d.).

Inquiry-based instruction itself ranges along a spectrum that includes structured inquiry, guided inquiry, and open inquiry. A class's level of inquiry depends on how much leeway students have to define the main question, as well as on the scope of their investigation.

As the following examples show, inquiry in the science classroom takes a variety of forms. Teachers can foster certain skills common to all scientific inquiry—forming questions, gathering and using data, and sharing explanations, for example—while understanding that varied approaches to investigation reflect the differences among disciplines within science, such as biology, chemistry, and earth and space science.

At the beginning of the school year, Terry Wilson uses a series of "starter" guided inquiry lessons to gauge her students' abilities to think scientifically—to observe, question, make predictions, solve problems, and reflect—and to work cooperatively. In guided inquiry, the teacher usually provides the materials and defines the questions to explore, but students largely determine the procedures for finding answers and interpreting data.

The first activity is simple. Wilson gives each student a cardboard toilet-tissue tube and instructs everyone to cut along its diagonal seam. Before students begin, however, they must each predict and draw what they think the cut tube's shape will look like. Wilson also asks students to offer evidence for their prediction. Even though students are afraid to make mistakes, she says, "I tell them with science—or with anything—don't be afraid to have an opinion, or a prediction, or to make a guess, or to wonder about something—even if it's wrong, that's OK." After cutting the cardboard tubes, students may be surprised by an unexpected outcome, pleased when a prediction was close, or puzzled when their thinking falls wide of the mark.

Another "starter" lesson fosters inquiry through collaboration. Early in the school year, Wilson invites teams of students to design and build the tallest possible straw structure that can support the weight of a large egg. Each group of two or three students receives 25 straws, 36 inches of masking tape, 1 egg, and only 45 minutes to complete the task.

"The students enjoy this challenge for many reasons. It's empowering because there isn't one correct design, and they can approach this task

Collaboration fosters inquiry and feelings of satisfaction, as these students who designed a structure under material and time constraints discovered. (Photo courtesy of Terry Wilson)

from a variety of angles. They have choices and the freedom to make decisions—good or not so good," Wilson explains. Sometimes, "they try to get me to commit to a specific answer, which I manage to avoid." For example, when students ask Wilson, "Does the egg have to be at the top?" she lobs the question back into their court with, "What do *you* think?" After completion of this project, teams reflect and share with the class why the designs were or were not successful.

Inquiry in Practice: 1st and 2nd Grades

Learning to Love Nature

Nicole Groeneweg's multi-age classroom of 1st and 2nd graders is a riot of colorful, purposeful artwork. Snaking along one wall is a student-made alphabet featuring drawings of intensely saturated colors that depict words linked to the four seasons—"Aa" for *autumn*, "Cc" for *cherry blossom* and *crocus,* "Ii" for *igloo,* and so on. Across the room on a countertop lie student-made books whose covers feature crayon drawings of well-known historical figures like Benjamin Franklin and Martin Luther King Jr. A long table at the front of the classroom displays fruits of the forest: cross-sections of tree trunks revealing annual rings,

a hollowed-out trunk with a toy squirrel perched in the opening, file folder–sized strips of brown and white bark, and pinecones of every shape and size. Picture books stand nearby for the taking, ready to help explain it all.

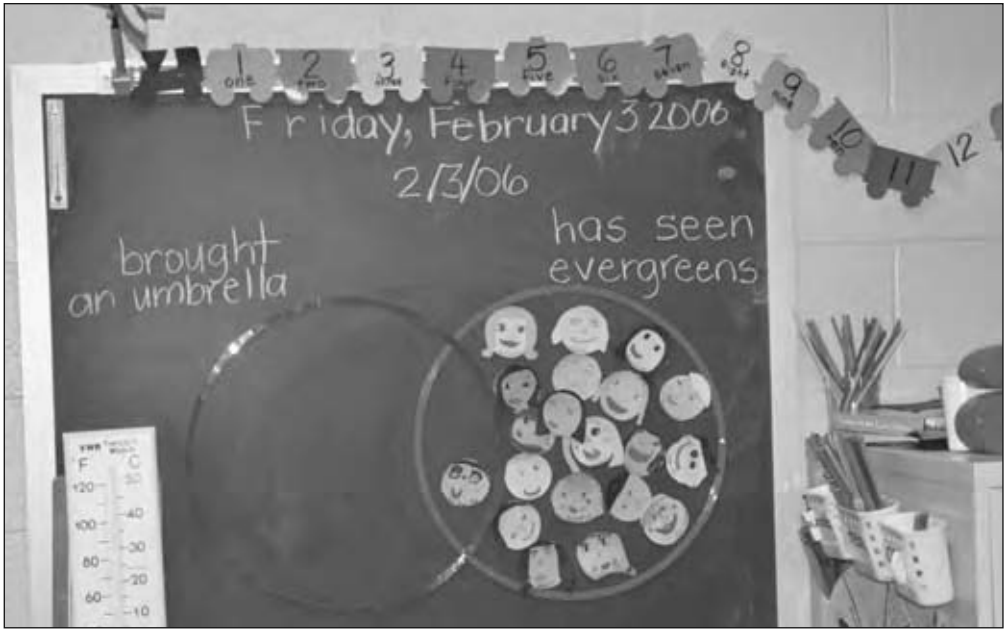
Groeneweg, who teaches at Anthony T. Lane Elementary School in Fairfax County, Virginia, loves art and nature, and science allows her to encourage those passions in her students. The study of nature predominates in the science curriculum for her primary-grade students. Students will learn about life cycles, animals and their environments, and the effects that weather and the changing seasons have on plants, animals, and people. "I want [students] to really love nature," Groeneweg says. "And I want them to know that we cause problems in the world, but that we can do things not to cause problems—that we can help nature."

Groeneweg figures she teaches five hours of science weekly, including integration with language arts, math, and art. "You have to integrate to get all the content covered—life is all intertwined anyway, so it shouldn't be separated," she affirms.

Revealing Evergreens

A good example of Groeneweg's inquiry approach in action is her science class on evergreens. To start the lesson, Groeneweg asks her 6-, 7-, and 8-year-olds if they ever have seen one. Students respond to the question by placing construction paper drawings of their faces onto the appropriate circle of a large Venn diagram on the board. (The other circle in the diagram represents students who brought an umbrella to class that day.) Next, Groeneweg poses and examines three questions that probe possible misconceptions and add elements of intrigue to the topic. She has written the questions on a large tear-away pad that serves as the focal point for the writing segments of the science class.

To answer the first question—"Do evergreens have leaves?"—Groeneweg takes another quick survey. Students transfer their paper faces from the Venn diagram to the appropriate column on a floor-poster bar graph. Nine students believe evergreens do have leaves; eight students believe that they do not. Next, from a plastic shopping bag contorted with a trove of different evergreen branches, Groeneweg pulls out a pine



In Nicole Groeneweg's class, students quantify their data visually. (Photo courtesy of Stephanie Roche, Fairfax County Public Schools)

branch and hands it to the semicircle of students sitting on the floor. One student says the branch is full of "thorns," another student says it's covered with "needles," and a third tentatively declares that they are "leaves."

One student, Avneet, suggests that a book might help the class answer the question. Even these young students see science learning as a combination of direct observation and reading for information. After reminding students that they can get the picture book in her hands from the school library, Groeneweg reads from Susan Canizares's *Evergreens Are Green* to establish that such trees do in fact have leaves—some needle-like and others broad and flat, resembling more typical leaves. Groeneweg finally asks students for a "complete sentence" that she can write on the display pad as their response to this first question.

Students dispatch the next question—"Do evergreen leaves fall?"—more quickly, as they share that evergreen needles turn brown, or fall off when you give the tree's branches a good shake. The students decide that evergreen leaves don't fall in autumn; actually, they're not entirely convinced that the trees shed much at all.

As she passes flowerlike clusters of lustrous magnolia leaves to the students, Groeneweg invites them to describe the physical traits of those leaves. The leaves are green, and shiny, and thick, say the students. Gabriella notices the magnolia leaf is "waxy" on one side—like the crayon resist artwork they created for their biographies of historical figures.

Groeneweg commends the students, obviously pleased with the connection Gabriella made to another subject. The remark also provides a convenient segue into a hands-on activity that will reveal part of the answer to the third question: "How do evergreens stay green all year?" Groeneweg's science class is a study in choreography for young learners as they move back and forth between sitting on the floor for whole-class activities and writing and drawing at their tables. The cycle repeats several times in this two-hour block period.

Leaf Models

Working at their tables, the students put precut "leaves" made of green construction paper into wax-paper bags. With a medicine dropper, each student draws a few drops of water and dribbles them into the bag. The paper leaf absorbs the water and is shielded from evaporation by its wax covering. This activity demonstrates how the waxy coating of evergreen leaves and needles keeps water inside throughout the winter—one key to staying green year-round. Groeneweg tells the students that the evergreen's special ability to retain water through the harsh, cold winter is similar to that of the classroom cactus, sitting on the window ledge and rarely needing water. Leaking wax bags caused confusion for some students, so in the follow-up meeting, the class talks about what went wrong and discusses how the model leaf differs from a real evergreen leaf.

In this unit, Groeneweg fulfills the state science standards that call for 1st graders to be able to classify plants as deciduous or evergreen according to their characteristics, and to understand that water helps plants live and grow. Throughout their exploration, students draw and write about their findings in "My Evergreen Lab Book," copying what Groeneweg has written on the classroom notepad. "The notebooks enable children to review concepts and refer back when necessary," she says. "Sometimes

they will go back and revise their thinking after a unit." Such records, common for most of the class's science units, also allow Groeneweg to model correct spelling, vocabulary, and sentence structure.

For Groeneweg's students, science investigations help unlock the mysteries of the natural world around them. By examining objects from nature inside the classroom—and by getting out of the classroom to work in the school garden or visit local nature centers—even the youngest students get firsthand stimulation to observe, wonder, think, discuss, and engage in thoughtful science. Groeneweg believes in deploying students' mental faculties as much as their physical ones through the five senses. "Hands-on science is essential because they discover things themselves," she says. "They find it more fulfilling, so they're more apt to learn."

Inquiry in Practice: 3rd Grade

Science and Literacy

In the push for standards-based reform in reading and math, science "can be left in the dust," says elementary science curriculum specialist Karen Ansberry. That's why she teamed up with her colleague, 3rd grade science lab teacher Emily Morgan, to write *Picture-Perfect Science: Using Children's Books to Guide Inquiry* (2006). Even in the high-achieving Mason City (Ohio) School District where Ansberry works, teachers still fret over preparation for state testing, she says.

Integrating science and literature can appeal to lower- and upper-elementary teachers for different reasons. "In younger grades, we're hooking teachers because they love literature," Ansberry explains. Meanwhile, she notes, plenty of upper-elementary single-subject teachers "don't realize that readers may still struggle and need constant reinforcement in the reading classroom." Embedding reading comprehension strategies into inquiry-based science strengthens students' skills in both subjects.

Embedding Reading into the 5Es Model

Ansberry and Morgan use elements of the 5Es model of instruction as the framework for the science lessons in their book. Developed by

the Biological Sciences Curriculum Study, the research-based instructional model of the 5Es—*engage, explore, explain, elaborate,* and *evaluate*—helps teachers cycle through the before, during, and after phases of a scientific investigation. Like its predecessor the learning cycle, the 5Es model relies on hands-on work, student initiative, and teacher direction to help students connect new learning to prior knowledge—what Piaget called *self-regulation* (DeBoer, 1991).

Using children's literature and reading comprehension strategies in a science lesson can be especially pivotal during the *engage* and *explain* phases, Ansberry says. During the initial engage phase, reading gives students the chance to make "text-to-self connections," a reading comprehension strategy that "activates [students'] prior experiences and background knowledge and gives them a personal interest in the reading."

One strategy to hook students in this crucial first phase is *visualization*. Ansberry and Morgan advise teachers to get their young students to "visualize and put themselves 'in' the book." For example, as students anxiously anticipate the action depicted on the cover of Brian J. Heinz's *Butternut Hollow Pond*—a hawk swooping down on a gopher at the edge of a pond—they usually also infer that the story will be about the food chain.

In a Web seminar presented by the National Science Teachers Association, Ansberry and Morgan walked 78 participants from school districts across North America through a typical 3rd grade hands-on lesson centering around owl pellets—the indigestible bits of bones, fur, and feathers that these birds of prey cough up after dinner. In the *explore* phase of this lesson, students work with real owl pellets to decipher and document the various types of animal bones and remains contained inside. But before this hands-on stage takes place, Sally Tagholm's *Animal Lives: The Barn Owl* engages students with its story of a farmer mystified by the small black objects he finds in his barn.

In another unit, Rita Golden Gelman's *Rice Is Life* appeals to students with its illustrations, stories, and poems about the rice fields of Bali. Here, during the engage phase, students learn about the global value of rice—that the grain feeds half the world's population. The hands-on explore phase that follows involves growing rice plants. At this time,

the teacher also reads aloud a nonfiction book on rice that brings in academic vocabulary and reinforces certain concepts addressed in the investigation.

During these initial engage and explore phases, teachers should be helping students to connect the *explain* phase to their experiences. This is the phase that gives students a chance to make meaning. According to Ansberry, "The explain phase is most important—if kids have not internalized what they've learned. If they can't explain it, then maybe they have not learned it." The explain phase should not be rushed, Ansberry cautions: "Sometimes we don't give kids time to explain and articulate their ideas in their own words." After learning what students have made of their initial explorations, teaches can clarify concepts, introduce or define scientific vocabulary, and correct any misconceptions that students might have gotten from the reading or investigation.

Vetting Picture Books

Although beautifully illustrated books that imaginatively portray the natural world are surefire attention-getters for children, teachers should be aware of possible misconceptions that can appear in fiction—and even nonfiction—books. In John Himmelman's *A Salamander's Life*, for example, one caption describes the salamander hunting for "insects," but the accompanying illustration depicts worms and pill bugs—the latter being, in fact, a land-based crustacean.

In *Papa, Please Get the Moon for Me* by Eric Carle, the phases of the moon are illustrated inaccurately, with the crescent moon becoming an increasingly larger crescent until it becomes a full moon—omitted are the first-quarter and gibbous phases, Ansberry points out.

"We're always careful to tell students that Eric Carle didn't write the book as a science book, so it's OK that he took artistic liberties," explains Ansberry. "The key is to be aware of misconceptions in books and to point them out and use them in a lesson." After the explore phase in the 5Es progression, students could apply their learning and say why some moon pictures might be inaccurate, she suggests. "It's fun as well as good practice."

In the 40-plus workshops that Ansberry and Morgan have led throughout the United States, the strategy of linking science and language arts strikes a chord with elementary teachers. "Teachers leave the workshop pumped. They love the literature; it makes them more excited about teaching science," says Ansberry. "It takes out some of that fear of teaching science—and makes it a lot more accessible, for them and for students."

Inquiry in Practice: 4th Grade

Flowers as Problems

For a unit covering the anatomy and life cycle of plants, a teacher might be tempted to assign a picture worksheet for students to label—with the teacher's help, of course. It's briskly efficient, but how much of the material would students really learn?

Instead, here's what 4th grade teacher Tanya Siwik does. In a carousel activity, she sets up four charts around the classroom labeled "How Plants Grow," "Products of Plants," "Parts of Plants," and "What Plants Need to Be Healthy." Each chart, a modified K-W-L chart, has a T-formation drawn on it, with a "We know . . ." prompt on one side of the dividing line and a "We want to know . . ." prompt on the other side. Divided into four groups, the students rotate around the room to fill out each chart. While students meet to "share out" afterward, Siwik uses the charts to assess their prior knowledge about plants and inform her instruction in that unit. As the unit on plants progresses, the class will refer back to the charts to fill in gaps and refine their original statements.

Other times, Siwik has played children's songs from "natural science song and dance man" Billy B. Selections include "Yo, I'm a Flower," which explains how flowers and bees work together, through pollination, to survive. Siwik then buys several big bouquets of cut flowers and plants, including lilies, carnations, ferns, and eucalyptus. Working alone in small groups, the students dissect the bouquets, carefully separating leaves, petals, sepals, anthers, stamens, and pistils and taping the parts onto 13-by-18-inch yellow poster boards. They label each part with a name and function that they make up based on their current knowledge of plants.

Ximena dissects a flowering plant to describe and label its parts. (Photo courtesy of Tanya Siwik)

The students' knowledge falls short, of course, and they reveal several misconceptions about the actual functions of flower parts. At this point, however, Siwik is not concerned that the student who recently arrived from El Salvador with little formal schooling labels many items *floreta,* or that another student mistakenly labels an anther, which produces and holds pollen, as the "nectar collector." A third student designates a dime-sized greenish-gray leaf of the eucalyptus plant as "a smelly-leaf." Getting such direct experience with materials before being formally introduced to terms and concepts helps students' learning to proceed efficiently, according to the 5Es model and to inquiry-based science in general.

Siwik's students are "making estimates," she says. Like good scientists, they will revise these estimates with further investigation and vocabulary instruction. After students share their posters within their small groups, they circle particular parts of the plants that they want

to explore further, either out of curiosity or because they are uncertain about the names or functions they have ascribed to them.

"To me, the best thing about learning is not finding the answer. The best thing about learning is finding the problem," Siwik maintains. Once students find the problem, they can work on finding a solution. It's the process, not the end result, Siwik insists, that's important. Even if students never come up with "the" answer, she says, they learn from having devised a process to attempt to solve the problem.

Dialogue—between pairs of students, among small groups, and with the whole class—is an important element of the science investigation because it stimulates further thinking. Students gather in a circle on the floor and share their plant samples, using their own terms and raising questions they still have about the plants. Juan asks, "I wonder why my smellsters smell a lot?" Siwik gently gives him the correct term *flower* to replace his own coinage. Another student wants to know the function for the "long skinny things in the flower." Siwik encourages students to take several minutes to share their tentative answers to one question that a student raised in the circle: Why do some leaves have "hair"?

A student may arrive at a result that doesn't meet a lesson objective, but, Siwik notes, the teacher can use that result to redirect the student back to the lesson. "Maybe they discover something that's never been discovered before, or they find something else that gets them researching," she says. Students write their most compelling questions and insights about plant and flower parts in their interactive notebooks—journals in which they record and make sense of information gleaned from their own investigations and from content introduced by Siwik. In essence, the notebooks become "nonfiction books," says Siwik.

The plant dissection and naming exercise prepares students for an upcoming investigative unit on "fast plants," in which students will use kits to grow plants themselves. Siwik promises students that many of the questions they have raised about plants and flowers will be answered as they watch the plants grow from seed to seed-bearing maturity in 40 days. The plant unit will cover such concepts as life processes, living systems, and scientific reasoning, as well as other content and skills for 4th grade science.

Connecting to the Environment

Cuba Elementary School sits on 250 acres of land in northwestern New Mexico. About 40 percent of the students are Navajo Nation, and the rest speak Spanish as their first language. Cuba's own Nature Trail has been a central focus of elementary science class for 12 years, says teacher Pita Martinez-McDonald, a recipient of the 2004 Presidential Award for Excellence in Mathematics and Science Teaching.

The Nature Trail is a mile-long path on school grounds with stations along the way where students can view huge ant mounds, trees, wildflowers, cactuses, sandstone, petrified wood, and the effects of erosion. Cuba Elementary has also developed a Web site extension of the Nature Trail enabling teachers to download related student activities, such as identifying wildflowers, creating a simulated cactus, or comparing animal habitats of forest, meadow, and chaparral.

"By going outside, instead of just reading about it in books, children get a much greater depth of understanding about their environment. That's the way it should be. The more students can be a part of something and manipulate it, the better they can grasp and internalize the understanding," says Martinez-McDonald.

For example, in winter, students may measure the temperature of large anthills to learn how the colony regulates the internal environment when the outside temperature regularly falls below freezing. In another part of the trail, students learn how storms can turn a sleepy little *arroyo,* or dry creek bed, into a running river. Students also work with a variety of professionals from the USDA Forest Service, the Bureau of Land Management, and soil conservation groups, who take them out on the trail weekly during the school year to learn about erosion, the role of plants, and aspects of a healthy watershed environment.

Nonetheless, literacy demands and testing pressures can make it difficult to get students to the Nature Trail. Martinez-McDonald says,

> Some years, with the pressures of testing, I'm not as committed to getting the kids outside. But I know in my heart that that is the way they learn best. If they know about their environment, and how to help take care of it, then they'll have a greater

Pita Martinez-McDonald's students write in their geology notebooks at a sandstone "station" along Cuba (New Mexico) Elementary School's Nature Trail. (Photo courtesy of Kavita Krishna, Rio Puerco Watershed Initiative)

understanding of how to live their lives. The kids in this area are so connected to the land. A majority of their grandparents have cows or ranches—and 90 percent of the Navajo students have sheep. They are going to be the caretakers of this great world of ours, and they need to know how to respect it.

The Problem with Goatheads

Martinez-McDonald knows that when her 4th and 5th graders find answers to questions about the world around them, their enjoyment of science intensifies and their engagement with content increases. Students' irritation with burrs known as "goathead stickers" provided fodder for one investigation that also drew on their math skills, taught them about plant life cycles, and prompted a change in the school environment.

Goathead stickers, whose quarter-inch spikes are sharp enough to puncture bicycle tires (the plant also goes by the name *puncturevine*),

had been the bane of the Cuba Elementary School playground. Although these painful burrs often stuck to clothing or hair, "kids really didn't *know* exactly what the goatheads were," Martinez-McDonald notes. Her class first pulled up and measured plant samples, counting the number of burrs per plant, and then arrived at an average number of burrs per square foot of ground. After calculating the playground's area, they estimated that the playground contained 17 million goatheads!

The goathead stickers of the puncturevine prompted one class's science investigation. (Photo courtesy of Forest and Kim Starr, USGS)

Some students suggested planting the burrs, but the class was still uncertain anything would come of them, "simply because goatheads were so nasty and horrible," Martinez-McDonald laughs. The pursuit of science and their curiosity got the better of the students, however.

After planting the goatheads and studying, drawing, and measuring the plants for several weeks, "there was an 'aha' moment when one student screamed, 'I know what they are—they're seeds!'" she recalls. "There was a lot of rejoicing."

With that knowledge and all their statistics under their belts, students then rallied for "a cleansing of the goathead population" and petitioned the principal to take action. Afterward, the plants were plowed under on a regular basis, and the whole playground was eventually covered with sand to minimize the number of plants. Martinez-McDonald points out that not only did the class learn the plant's growth cycle and use "a lot of good solid math, finding averages and area," but student learning and initiative also helped students to change their own environment.

Inquiry in Practice: 5th Grade

Experimental Design

If *inquiry* is the umbrella term to describe how scientists probe the natural world and devise explanations based on evidence, then *experimental design* refers to planning how such investigations can be carried out.

Helping students to understand experimental design is one of the more daunting goals for elementary school science teachers. It's also the bedrock of science. Students who learn how to set up an experiment and make sense of its results will not only be well prepared for secondary school science but also have a key insight into the very nature of science as a discipline.

For 5th graders in Fairfax County Public Schools, Virginia, understanding experimental design means learning to use such key terms as *variable, hypothesis,* and *constant,* with the practical help of four kit experiments during the year. Bobbie Sierzant doesn't shy away from introducing such science terms to 5th graders in the first week of school. To explain the term *variable,* for example, she invites students to choose a pair of items in the classroom that differ in only one characteristic. "It takes a long time to feel comfortable with the terminology of experimental design. Students have to have a lot of practice using the terms," says Sierzant.

Today, her class, which has been studying the scientific classification of living things into five kingdoms, will design an experiment focusing on the kingdom of the lowly fungi—specifically, the one-celled yeast. To start, Sierzant reviews a previous experiment exploring the rate of evaporation of a solution in two flasks—one with a narrow opening, the other with a wide one. She reminds students how one variable (the size of the flask opening) can change an event (evaporation). This variable is known as the *dependent variable*.

The let's-grow-yeast investigation has doubtless been performed in many classroom settings since the 1860s, when Louis Pasteur first trained his microscope on yeast and discovered that it was alive. But Sierzant avoids outlining the common step-by-step approach in favor of having her students "feel" their way toward structuring their experiments.

Using an overhead projector so that she can face the class, Sierzant lays out the items for this experiment one by one so that students can see them first in her hands and then on the large screen. Each small group receives a bin containing these items: three cups with milliliter measurements, three timers, a teaspoon, stirring sticks, and packets of yeast and sugar. A thermos of heated water and containers of room-temperature and cold water stand on a table at the back of the room.

"So what do you think we can do with all this?" invites Sierzant. This question seems a shot in the dark—almost unscientific—but she wants her students to consider the possible effect of each item she shows them. "They might not move in the right direction because they all don't have experimental design under their belts," Sierzant later admits. The yeast investigation would be classified as guided inquiry, but the open invitation "gets students thinking," she adds.

Making the Most of Background Knowledge

From their experience conducting science experiments in previous grades, Sierzant's 5th graders already have some idea that mixing substances may produce a reaction. Yet even in a post–Wonder Bread era of old world–style designer loaves, few have firsthand experience of yeast as one of humankind's oldest forms of biotechnology. One intrepid student ventures his hand. His mother bakes bread, and he knows that

yeast needs warm water to grow and thereby make the bread rise. Sierzant, ever encouraging, considering, and juggling student ideas to guide the investigation, picks up his thread to link their exploration of yeast to water temperature. She asks the class to frame a question for the investigation and then writes it on the board: "What temperature of water makes yeast rise the fastest?"

She wants students to consider themselves budding scientists and scientific thinkers, often prefacing her remarks or suggestions with, "As scientists, we . . ." When one student wonders aloud whether he should change his hypothesis, she says encouragingly, "Scientists think out loud all the time." But she reminds the class not to forget to show support for their final hypotheses.

Modeling Observation

As students carefully measure their constants—a teaspoon of sugar, a teaspoon of yeast, and five milliliters of water—into each of three cups designated for cold, room-temperature, or hot water, Sierzant asks her class to predict what kinds of changes they can monitor and measure. Measure the growth of bubbles and watch for color changes, volunteer the students.

The class grows noisy as groups get their allotments of water from Sierzant, who is stationed at the back of the classroom at a table crowded round with students. Back at their desks, the students stir the yeast and sugar with the water and patiently wait for a reaction, counting the seconds with timers. The voices of students crescendo as they watch some of the small cups bubble with milk-and-coffee-colored foam as the yeast begins to ferment.

Sierzant circulates from group to group, asking questions and modeling her own observations for them in precise language: "That's almost doubled since the last time I was over here. That white layer—I wonder what that is?"

"That's the yeast," offers one student.

"It smells like yeast," affirms Sierzant. "I love the smell of yeast."

"I hate the smell. It makes me dizzy," counters another student.

Other students must be content with clumps of yeast resting inert at the bottom of the cup or floating on the surface of the water. Several questionable bubbles later, they still hope a dramatic reaction will occur. For at least one group, the yeast fails to grow at all. The students are disappointed, and speculation about their results turns to finger-pointing and a sense of defeat. "Maybe we did something wrong, but I don't think so," says one boy.

Analysis and Reflection

Sierzant ratchets down the noise level as students return to their desks for a post-investigation report. A good number of the yeast mixtures have yielded little or no reaction. Perplexed students question their measurements or methods: Did we stir too little or too much? As students discuss the relative merits of each temperature of water, the yeast continues to bubble away, its beery aroma wafting from different corners of the room.

Plainly, some students are still baffled by the lack of yeast growth in any of their sugary solutions. So is their teacher. Sierzant had been mixing a thermos of hot water with cooler water to get an ideal temperature range for yeast growth (110–120 degrees Fahrenheit) before handing the water to students. Eventually it comes to light that in the clamor of filling containers, a number of students poured the hot water directly from the thermos into their cups. Unluckily, the water was too hot and killed the yeast, Sierzant confirms to the class. She suggests that that could explain the disappointing lack of organic bubble and fizz in the yeast pots.

So how does a teacher deal with experiments that flat-out fail? Sierzant emphasizes that things can go wrong with many science investigations, and outcomes may be unexpected. Also, having done experiments before, students do realize that not everything will go perfectly in an investigation. A positive outcome is that students will be more careful next time, thus acquiring some of the patience and thoughtfulness that are the hallmarks of a good scientist.

Class Management

Sierzant balances the noise and seeming confusion of the yeast investigation with orderly coverage of scientific processes and objectives. She uses pre- and post-investigation class time to emphasize procedures and cognitive hooks on which students can hang their thinking. For example, she reminds students of the importance of labeling cups for identification purposes, but in a way that still allows them to clearly observe and measure the yeast reaction. And she makes comparisons to previous investigations to remind students of the vocabulary of experimental design.

Nearly all the students raise their hands when she asks whether the class should repeat the yeast trial. The class agrees to leave the yeast mixture over the weekend to see what happens. Sierzant solicits students' predictions about what they think will happen as she tosses out one more variable: the school heating system will be turned off. For the next yeast trial, she reminds students, they will look for reasons for improved growth and possible growth patterns.

Science education professor Alan Colburn emphasizes that investigations that seem to go wrong—like the yeast experiment—merely mean that nature is behaving as it ought to. "The trick lies in figuring out why one got a particular result—and then testing the explanation in the next investigation," he says. "Students often conclude—incorrectly—that they got the 'wrong' results and are therefore not good at science."

Inquiry in Practice: 6th Grade

Bubblicious Versus Bubble Yum

What better way to get young students involved in real inquiry than to use the stuff of their everyday life—like bubble gum? Bob Chaplin, who teaches at Conners Emerson School in Bar Harbor, Maine, uses a "gum lab" to walk students through a typical inquiry involving comparison, multiple trials, observation, data analysis, and a follow-up experiment based on their conclusions and unanswered questions. The inquiry enables students to learn, in step-by-step fashion, inquiry processes

while having a lot of fun. "It's completely hysterical," Chaplin laughs. "But it's very practical. Kids are observing, making inferences, recording data, and doing graphs."

For this experiment, small groups of students chew pieces of four brands of bubble gum for one minute each, then carefully stretch each piece to its breaking point. The activity raises numerous questions among students. For example, stretching a piece of cotton candy–flavored Bubble Yum 750 centimeters—enough to bring the strand of gum down the hallway—causes one student to wonder whether the quantity of sugar ("so much you can see it") allowed it to stretch so far. The same student speculates that chewing time and saliva might also affect the elasticity. Other students conclude that there is something in the gum enabling its molecules to "adhere together." The experiment prompts some students to discuss the comparative elasticity of rubber bands and others to delve into further research about the science behind bubble gum's particular strengths.

Chaplin uses the bubble gum project as a quick way for students to get the gist of the scientific method's terms and processes, but it also prepares them for their longer-term investigation into the changing seasons.

Understanding the Changing Seasons

Chaplin knows that the students in his rural Maine school district thrive in an outdoor classroom environment. Once a month, at precisely the same time of day, his 6th graders trek to the school's one-acre outdoor lab, where they record a variety of observations.

In this year-round unit, called "Changes Through the Seasons," Chaplin's students record weather observations, use instruments in the school weather station, identify clouds, and employ their five senses to detect both subtle and obvious changes in the hairy cap moss and the oak tree that grow on site (see Figure 3.1).

In the frigid Maine winter, they measure the depth and temperature of the snowpack. Students also measure the length of the shadow cast by a meter stick on the nearby school parking lot and calculate the angle of the sun's rays in relation to where they stand on the earth.

FIGURE 3.1

JOURNAL ENTRY OBSERVATION
Please choose two things to study in your plot for the duration of this project October 05 – June 06.
All final draft observations must be done in complete sentences.

Touch – How does it feel?

1. **Name** Oak Tree It feels rough and ridged, though some areas are smooth. It is slightly [illegible].

2. **Name** Hairy Cap Moss It feels soft and slightly prickly to the touch. It is wet and slightly [illegible].

Sight – What color is it? What does it look like?

1. Name Oak Tree It is gray with [illegible] the bark and leaves. It has green leaves on some of the branches.

2. Name Hairy Cap Moss It is olive green in color, and its spines [illegible] like a [illegible] of a [illegible] tree.

Smell – What does it smell like?

1. Name Oak Tree Smells like the smoky [illegible] from fires when [illegible] is being cooked.

2. Name Hairy Cap Moss It smells like a barn with goats and sheep.

Sound - What sounds do you hear? I hear cars and the wind [illegible]. I hear crows and [illegible] ringing.

Prediction – What do you think your plot will be like next month? I think the moss will become dormant and the tree will be rid of all its leaves.

Students in Bar Harbor, Maine, measure the length of the shadow cast by a meter stick on the summer solstice at 80 centimeters, showing that the sun's rays now hit the northern hemisphere more directly. On the winter solstice, students had recorded a 320-centimeter shadow for the stick. (Photo courtesy of Bob Chaplin)

"Both shadow and angle measurements are entered into a spreadsheet, so we can compare and contrast what's going on each month due to the earth's tilt—first to the fall equinox and then to the winter solstice," Chaplin explains. Students also monitor and record how the shortening days and the cooling nights affect the plants, trees, and shrubs of the outdoor lab.

This wide-angle view of the relationship between the earth and the sun, combined with close-up observations of plants and trees, gives students a truly scientific understanding of the changing seasons. The activities help students draw inferences about many seasonal occurrences—the effects of diminishing amounts of sunlight on deciduous trees, for example—and gain a deeper understanding of photosynthesis and the color of fall leaves. At the end of the school year, students synthesize the information they've accumulated in an essay, analyzing and drawing their conclusions from their own real-world data.

Science Beyond the Classroom

Good science classes stimulate students to go beyond the investigation. Bobbie Sierzant encourages her students to take the initiative to seek out more information on topics that interest them. For example, her students regularly bring in items to examine under the microscope. Students also feel a sense of obligation to the scientific enterprises of the class; on a weekly basis, someone will bring in organic trash, such as blackened bananas or vegetable peelings, to sustain the class worm farm—a large translucent plastic bin of dirt, mulch, and shredded newspaper, overrun by hundreds of earthworms recycling it all into rich soil.

Sierzant, who considers herself a "science junkie" with projects running both at home and in the classroom, believes that science "sells" itself: students are always ready for the hands-on approach of good science. As a teacher, she's rewarded when students take their classroom learning home and return to class bubbling with excitement, saying, "I saw that bracket fungi in my backyard, just like you said."

Encouraging a Sense of Wonder

By the time students leave elementary school, Sierzant expects them not only to understand experimental design but also to have a sense of wonder about the world and to know how to find answers to their own science questions.

To help students realize that science has connections to life beyond the classroom, on the first day of class Sierzant challenges students to "tell me something that doesn't relate to science." Transportation! Well, that leads to roads, which lead to asphalt—and where does that come from? She has even started talking about engines.

"Having children wonder about things is really crucial," she affirms. "The more questions you have about the world, the more answers you won't have. The more you know, the deeper you can think about things that you have a quest for. . . . There are so many students who play their video games—they don't wonder about things or they may wonder about things in a limited way—like how to raise their game scores."

Although video-gaming may require some reasoning skills, the predigested and programmed nature of such games can rob children of a connection to the real world around them, Sierzant observes. She has noticed that students whose families watch TV programs like those on *Animal Planet* or who limit their time with the emptier forms of computer and television entertainment come to class curious and full of questions about science content. "Those are the types of students who will come up with inventions and new ways to improve our lives," Sierzant predicts.

Fostering students' capacity to observe also requires time and attention, says Terry Wilson. "Kids look for instantaneous results—it's the computer effect. Kids don't have the patience or capacity to watch things

or be observant," she notes. Wilson sometimes takes on the role of "a visitor from the planet Voltran" to encourage students to "use language that paints pictures" when describing what they see so that she can really understand what's going on.

For example, when students heat up a series of five unknown household chemicals (sugar, alum, talc, salt, and cornstarch), they might describe the burnt cornstarch as "smelling like burnt waffles." This use of prior experience to make connections is an intermediate step before students can focus on the property itself. Eventually, Wilson wants to help students focus on more objective description.

Keeping Questions Open

Good questions can encourage students to think more carefully about their own understanding. Open-ended questions in particular are "the kinds of questions that give teachers a sense of what students are thinking," says Alan Colburn. With such queries, a teacher can also "give students hints and prod them into things that they can try next without actually telling them everything," he says. Some of Colburn's examples of open-ended queries include

- So tell me about what you're doing here.
- Tell me about the kinds of things you're thinking about here.
- What do you think would happen if you were to . . . ?
- How confident are you about this? What would it take for you to be even more confident about this?

Allowing three to five seconds of "wait time" after asking a question enables students to reflect and usually draws out more of their thinking and ideas, Colburn says. It's important to *listen* to the students' responses and use the resulting information as the basis for further questions, he adds.

Questions That Clarify

Questions can also help students clarify their thinking. Wilson has one extremely bright 5th grader who occasionally brings some aspect of molecular biology into his observations using "some pretty impressive language." To make sure he comprehends what he's observing, she will ask him further questions and look at his notes. For example, she may ask, "That was an interesting way of stating it—why did you state it that way?" to help him reflect on whether he really understands the vocabulary he's using.

Wilson also asks students to reflect on their investigations: What did you do well? What didn't you understand? Why do you think you thought that way? Such questions "really get them to think about what they're stating" and steer them away from just looking for an answer that they think the teacher wants. If a student's conclusions are obviously "out of whack," Wilson helps that student figure out how he or she got there. Sometimes it's a matter of getting students to realize they're having an off day and didn't really take care with what they were doing, Wilson says.

Good questions in elementary science class take time. With four science classes a week, each ranging from one to one-and-a-half hours long, Sierzant's students have plenty of time to think. Still, she wants students to know that "I will try to really stick with them as they try to learn something." She warns, "You have to hang in there and ask lots of questions and give them time to respond and think. You have to keep going after them—otherwise, students will give up, thinking that the teacher will just keep plowing ahead."

Students also have their own questions. If time is short, the science teacher should balance the queries of individuals with the needs of the whole class, Sierzant says. Sometimes it makes sense to defer a question until the next day, telling students to think about it on their own overnight, she adds. Challenging students to find answers to their own questions necessarily takes more time.

When Students Investigate Their Own Questions

Asking questions is so important for building student understanding in science that Pita Martinez-McDonald has been focusing her professional development on just that for two years. "It's been hard for me to break out of that mode of 'I know all the answers—and will give them to you,'" she says. Besides holding off on supplying ready answers, she has also been looking for ways to get students to raise questions and to lead them through the process of answering questions on their own.

In one class, for example, Martinez-McDonald and her students read a Navajo coyote story, traditional entertainment during long winter nights. Coyote, who has a reputation as a prankster and a trickster, slides down a hill on a small flat rock and then again on a larger flat rock, which overturns and crashes, killing Coyote. "I don't think that would happen with a big rock. If he were on a *smaller* rock he would go faster," a student objects.

"In past years, I would have said, 'No. That's not right—because the larger rock gains more momentum,'" Martinez-McDonald explains. Now she asks all her students, "What do you think?" Hands shoot up immediately; it's apparent that students have strong opinions on the matter. So they decide to slide a variety of flagstone rocks down inclined planes and measure the stones' speed and distance. Each pair of students chooses a rock according to their theory on the matter, Martinez-McDonald observes: "Some students chose pointy rocks thinking these would 'plow' through the plane. Others thought a flat-fronted surface would be faster."

After the investigation, students determine that their data are inconclusive. In probing further, they find out that on average, there was only a three-centimeter size difference between the larger and smaller rocks, which did not seem to make a meaningful difference. Each team had also chosen slightly different incline angles to test.

"In the end, they realized that having fewer variables was very important to gathering conclusive evidence," Martinez-McDonald says. She is proud, however, that her students were able to design and troubleshoot an experiment and suggest improvements for later trials—and

that she was able to hold back from giving her class the authoritative easy answer.

Reflections ◆ ◆ ◆

These examples of classroom practice demonstrate that the most important element in the science classroom is neither textbooks nor kits, neither equipment nor technology—it's the teacher and the attitude he or she brings to science. Good science teachers have a plan for tackling a topic, a willingness to learn more, and the thoughtful patience to meet students wherever they are in their understanding of science. With these habits, teachers can make their students' journey into learning about the natural world both productive and enjoyable.

4 Motivating Students in Science

As long as our brain is a mystery, the universe, the reflection of the structure of the brain will also be a mystery.

—Santiago Ramón y Cajal, Spanish Nobel laureate

Many science teachers, with good reason, make the claim that "science sells itself" to students. Yet even science specialists are always on the lookout for strategies to further engage their students—to make the curriculum "fresh and surprising," as Tomlinson (2004) advises. Yet for an increasing number of students—especially English language learners (ELLs)—literacy difficulties stymie their understanding and enjoyment of science, a vocabulary- and concept-intensive subject if ever there was one. Addressing these literacy needs in tandem with an inquiry-based, hands-on approach to science can help students become more proficient in both science and English.

Another proven strategy for engaging students in science is making connections to everyday life through personal interests, community issues, and family ties. One of the most powerful things students can realize is the uniquely human pleasure of learning and problem solving in the field or the lab—what the NRC's science education standards call "science as a human endeavor" (1996, p. 139).

Reaching English Language Learners

"One thing we know is that the more education you have, the better off you'll be economically. You'll have a better chance of success in this

life. The more science and math you know, again, the better off you'll be economically—and you'll fit in better into this culture or whatever culture is going to be around 20 years from now," says Michael Padilla, president of the National Science Teachers Association and science education professor at the University of Georgia.

Unfortunately, students from non-English-speaking families have extra hurdles to jump to get this education. They have to overcome language barriers just to make sense of everyday English, not to mention become proficient at academic reading and writing, Padilla notes.

Like many countries, the United States must accommodate growing cultural and linguistic diversity resulting from immigration. In urban schools, students from other countries may represent a dozen or more cultures or languages. These students are at risk of low achievement or dropping out of school because their generally limited knowledge of English hinders their understanding.

"You realize the difficulty of a kid who comes over here at age 7 or 10 and doesn't understand English. It takes five to six years to get up to snuff to be able to do their academic work in English—and yet they are taught in English," Padilla says. "Then all of a sudden, they're in 8th grade and they are *way* behind, and the likelihood of dropping out is high. It starts this terrible cycle of dropping out because they're not doing well," which, in turn, can contribute to their own children underachieving, Padilla adds.

Understanding Culture

Padilla believes that parents, students, and educators alike will benefit from even small mutual efforts at cross-cultural exchange within the classroom. In 2001–2002, minority students accounted for 4 in 10 students in U.S. public schools. Of these, Hispanic children make up the largest and fastest-growing group, comprising nearly 20 percent of K–12 U.S. public school enrollment in 2004 (National Center for Education Statistics, 2006). This level of enrollment requires administrators and teachers in school systems unused to language issues to make an extra effort to help English language learners.

In particular, educators should be aware of cultural differences that can hinder academic achievement for ELLs. Padilla points out, for example, that "Latino families tend to be very supportive but hands-off about their children's education. That doesn't fit well with the U.S. system." In other words, Latino parents may not realize that they, rather than the teacher, may be the key to getting their children to study. "A kid might go home and say, 'No homework,'" says Padilla, but Latino parents—like any parents—need to follow up. Understanding how the school system works at both the classroom and the administrative level will not only help parents monitor their children better but also give them the know-how to push for their children's interests in the school or district.

Padilla cautions that follow-up shouldn't be a one-way street; teachers and administrators should make the effort to learn about the workings of immigrants' native school systems and societies. In Georgia, 75 percent of Latino students come from Mexico, he says, so if a teacher can understand transcripts from Mexican schools, he or she will have a better idea of what students have already learned. Bridging that communication gap at the cultural and administrative levels will help teachers focus on students as individuals, Padilla explains.

Overcoming Challenges

Learning the complex concepts of science, complete with their specialized vocabulary, is always challenging—but it is even more so for English language learners. Padilla suggests helping Latino students learn science vocabulary by drawing parallels with cognates from Spanish. For example, words such as *insect, magnification,* and *machine* have the Spanish cognates of *insecto*, *magnificación*, and *máquina*. If scientific terms are new to all language groups in the class, however, some experts advise introducing and reinforcing these terms in English. *Science for English Language Learners* suggests classroom strategies for partnering language arts with science to mutual advantage, including "re-presenting" a text for deeper understanding through role playing, cooperative dialogue, or genre-transforming exercises (Maatta, Dobb, & Ostlund, 2006).

• **Role playing.** Students act out the text that they have read. For example, students could take on the roles of organisms in the food chain, from plankton to humans, and act out the series of who eats whom.

• **Cooperative dialogue.** Teams of students write a dialogue based on a text. For example, after reading about erosion in a unit on landforms, students could write a discussion that home builders might have before starting construction on a hill or beachfront.

• **Genre-transforming exercises.** Students rewrite a text into another genre. For example, students could turn a passage about the growth cycle of a plant into a storyboard with pictures and simple captions.

Other strategies to foster science literacy and understanding include using prompts that give ELLs starting points for wording their hypotheses and focusing on one or two specific writing objectives for any given assignment. Teachers can also foster language generation skills in small-group settings by using timers that allow one minute of talk time per student during post-investigation sharing (Maatta et al., 2006).

Teaching Academic Vocabulary

Research shows that teaching students content-area terms improves their understanding and achievement in that subject and can help make up for any deficiencies in academic background knowledge (often built through such cultural experiences as travel). The following six steps for teaching academic vocabulary to English language learners in the context of science have been adapted from *Building Academic Vocabulary: Teacher's Manual* (Marzano & Pickering, 2005, p. 34).

Step 1: Provide a description, explanation, or example of the new term (along with a nonlinguistic representation). Ideally, give the initial explanation in ELLs' native languages. Or group students speaking the same native language together, with at least one of them having a stronger command of English to explain the new term. Also, provide a nonlinguistic representation of the term, such as a picture, to give ELLs another basis for understanding.

Step 2: Ask students to restate the description, explanation, or example of the new term in their own words. Allow students to write the description, explanation, or example in their native languages unless they prefer to use English. This activity integrates new information into an existing knowledge base. Encourage students to also record familiar English terms related to the new term.

Step 3: Ask students to construct a picture, symbol, or graphic representing the term or phrase. Students should create their own nonlinguistic depiction of the term, not copy the teacher's. This activity allows students to make a connection with their native cultures.

Step 4: Periodically engage students in activities that help them add to their knowledge of the terms in their notebooks. Encourage students to engage in such activities—analogies, word associations, and comparisons, for example—in their native languages.

Step 5: Periodically ask students to discuss the terms with one another. Again, place students in small groups, with one member more proficient in English.

Step 6: Periodically involve students in games that allow them to play with the terms. Bilingual members of the small groups can facilitate the games for partners less proficient in English.

This systematic delivery of academic vocabulary through different modes of learning enables students to cement their understanding of important terms and concepts tied to a specific subject area. To supplement the highly personalized vocabulary notebooks suggested by Marzano and Pickering, word walls—bulletin board displays that group families of similar or conceptually related terms, such as *electricity*, *circuit*, *parallel*, and *series*—can also reinforce understanding.

Marzano and Pickering emphasize that any program of direct instruction in academic terms should be accompanied by wide reading in fiction and nonfiction so that students can learn "high frequency terms that are important to general literacy development" (2005, p. 34).

Using All the Senses

Hands-on inquiry-based science provides another vital conduit of learning for students facing language barriers. Hands-on experiences, along with such strategies as visual aids and graphic organizers, should be part of the toolkit for teaching all students science, but the value of such tools increases when used for ELLs, say educators.

"Students just can't sit in class listening to a teacher whose words are making no sense," Padilla insists. Instead, engaging in actual investigations with other students can boost ELLs' understanding of science concepts while at the same time developing their English skills, he says. English language learners especially benefit when classes support different types of learning, including verbal and social as well as hands-on. "If you put one ahead of the other, or only emphasize one side, they're going to be the losers," Padilla warns.

In a highly technological world, we need to take into account the fact that new job growth will more than likely be tied to science, math, and technology. A basic education may work for someone who will be a manual laborer, but the reality is that most students need a thorough grounding in math and science, or "they'll end up being poor," Padilla predicts.

Cuba Elementary School teacher Pita Martinez-McDonald credits professional development with inspiring her to better understand the science that she teaches to language-minority students in rural New Mexico. The school campus is located at an altitude of 7,000 feet amid mountains ranging up to 10,000 feet. Many students are of either Hispanic or Navajo heritage and come from ranching families or otherwise have close ties to the land. Using the hands-on aspect of the natural world to teach science has always been a focal point of her class, but getting outside has become more difficult in the current era of accountability.

Because some students read one to three years below grade level, Cuba Elementary "really hammers literacy" to meet adequate yearly progress goals under No Child Left Behind. The district also recently began implementing weekly art classes and alternate-day physical education, all of which, while great, Martinez-McDonald says, makes "finding time for science a struggle."

To meet both literacy and science goals, Martinez-McDonald often integrates science into her reading block. That way, "I find that we're not so stressed for time," she says. For example, she integrated a science unit on water into her students' reading of Robert D. Ballard's nonfiction *Finding the Titanic*. "Kids here, from the desert or the high mountains, don't have good concepts about sinking or floating," Martinez-McDonald says, so she takes extra care to help students understand the concept of buoyancy. Her students experiment with shapes of boats to see which ones work to carry heavier loads, using a water table in her classroom to test the small foil and clay boats they make. "Every time we have a chance to use water, we incorporate it into our class lessons because kids don't really have these experiences," says Martinez-McDonald.

Having wide open spaces can be an advantage, too. To integrate math into the science and language arts aspects of the *Titanic* reading, students will estimate, then measure, the outline of the *Titanic* on the school grounds.

Besides hands-on experiences, repeating vocabulary is "crucial" to help Martinez-McDonald's English language learners, who speak Spanish or Navajo in their homes. The meaning of small cultural details may elude many students, she says. For example, while reading a story, students were confused by the word *cuff* until she rolled up her sleeves to show them.

For science teachers, knowing whether students understand the meaning and connotations of even commonplace words is important. In an investigation that involved sliding flat stones down inclines (see Chapter 3, p. 62), "students kept saying, 'The rock on the *soft* surface will go the farthest.' I finally had them show me and found out they were interchanging *soft* and *smooth*," says Martinez-McDonald.

Connecting Science and Students in the Real World

Another way to motivate students in science is through service learning projects that allow them to apply a variety of science processes and research skills in their own community. For example, in Nevada's Lyon

County School District, located in the high-desert area near the California border, 4th grade students have monitored the Middle Carson River monthly, taking readings for oxygen, pH, and turbidity, and identifying and counting various aquatic organisms. In Maine, 6th graders monitor the saltwater bay of Bar Harbor, testing its salinity and using microscopes to monitor the population of certain plankton. In both instances, state environmental authorities use student information as part of a larger public effort to monitor and improve the environment.

Elementary students in Lyon County, Nevada, take readings for oxygen levels, pH, and turbidity in the Middle Carson River. (Photo courtesy of Jim Berryman-Shafer)

The NRC's science education standards consider such projects valuable for helping students understand the connections between humans and their environment. At the elementary level, students can understand that "pollution can be solved by cleaning up the environment and

producing less waste," and as they get older, they learn that a concerted social effort can help get at the root of the problem (1996, p. 139).

Where Have All the Science Heroes Gone?

At a Washington, D.C., reception at the National Academy of Sciences, local scientists, government officials, science educators, students, and other members of the public came together to celebrate the 100th anniversary of Albert Einstein's *annus mirabilis,* his "extraordinary year." That year, 1905, Einstein published five papers on physics, including one that contained his famous equation $E = mc^2$. This equation states that mass and energy are two forms of the same thing—a discovery that eventually unlocked the secret of nuclear energy that led to the devastating atomic bomb.

The centennial celebration featured a new installment of the award-winning TV science series *NOVA,* titled "Einstein's Big Idea." That program, based on David Bodanis's book *$E = mc^2$: A Biography of the World's Most Famous Equation*, engagingly depicts both the personal and scientific sides of a string of scientists who preceded or followed Einstein. Einstein's predecessors' work provided the basis for his own monumental discoveries, the program implies, and his equation in turn became the key piece to help future scientists understand how energy is released when uranium nuclei are split.

In "Einstein's Big Idea," the viewer gets a full picture of what the NRC's national science education standards call "science as a human endeavor." The program shows that the nature and history of science involve a host of scientists and mathematicians working across space and time, learning from one another and refining or building on what others begin. The program gives due accord to well-known scientific giants like Sir Issac Newton and his laws on matter, motion, and light, but it also highlights the lives and work of more obscure figures, like mathematician and physicist Émilie du Châtelet, who helped champion the idea that an object's energy is a result of its mass times its velocity squared, and physicists Lise Meitner and her nephew Otto Robert Frisch, who

calculated how much energy nuclear fission would release, a key validation of Einstein's energy equation.

After viewing highlights of the program at the centennial celebration, *NOVA* executive producer Paula Apsell wondered aloud to the audience why young people—and society in general—didn't seem to have "science heroes" as they did in the past. Indeed, the program showed that in 19th century England, scientific lectures drew crowds of the curious public. In fact, the great English scientist Michael Faraday, who had only an elementary school education, nurtured his own love of science by attending public science lectures and demonstrations. In the mid-1820s, after establishing his own reputation in science, Faraday initiated Friday Evening Discourses and the annual Christmas Lectures for young people, both programs that continue at the Royal Institution of Great Britain to this day.

Bob Chaplin, for one, hopes that having his students learn about famous scientists of the past may encourage them to choose careers as scientists of the future. Chaplin, who teaches 6th–8th grade science at Connor Emerson Elementary School in Maine, has his students research the career of a famous scientist, mathematician, or inventor and then "become" that person in a skit. Students work in pairs to find out about their subject's life and consider pivotal events that influenced his or her work in science, math, or technology. Students must also explain why their subject's discovery or invention is relevant today and whether it has evolved.

Michael Faraday switched from bookbinding to science, stimulated by his own reading and by popular public lectures given by leading scientists of the day. (Image © British Library Board. All rights reserved.)

This project integrates science, social studies, math, language arts, art, and dramatic arts. For the culminating activity, each pair conducts

a talk show–style interview, with one student playing the inquiring host and the other playing the famous scientist, who in some cases defies the scientific laws of nature and "returns from the dead," usually with time machines.

Best of all, students have a lot of fun with their performances, says Chaplin, who videotapes the projects. One year, a student playing Thomas Edison emerged, coughing and dazed, from his time machine (a huge aluminum foil–covered box) to modestly talk about his numerous inventions, including the phonograph and the lightbulb. After explaining the details of the first successful lightbulb's filament, Mr. Edison took a gander at the classroom's bright fluorescent lighting and declared triumphantly, "Looks like I'm still pretty popular in the 21st century!"

In another instance, a student playing marine biologist Rachel Carson, who in the 1960s sounded the alarm about environmental degradation caused by humans, admonished the audience not to use pesticides or weed killers.

A little melodrama also gets the message across. After detailing the science behind the bulletproof material Kevlar, a student playing inventor Stephanie Kwolek and her talk show host partner took delight in staging a "mishap" in true student skit fashion. During a demonstration of Kevlar's strength, it became unfortunately clear that the show's host had forgotten to put on his bulletproof vest. His untimely demise drove home the value of the science.

"My hope is that students become interested enough to start thinking about becoming a scientist or an engineer as a career choice," Chaplin says. "It does help for them to see these famous figures as real people who have made a contribution for the common good of the planet and its citizens. I encourage them to aspire to do the same."

Students are graded not only on their performances and their use of historically appropriate costumes and props, but also on a host of other criteria, including library skills, bibliography, notes, presentation poster, and script. "It's a real treat to come across students later and have them say, 'I remember when I learned about Madame Curie! That was a cool project!'" says Chaplin. "That tells me that the knowledge they have gained has stayed with them. This is a great way to assess students."

A Family That Stargazes Together . . .

If studying the lives of scientists adds layers of depth and understanding to the pursuit of science, then a curiosity about the world fostered in the home can vastly influence students' tendencies to enjoy science and even pursue careers in that field.

The late physicist Richard P. Feynman, who won the Nobel Prize for his work on quantum electrodynamics, credited his father, a uniform salesman, with inspiring him to be a scientist. When Feynman was a small boy, he would sit on his father's lap to hear him read from the *Encyclopædia Britannica*. As an adult, Feynman recalled one instance when they were reading about the dimensions of the *Tyrannosaurus rex*. His father stopped and said, "Let's see what that means. If [the *Tyrannosaurus rex*] were standing in our front yard, that means he would be high enough to put his head through the window. But not quite—because its head is a little bit too wide, and it would break the window as it came by."

"Everything we would read, would be translated, as best we could, into some reality. I learned to do that, so that everything I would read, I tried to figure out what it really means, what it's really saying, by translating," Feynman told a television interviewer. "It was very exciting and interesting to think that there were these animals of such magnitude. I wasn't frightened that there would be one coming in my window. I thought it was very interesting that they all died out and, at that time, nobody knew why" (Sykes, 1981).

In another well-known anecdote, when young Feynman noticed that the ball in his wagon rolled forward as he stopped the wagon, his father explained that objects have a tendency to stay in motion if they are in motion or to stay at rest if they are at rest, unless a force acts on them. The boy got down on his haunches and saw that the ball indeed stayed in its position relative to the sidewalk, even as the wagon moved forward. "He knew the difference between knowing the name of something and knowing something," Feynman says. "That's the way I was educated by my father. With those kinds of example and discussion. No pressure—just those lovely, interesting discussions" (Sykes, 1981).

With his enthusiasm for science welling over, Feynman in his turn influenced his younger sister Joan (who recently retired as a scientist

from NASA's Jet Propulsion Laboratory) by showing her the wonders of the aurora borealis in a midnight outing when she was 8 and giving her a college-level astronomy book as a present for her 14th birthday (Hirshberg, 2002).

Connecticut teacher Terry Wilson recalls that her earliest influences in her appreciation of science came from her family, especially her grandfather (see "Nurturing a Passion for Science"). These early experiences were further enriched by the many teachers who followed through college.

Nurturing a Passion for Science

Terry Wilson

Thinking back to my science experiences as a child, I realize that in our family, science was just a natural part of being curious about the world around us.

My paternal grandfather was a world traveler and a member of the Appalachian Mountain Club and the Sierra Club, who helped maintain a part of the Metacomet Trail in central Connecticut. His passion for nature and the environment was contagious. And he was always sharing it with my brother, my sister, and me through his *National Geographic* magazines and books, by taking us hiking along his favorite trails, and by telling us stories of his adventures hiking in the Alps, on Mount Washington, or on the Appalachian Trail. I hung on his every word.

I also have fond memories of learning about the world with my dad, who was a sheet-metal worker by trade. Anytime there was a solar eclipse, we would beg him to remember to have his welding mask on hand so that we could safely view the disappearing sun through its thick dark window.

Inquiry in Its Purest Sense

Science teacher Terry Wilson as a child with her grandfather Ludwig Fehrenbach and her younger brother Paul. (Photo courtesy of Terry Wilson)

My 8th grade science teacher Mr. Poland truly understood the effect of hands-on, minds-on science teaching. Mr. Poland never gave us the answers to our questions, nor did he distribute a list of preset questions to answer during our investigations. We would review what we needed to do, so we were clear about tasks, but he didn't tell us what to expect—only that we should be observant.

I can still vividly recall our chicken embryology project. Each day, we would open a fertilized egg and examine the embryonic chick inside. We recorded our observations in our log book and drew what we saw, then placed the chick in a baby-food jar of formaldehyde for preservation. Mr. Poland taught us inquiry in its purist sense. I couldn't wait for science class: What changes would we see in the next chicken embryo? What challenges would Mr. Poland have for us?

Another science teacher whose lessons have stayed with me to this day was Mrs. McKeever, my high school chemistry teacher, who had a tough, no-nonsense reputation. I now realize that being afraid of her class was crazy; she was demanding because she knew how much we were capable of. I wrote my first science research

paper—the assignment we students most dreaded in her class—on the sun. Much to my surprise, I discovered that researching and writing was not all that difficult for me. I grew to love Mrs. McKeever's class—and like her, I find myself having high expectations of my students.

My undergraduate science teaching experiences with Dr. Ralph Yulo also had a positive influence on my love of science. His passion and natural curiosity for the world around him was infectious, and he practiced what he preached in his methods classes. Dr. Yulo is still actively involved with science education, whether acting as a panelist for a science conference or giving public lectures on observing the stars.

These family members and educators nurtured my own desire to understand the world and helped shape the person—and teacher—I am today.

Terry Wilson teaches at Myrtle H. Stevens Elementary School in Rocky Hill, Connecticut.

Engaging Families in Science

A recent study analyzed what families talked about as they spent the day at the Eden Project, a science museum in Cornwall, England, featuring re-creations of tropical and Mediterranean biomes in the world's largest greenhouse. The researchers found that although many parents helped orient their children and facilitated learner-centered approaches such as asking questions, only a few encouraged their children to "make comparisons, raise their own questions, or to follow these up independently" (Peacock, 2004). The implications are that parents can do much more to help their children see themselves as in charge of their own learning.

Schools can encourage a family's participation in science learning through science fairs, family science nights offering hands-on demonstrations, or homework assignments asking parents to conduct a science investigation. Some teachers send home a brief note about that week's science experiences that can tip off parents on what to chat about with

their children. Science teachers can also tap the local community by enlisting visits from scientists from research and applied science fields, the health care professions, and engineering.

In the National Science Teachers Association's *The Early Years* blog, parent Sharon Esker describes a Science Fun Day she organized at her son's elementary school in the Akron–Cleveland, Ohio, area that had students floating boats; digging for fossils; playing with *ooblek* (a cornstarch-water mixture that's a solid and a liquid at the same time); and learning about space, oceans, and dinosaurs. An army of volunteers, including engineers, local NASA staff, and orthodontists, set up displays and gave demonstrations. Local farmers, a sled dog racing team, a representative from a research firm, and representatives from local businesses and organizations brought animals for students to learn about, from llamas and baby bears to snakes and lizards.

Esker, who has since become a science teacher, notes that the yearly event "took hours of planning, but it was worth every minute of the time required. Each event sparked an increased interest in science and brought a good portion of the school community together to participate."

At this Science Fun Day, students have a chance to share their ongoing science learning with family members. (Photo courtesy of Sharon Esker)

Reflections ◆ ◆ ◆

In today's modern world, science and technology play a decisive role in the economic and daily lives of its citizens. As a result, schools need to ensure that all students—whatever their backgrounds—understand the language and concepts of science. When teachers take pains to understand the language and cultural needs of diverse students and relate science to students' everyday world, they empower those students to see the value of science in society. Family and community groups can be strong allies for increasing student participation and understanding of science.

Assessment for Learning

5

Nothing in this world is to be feared . . . only understood.

—Marie Curie

In 1998, education researchers Paul Black and Dylan Wiliam published an extensive review of international research literature on formative assessment concluding that using such assessments to tailor instruction can raise student achievement (1998a). Yet they also found that most teachers carry out such assessments poorly, often defaulting to practices that encourage rote learning and competition rather than thoughtful understanding. In a later paper, the researchers identified three main problems: "The first was that the assessment methods that teachers use are not effective in promoting good learning. The second was that marking and grading practices tend to emphasise competition rather than personal improvement. The third problem was that assessment feedback often has a negative impact, particularly on pupils with low attainments who are led to believe that they lack 'ability' and are not able to learn" (Black, Harrison, Lee, Marshall, & Wiliam, 2003).

Black and Wiliam criticized the high-stakes standardized tests that dominate teaching and assessment in many nations as "poor models for formative assessment" because of their limited function as mere summaries of achievement rather than helpful diagnoses (1998b). But they also believed that changing teaching practices would be difficult because of public policy beliefs and ingrained habits among educators.

Despite such challenges, in a follow-up project carried out by the King's College London Assessment for Learning Group in England, these

researchers recruited 36 teachers—24 of whom taught math or science—to integrate certain formative assessment practices in their classrooms. The results led to a new report (Black, Harrison, Lee, Marshall, & Wiliam, 2004) recommending the following in-class assessment practices as key ways to improve classroom standards and student performance.

Questioning. Increase wait time after questions to at least several seconds to give students room to think. Then use students' answers—whether right or wrong—to develop student understanding. This strategy can also help shift the questioning from fact-finding competitions to exchanges that help students explore deeper content issues.

Feedback. Give written feedback that both points out what students have done well and offers guidance on making improvements. Follow up by giving students a chance to respond, and then provide them with time to revise their work based on the feedback. Research shows that when teachers give both written comments and a grade or numerical score, students will focus on the grade and ignore the comments. When teachers in the study decided to use comments alone to assess student work, they found students more enthusiastic about improving their work.

Self-assessment and peer assessment. Let students know the criteria for evaluating their learning, then give them opportunities to grade their own and their peers' work. Peer judging, the study found, encourages students to reevaluate their own work more objectively. Teachers taught students to use the effective technique of "traffic light" icons (green for good understanding, yellow for partial understanding, and red for little understanding) to ease them into self-assessment.

Formative use of summative assessments. To help students prepare effectively for a test, have them reflect on what they know about key concepts and terms, using such methods as the traffic light technique. Or have students devise possible test questions and grade them so that they better understand the assessment process and where they can improve. Consider letting students apply criteria (even creating a test's scoring rubric) through peer assessment and self-assessment opportunities.

This work could be considered the cutting edge of assessment practice and reform. The preference of formative assessments over high-stakes tests is rare throughout the world. Only the state of Queensland, Australia, has abandoned high-stakes testing requirements for high school graduation and university entry in favor of teacher assessment of student portfolios (Black et al., 2003), and it took several years of professional development to alter the state's assessment practices. Black and Wiliam describe the multistep process involved: "First, they needed help to break their initial reliance on the types of test that the earlier external test system used. Second, they needed to develop formative skills, in part so that they were better able to guide and judge students' use of portfolios. Third, they needed to develop the procedures and skill for the conduct of moderation meetings at which samples of student portfolios have to be exchanged between teachers to help arrive at agreement on common standards" (2004, p. 29).

Nations, states, and school districts are unlikely to abandon summative testing in favor of formative assessments in the near future. But teachers can still help their students learn better through a variety of formal and informal ongoing assessments that reveal student understanding at specific points in time. When teachers provide students with specific feedback and guidance about how to improve their work and reach their goals for the assignment, student engagement and understanding increase. For example, teachers at Corinne A. Seeds University Elementary School in Los Angeles, California, find that using formative assessment practices has changed their instruction and their approach to investigations to better assist student understanding. By giving students ongoing written and oral feedback, providing them with class time to revise their work, and allowing them to demonstrate their learning in diverse ways, the teachers manage to help students reach their own personal best (see Appendix B).

Some specific formative assessment tools, including concept cartoons and science notebooks, make it easier for teachers to continually check for student understanding and decide their next instructional move.

Concept Cartoons: Assessing Preconceptions, Raising Questions

In *How Students Learn: Science in the Classroom* (Donovan & Bransford, 2005), researchers pointed out the importance of understanding what students already know about a topic or concept before delving into a deeper study of it. Although science teachers might already use various pre-assessment strategies, such as K-W-L (What I *know*; What I *want* to know; What I *learned*), some researchers worry that such tactics don't probe deeply enough. "We don't often gain an accurate account of student ideas and what students already know or think. Even using K-W-L doesn't work well—it gets dominated by four or five kids and the rest are left off the hook," says Janice Earle of the National Science Foundation.

In the United Kingdom, some teachers use *concept cartoons* as an innovative pre-assessment approach that engages young students in science while gauging their background knowledge. These single-panel cartoons, complete with speech bubbles, depict children discussing a situation that offers a science lesson. The cartoons seem simple, but they unearth a wealth of nuance in everyday situations. In one picture, five children speculate why no plants are growing under a fir tree. One child says a fir tree poisons nearby plants; another reasons that it blocks the sun; a third observes that there's just no space left for other plants; and so on. In another cartoon, shown in Figure 5.1, children argue whether putting a coat on a snowman will make it melt faster or slower. (Slower, it turns out, due to the insulating effect of the coat!)

Researchers and science consultants Brenda Keogh and Stuart Naylor, strong advocates of constructivist approaches to teaching science, developed concept cartoons to help learners confront their own ideas about science concepts and reach scientifically valid understandings. Keogh points out that "you do not always know what you think about something until you are forced to think it through for yourself, or, even better, explain it to someone else. This is more easily said than done. We found children and teachers reluctant to share their ideas because they felt that they may be wrong or be made to feel foolish." But because the

FIGURE 5.1
Concept Cartoon

Source: Concept Cartoons in Science Education 2000, © Stuart Naylor and Brenda Keogh, Millgate House Publishers, Sandbach, UK. Web site: www.millgatehouse.co.uk

Concept cartoons stimulate student discussion by presenting a variety of plausible viewpoints about a science concept.

cartoons give equal status to a variety of viewpoints, they encourage discussion, elicit ideas, and challenge existing conceptions.

Initial research has found positive results. The cartoons helped preservice teachers audit their understanding and address their own misconceptions in science (Keogh, Naylor, de Boo, & Feasey, 1999). The cartoons are also useful tools for introducing new topics. A teacher can kick off a lesson with a cartoon that poses a dilemma that students then attempt to resolve through a scientific investigation, Keogh says. Teachers can also use concept cartoons for review or to assess understanding at the end of a unit.

John Dabell, an elementary school teacher of 8- and 9-year-olds, has used concept cartoons as "starting points to find out what children know, what they don't know, and, more important, what they partly know." Dabell, who has extended concept cartoons into math and other subjects, speculates that the cartoons' neutral presentation of various viewpoints inspires "cognitive conflict" that moves students to think with more energy. The exercise shows students that "every point of view is valid—all conceptions contribute to an answer," he notes.

For example, in a concept cartoon about the rotation of the earth that Dabell presented to his class, the conversation goes as follows:

Child 1: "I think the earth rotates anticlockwise."

Child 2: "It moves clockwise, doesn't it?"

Child 3: "I think it moves in both directions."

"What do *you* think?" the cartoon then poses to the reader.

"I was interested to find out how many children would fall into the stereotypical view of the anticlockwise earth," because in the northern hemisphere, students traditionally learn that the earth rotates anticlockwise (or counterclockwise), says Dabell. Indeed, most of Dabell's students aligned themselves with Child 1, with some agreeing with Child 2 and none with Child 3. He then suggested that students discuss how sundials might work in the northern hemisphere and the southern hemisphere. "This sustained the discussion, and a rich dialogue opened up about the movement of shadow," he says.

Next, students looked at upside-down maps and modeled the rotation of the earth using tennis balls. "The delight of a number of children

was obvious as their 'eureka' moment dawned: 'The earth spins in both directions! It depends on which part you view it from,'" Dabell recalls. "With little help from me, they got there themselves—I merely facilitated their discussions and provided the resources for them to think more deeply."

As students ponder their options in this way, they think, discuss, argue, reflect, and justify their reasoning. "Only then do they move away from an alternative conception—note *alternative conception* and not *misconception*," Dabell emphasizes. "We must value everything children say and embrace their ways of thinking as alternative constructs based on their experience of the world. *Misconception* is a negative term that implies error. Yes, children's knowledge and understanding might be faulty, but it is our job to upgrade their conceptions into what might be called the 'right answer.'"

Overall, Keogh observes, the cartoons "seem to help pupils to see that it is acceptable to have a range of views in science and that discussion and argument are important parts of learning."

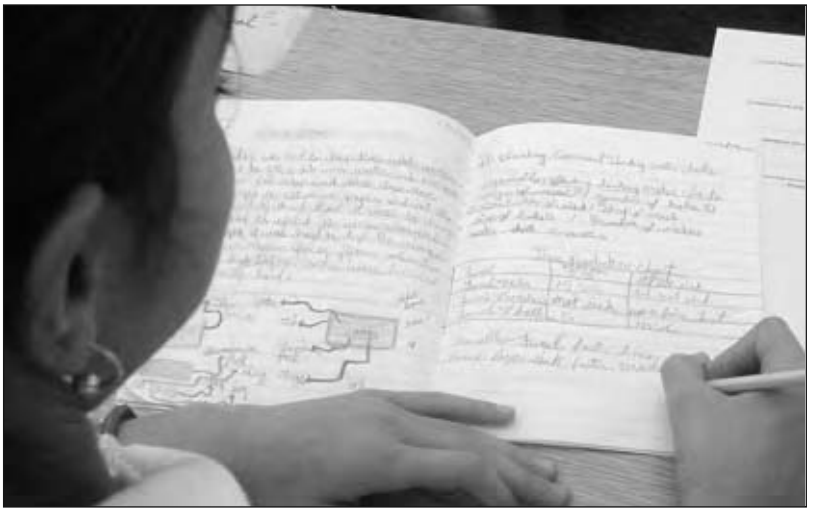
Science Notebooks: Talking and Writing as Ongoing Assessment

In Imperial County, California—one of the poorest counties in the state, with a per capita annual income of approximately $13,000 and a 20 percent unemployment rate—elementary science has been undergoing a positive transformation that has been noted around the world (Ecole Nationale Supérieure des Mines, 2006).

The key strategy in helping to close Imperial County's achievement gap? Science notebooks. These notebooks, in which students write individualized and meaningful accounts of their science investigations, give teachers an ongoing reference to check their students' understanding of concepts, content, and process skills.

The Valle Imperial Project in Science—a National Science Foundation–funded partnership between the 14 Imperial County school districts and San Diego State University, Imperial Valley campus—has targeted improvement in science and literacy for 6,500 K–8 students in

the El Centro Elementary School District. Students conduct hands-on science investigations using a variety of science kits (such as Full Option Science System [FOSS], Science and Technology for Children [STC], and Insights) and then write accounts of their experiments in their science notebooks. In the process, students not only show what they've learned but also map out new lines of inquiry resulting from their reflection and discussion.



An elementary student in El Centro, California, documents her investigation using the science notebook framework developed in her district. (Photo courtesy of Valle Imperial Project in Science)

Students have the opportunity to analyze their own understanding as they put their questions, plans, observations, and results into their own words and pictures. The notebooks and the discussion they elicit enable educators to integrate formative assessments naturally into the class, say El Centro teachers. "For kids who are not up to grade level, once they illustrate a word, they'll ask another student how to write it. But the drawing allows me to see whether they are understanding the concept or not," says 1st grade teacher Alfred Duron. His students at Blanche Charles Elementary School in Calexico, California, were recently engaged in a study of solids and liquids when one student discovered that he could make "tornadoes" in a container of water. Other students started to do the same, then moved on to drawing tornadoes, and then shared the proper spelling of their discovery.

El Centro's use of science notebooks allows students to engage in guided inquiry-based activities that have an open-ended quality to them while still holding students accountable to a framework that outlines the essential lines of scientific thinking (see "Science Notebook Essentials").

Science Notebook Essentials

Question/Problem/Purpose: Students state the problem, usually with a question that begins with "How . . .?" or "What . . . ?" Avoid questions requiring yes/no answers, or those beginning with "Why . . . ?" The complexity of the latter doesn't always lend itself to student investigation.

Prediction: To make sure students state what they think will happen in an investigation and support it with a reason or explanation, have them use frameworks like "I think . . . because . . ." or "If . . . then . . ."—for example, "*If* more magnets are added to the magnet stack, *then* more washers will stick to the magnet."

Planning: Students list materials, figure out a sequence of steps, identify variables and a control, and fashion a data organizer. Have students briefly share plans for mutual learning—especially data organizers, which are usually the hardest for students to craft.

Observations/Data/Claims-Evidence: Students record what they *actually* see and do during the investigation—not what they think the teacher expects them to see and do. Data can be recorded using labeled drawings, record charts, graphs, or narrative format. Claims must be related to the evidence seen in the data.

What Have You Learned?: Sharing their data in a whole-class "making meaning conference," students write their own conclusions after hearing the claims and evidence of other students. In a written reflection, students affirm or revise their own predictions,

summarize what they have learned, and note how their ideas have changed.

Next Steps/New Questions: Encourage students to record further questions that arise from their investigations. Allow time for extension activities that help students pursue individual interests in a topic.

Inquiry-based kits are an important part of the Imperial Valley science initiative, say school officials. "If we're really serious about science reform, we need to provide students a coherent base of hands-on experiences that give them personal experiences to make meaning," says Michael Klentschy, El Centro's superintendent. Still, he emphasizes, class discussion, small-group exchanges, and science notebooks show where real learning takes place. The two sides of scientific investigation —hands-on experimentation and thoughtful analysis—are equally important, and interdependent.

With this in mind, for 10 years Klentschy has been seeking to "co-opt" some of the time that's been taken over by what he and other teachers call the "bully curriculum" of reading. Sinking more and more time into isolated reading and language arts instruction isn't necessarily going to make students better readers and writers, Klentschy insists. Rather, language and literacy reach their full power when students apply their language arts skills to content areas, such as science. Discussion and writing provide channels into the content areas that would be missing if classes engaged exclusively in hands-on experiences or just read science textbooks.

Preliminary research data show that the science notebook and inquiry approach has a positive effect on student achievement. Klentschy—who leads the research for the Valle Imperial Project in Science—and his

research team have examined the scores of 1,200 5th graders on the science subtest of the California Standards Assessment and found that students whose teachers were specially trained in writing in science through the use of notebooks demonstrated significantly higher scores and a better understanding of science.

Klentschy further points out that "the students who made the greatest gains were the English learners who closed the gap with the native English speakers." He believes that the study further cements the research that supports the use of language arts strategies in the content areas. Educators can now say that the use of notebooks and discussion in science is a "research-based best practice," Klentschy says.

Keeping Work in Context

It can take time for teachers to move beyond seeing a science notebook as a mere recording tool and use it to diagnose student understanding. Even with professional development, teachers are still sometimes unclear about how student work, kit activities, and content standards get synthesized into the notebook, says El Centro science coordinator Elizabeth Molina-De La Torre.

"We found that a lot of times students were doing beautiful diagrams, beautiful charts, wonderful data collection—but they didn't know what the problem was, what the investigation was about. Or more important, they could not make claims from evidence," she recalls.

For example, 4th grade students might write that they learned a bulb can be lit using a battery but not be able to describe how. In their notebooks, students need to show that they grasp the concept of there being critical contact points and specific placements of bulb, battery, and wires to complete the electric circuit, says Molina-De La Torre.

To help teachers ensure that students record their own thinking and avoid using kit activities as ends in themselves, grade-level teams in El Centro have written supplements to the commercial kits' teacher guides. The homegrown additions, called "scaffolded inquiry," clearly outline each lesson's content goals and guiding questions, list applicable California science standards, and, most important, walk teachers through

the investigation within the framework of the six parts of the science notebook.

To prompt students to frame an appropriate "focus question" before the kit activity, teachers outline a fictional "engaging scenario" that gives students a real-world context for their investigation. For example, in one scenario for magnetism and electricity, two students on a hike stumble accidentally into a dark cave without a flashlight. Among the loose odds and ends in their backpacks are a bulb, a battery, and some wires. The fictional students construct a simple circuit that lights the bulb, but they find the light is not bright enough. Further digging in the backpack produces more bulbs, batteries, and wire. The scenario asks students to come up with a question that will focus on their problem—for example, What can we do to make the light bulb brighter so that we can see better in the cave?

The teacher guide supplements have increased El Centro's elementary teachers' comfort with the science notebooks because they now know exactly how to help their students use their notebooks more successfully. Teachers finish a unit knowing that their students have focused on crucial science concepts, Molina-De La Torre says.

Reinforcing Concepts

Claudia Ortega uses science notebooks to assess her students' understanding of concepts in landforms, electricity and magnetism, and food chains and webs—the main units for her 4th grade science class at Mains Elementary School in Calexico, California. She gives the notebooks greater weight than tests in determining student understanding because most of her students are English language learners who find the language in the end-of-unit tests too advanced.

A hands-on investigation that has students test the properties of minerals and rocks, for example, is typically followed by a whole-class discussion to "make meaning." Class members talk about what they've observed, what they've learned, and the data they have gathered in their notebooks. "Students might say, 'I know that minerals have only one color, but rocks have many colors because they have many minerals in

them,'" Ortega observes, but they then need to relate these claims to evidence they've recorded in their notebooks during their investigation.

These discussion periods also give Ortega a chance to reinforce student learning with real-life examples. As students study landforms, for example, Ortega brings up the local sand dunes in Imperial Valley, which shift in shape regularly due to changing wind patterns. Whether students are learning about the effects of erosion or the rock cycle, Ortega makes sure they relate the content to the big idea that "things change over time."

As with any reform, positive change occurs through continual reevaluation and tweaking of the program. While recently reviewing 10 years' worth of student science notebooks, Molina-De La Torre said she "got chills" when she saw a kindergartner's notebook from 1998 filled with page after page of hand tracings, presumably related to a lesson comparing student hand sizes for the theme "Myself and Others."

Today, a kindergartner's science notebook would be far richer. An example El Centro staff use to show the kind of scientific thinking a kindergartner is capable of depicts a wood chip sunk in a container of water, accompanied by a student-written caption predicting the number of paper clips he thinks will sink a wood chip. "That's how far we've come—from kindergartners tracing to actually documenting what they've observed," says Molina-De La Torre.

Reflections ◆ ◆ ◆

Assessment for learning involves a qualitatively different approach to seeking evidence of student understanding than do typical end-of-unit tests. Unlike summative assessment, formative assessment determines what students know before they dive into a science topic as well as assessing their understanding when their investigations are well under way. The approach encompasses such techniques as questioning, written feedback, and peer and self-assessment, all of which teachers can implement using several innovative tools. For example, concept cartoons enable teachers to probe students' science preconceptions through stimulating prompts, and science notebooks help students to work through

and document their own scientific understanding while giving teachers an ongoing means for discerning their students' grasp of science content and methods.

Implications for Professional Development

6

Give me a lever long enough and a fulcrum on which to place it, and I shall move the world.

—Archimedes

At the start of this book, we acknowledged that lack of confidence in teaching science is an obstacle facing many elementary school teachers. In Chapter 3, we looked at the practice and listened to the advice of successful elementary teachers who truly believe in the joy of science. The question now is, How do you make the transition from apprehension to self-assurance?

The answer is one we've heard before: professional development. Although the reasons for pursuing additional training in science are as varied as the resources and programs on offer, many of the science teachers interviewed for this book believe that professional development helped jump-start or deepen their love for science. At its best, professional development can help elementary educators realize the hidden science teacher within.

Bringing Out the Inner Science Teacher

Tanya Siwik is a self-confessed "social studies freak" who finally decided that mere passing marks on the Virginia state science assessment was not good enough for her students. She admits that "if I spent as much time dreaming about science as I did about social studies, my students would be as awesome with science as they are with social studies." Yet she's no

slacker in science: after pursuing professional development, she is now one of four elementary science trainers in her district. Her job now is "finding the balance" between her old love of social studies and her new passion for science.

Pita Martinez-McDonald of Cuba Elementary School credits National Science Foundation–funded training at the Museum of Natural History and Science in Albuquerque, New Mexico, as "launching" her science career. "I had taught science and enjoyed it, but before that project, I really had no training," she says. "It was the hook that got me interested in teaching science, especially to minority children and children in rural areas."

Since then, she has sought opportunities for further professional development through the Northern New Mexico Network for Rural Education's UCAN Rural Systemic Initiative, attending its workshops over the course of eight years. Such training was especially helpful for understanding the implications of the NRC's national science education standards, she notes.

Martinez-McDonald told a U.S. congressional panel that teachers not only believe that they don't know enough science and math to go beyond the textbook, but also "don't [even] know to go beyond the textbook. Reading is everything . . . but we really need to see ourselves as teachers of science" (U.S. House of Representatives Committee on Science, 2005). For most elementary teachers, "seeing" themselves as teachers of science will start to happen after they take their first steps in professional development.

Promoting Teachers' Enjoyment of Science

In this era of accountability, district curriculum directors must ensure that their teachers have the knowledge and the instructional strategies to teach science well. No Child Left Behind requires schools to prove that all teachers of core academic classes—including science—are "highly qualified," as defined in the law. And starting in 2007–2008, states must start implementing annual science assessments, testing one grade within each of three grade ranges—3–5, 6–9, and 10–12.

This spotlight on testing stirs ups teachers' legitimate fears that "in focusing on the test, we forget about the child," says Brett Moulding, state science education specialist for Utah. Moulding points out the difficulty of balancing the need for interesting instruction with "the desire of the district to move to an accountability model that is, in effect, counting the number of facts kids have mastered—rather than their enjoyment in taking a science class." Curriculum directors face a major professional development challenge: how can they help teachers keep this balance, delivering instruction that is effective yet enjoyable enough to propel students to take more science, rather than less?

In Utah, state officials want professional development for elementary teachers to focus on increasing their science literacy, aligning their instruction to the intent of the standards, and, most important, encouraging "a positive attitude about science," Moulding says. "There's nothing more exciting than having a teacher who is truly excited about the subject matter." Because the seven years of elementary school provide the foundation for later learning, education officials point out, Utah's Elementary Science Core Curriculum drives home "the important goal" of ensuring that students experience the joy of doing science. Indeed, the curriculum charges Utah teachers with making their science instruction "as thrilling an experience for a child as seeing a rainbow, growing a flower, or holding a toad." That's a pretty tall order! And it applies to all students; it is "not just for those who have traditionally succeeded in the subject, and it is not just for those who will choose science-related careers" (Utah State Board of Education, 2002).

Every summer, more than 3,500 K–6 teachers in Utah take part in an intensive three-day workshop targeting science, math, and K–2 curriculum. Called the Elementary CORE Academy, the sessions are funded by a combination of federal, state, and local monies, as well as some fees paid by teachers. Training sessions centered on the state's core curriculum feature a special highlight each year—for example, research-based instructional practices or formative assessment—and participants are encouraged to engage in related follow-up activities delivered during the school year.

The Rewards of Sustained Professional Development

A recent National Science Foundation–sponsored study, *Lessons from a Decade of Mathematics and Science Reform* (Banilower, Boyd, Pasley, & Weiss, 2006), has found that certain types of professional development in science and math play a significant role in helping teachers establish a classroom culture of discussion and analysis and promote active student involvement in investigation. The study synthesizes the evidence of 75,000 math and science teachers who cumulatively took part in 88 professional development programs over a 10-year period. The programs, part of the National Science Foundation's Local Systemic Change through Teacher Enhancement initiative, typically lasted several years or more and aimed to bolster instruction in science, mathematics, and technology by improving teachers' content knowledge, instruction, collaboration, and use of district-adopted instructional materials (such as inquiry-based kits).

The researchers observed positive effects on instruction after just 30 hours of training but found that a threshold of 80 hours of professional development produced optimal results. Teachers who took part in such long-term professional development improved the overall quality of their science lessons by

- Increasing time spent on science instruction in the elementary grades. K–5 teachers increased weekly science time from approximately 80 minutes to approximately 125 minutes (Horizon Research, 2006).
- Presenting higher-quality content to students.
- Promoting investigative practices, questioning, and sense-making practices.
- Creating a classroom culture promoting intellectual rigor and student engagement. For example, students were more likely to communicate their ideas and use evidence to support their claims.

Principals played a key role in the success of the Local Systemic Change (LSC) projects by encouraging teachers to undertake professional

development and use the inquiry-based practices they learned. Many LSC programs built support among principals by

- Bringing principals to national or local conferences to broaden their understanding of science and math reform.
- Holding workshops to brief principals on the goals, vision, and activities of LSC reforms.
- Devising professional development helping principals use innovations from reform projects in their own routines (in the areas of teacher evaluation and classroom observation, for example).

K–16 Professional Development Partnerships

In Washington State, research-based professional development draws on the meeting of the minds of K–16 science educators. The North Cascades and Olympic Science Partnership (NCOSP), based at Western Washington University in Bellingham, Washington, uses ongoing teacher training and summer institutes to give 160 teacher leaders from 28 mainly rural school districts a deeper understanding of science concepts and research-based instruction.

Each year, the program's professional development homes in on a science content area and trains participants in innovative instruction, on-site peer development, and leadership. George Nelson, Western Washington University physics professor and head of NCOSP, observes that "the model is fairly complex. The partnership involves trying to build a model of science education reform that is sustainable. In order to do that, we're working on not only what's taught in K–12 schools and how it's taught, but also what's taught at the university level and how *it's* taught, and how teachers are prepared."

According to Nelson, Western Washington University graduates about 500 teachers a year, with many of its elementary education majors arriving from local community colleges. To increase the preservice teachers' understanding of science, faculty from five regional community colleges and Western Washington University teamed up to design a hands-on, constructivist yearlong science course that is being piloted for

use at all five campuses. Such collaboration requires that college-level science instructors become "fluent" in national K–12 standards and align their own courses to them.

At Western Washington University, education students will then take two more specialized science courses, a methods course, and a practicum, so "they get quite a background in science," Nelson says. The program's overarching goal is to develop a system that develops and supports strong science teachers. Research in math and reading has shown that effective teachers have a tremendous influence on student achievement.

The Education Trust published a report titled *The Real Value of Teachers* calling for the use of *value-added systems* to determine a teacher's effectiveness. Taking into account an individual student's current academic level and such external factors as economic status, value-added systems measure the amount of learning students gain from the start to the end of the school year. Tennessee's value-added system, for example, uses student performance on five standardized tests as the basis for rating teacher effectiveness. A teacher who helps low-achieving students make significant gains over the year is deemed more effective than a teacher whose high-achieving students make only moderate progress over the year (Carey, 2004).

Nelson points out that the study found that "lower-achieving students who have effective teachers—say three years in a row—are likely to become high-achieving students." He further advises that "if we're going to have better student achievement, the system has to be built so that the most effective teachers are assigned to the students who need them the most—meaning the low-achieving students—and that's just the opposite of how the system works now."

Teacher leaders who participate in the NCOSP K–16 partnership bring new ideas on content, curriculum organization, and professional development to their schools. The bottom line is increased student achievement in science. Although schools freely choose teacher leaders to enroll in the training, there has also been some effort to encourage "younger teachers who may be around for a long time," Nelson says. "In the first year, teacher leaders were encouraged to work on their own

practice. In the second year, they model for their own peers. The following year, they'll be involved in getting peers to change their own practice seriously," he explains. "Over the five years of the program, you can take a longer-term approach."

Using Inquiry Boards

Fifth grade science teacher Marj Hendricks was one of six master teachers who, in collaboration with curriculum specialists and community college and university educators, recently trained K–12 science teacher leaders at monthly Learning Community Forums held at Western Washington University. Participating teacher leaders receive three days of professional development time each month for these activities, with two days of substitute teacher coverage paid for by NCOSP and the third day paid for by the district. The diverse group of teachers—from elementary, secondary, and higher education settings—"had to learn how to speak the same language. But as teachers, we brought the reality of the classroom to the program," Hendricks says. The daylong forums have already focused on topics in the physical sciences, the life sciences, and earth science.

One popular activity that Hendricks demonstrated at workshops shows elementary science teachers how to map out a scientific investigation using *inquiry boards*. Adapted from an activity in *Making Sense of Primary Science Investigations* (Goldsworthy & Feasey, 1997), Hendricks's workshop helps teachers create the inquiry boards for use the next day in class.

Inquiry boards rely on a series of poster boards, accompanied by sticky notes, to highlight the logical process behind changing a single variable during an experiment. For example, in Hendricks's "baggie garden" demonstration, students might decide to vary the amount of water poured in soil-filled plastic sandwich bags to determine the optimal water level for germinating a seed. The inquiry board process, as used in the baggie garden experiment, involves the following seven steps:

1. Brainstorm Board: Students first discuss the problem they want to probe. Next, they use one color of sticky notes to brainstorm all the possible *manipulated* variables affecting growth—water, sunlight, fertilizer amount, and so on. On another color of sticky notes, students then write all the *responding* variables that can be measured or observed in the experiment—for example, days until germination, seedling height, and growth of new leaves.

2. Choosing Variables Board: Students choose one manipulated variable and post it on this board under "I will change. . . ." They then choose one responding variable (also called a *measured* variable) under the heading "I will measure/observe. . . ." These variables anchor the experiment. The rest of the manipulated variables get grouped under the heading "I will keep the same. . . ." These are the controlled variables.

3. Ask a Question Board: Next, students fill in the blanks for the experimental question, "How does the [manipulated variable] affect the [responding variable]?"

4. Prediction Board: Students complete another fill-in-the-blank sentence, this one stating, "I predict that when [manipulated variable] changes, then [responding variable] will change because. . . ." The supporting statement for the prediction is the crucial part of the Prediction Board. This board is also where students decide how many trials (repeats of the experiment under the same conditions) or tests (repeats of the experiment with one variable changing at a time) they will conduct. They also record here the number of subjects in each test.

5. Table of Results Board: On this board, students record the raw data of what they manipulated and measured. For example, in one baggie garden experiment, students tested and recorded the effect of ammonia concentrate on the rate of plant germination.

6. Graph the Results Board: Students graph the data they gathered on the responding variable on the *y*-axis and the data they gathered on the manipulated data on the *x*-axis.

7. Conclusion Board: Students refer back to their experiment's original question, stating whether their prediction was correct and providing an explanation. They also record the lowest and highest data points here.

According to Hendricks, the inquiry board activity "was so well received by teachers." The hands-on approach "solidifies in the student mind [the fact] that you can change only one variable," she emphasizes. Teachers also freely admitted to Hendricks that the inquiry board process helped them better understand the logic behind carrying out a scientific experiment. Like science notebooks and other inquiry-based strategies, inquiry boards help students and teachers alike keep the elements of experimental design at the forefront, guiding both the procedures of an investigation and the thinking that should be an integral part of such hands-on science activities. (Go to www.ncosp.wwu.edu/Resources/Inquiry for more information about inquiry boards.)

As a result of its involvement in NCOSP, Hendricks's district, Lynden School District 504, has reembarked on the arduous process of curriculum adoption. Hendricks notes that "the program is getting the message out to all grade levels that science is an important part of the curriculum—science can be the practical application of reading, writing, and quantitative skills." For Hendricks herself, her work as a curriculum leader in a variety of schools and her renewed contact with college-level learning have inspired her to return to the university to pursue her credentials for becoming a principal.

Building Community with Lesson Study

Besides fostering collegiality and collaboration across K–16 levels, NCOSP promotes the value of school-level conversations around curriculum and instruction through an innovative approach called *lesson study*. Lesson study is a collaborative, teacher-led form of professional development widely used in Japan. In practice, a group of teachers designs a lesson that they will later observe carried out in a colleague's classroom. After the lesson, they meet again to share their observations and determine how successfully the lesson promoted student learning. The cycle may be repeated as necessary.

Because it's teacher-led and focuses on instruction, lesson study appeals to educators as a way "to bring high standards to life" in the classroom (Lewis, 2001). Science lead teacher Michael Shapiro calls

lesson study "a great opportunity to reflect with peers and build a larger science community." Shapiro, a 3rd grade teacher at Madison Elementary School in Mount Vernon, Washington, has been working on lesson study with teachers in nearby school districts after initial training through NCOSP.

Shapiro's lesson study team of five teachers from four school districts tackled a series of lessons on teaching a "pretty tough" unit on sound for 3rd–4th graders that "the kids were not quite getting," he says. His group consulted Ruby Payne's research on low-income students to find ways to help students bridge the gap between the sensory world of sounds and the abstract world typically represented on paper (California School Boards Association, n.d.).

The research lesson focused on the relationship between frequency of vibration and sound pitch, using everything from the human voice to twanging rulers and tuning forks. Teachers felt rewarded by their efforts when one student eloquently described the vibrations of his Adam's apple as he talked, using high and low pitches, as an "earthquake." Students used this image of the earth "quaking" to various pitches and volumes as a mental model for drawing their own representations of the various sounds. According to Shapiro, the drawing activity helped boost the understanding of students with limited English proficiency.

In debriefings, teachers refined the lesson to have students draw the actual vibrations of the sound. The revised lesson also reviewed vocabulary related to the properties of sound and provided students with some scaffolding on making predictions. Lesson study teachers refined the lesson further by showing students how sounds are represented as wave lines on the Web site Play a Piano/Synthesizer/Oscilloscope (www.frontiernet.net/~imaging/play_a_piano.html). "It was quite amazing," Shapiro notes. "By the end of the unit, 80 percent of the class could accurately draw wave lines to represent various sounds." He concludes, "The beauty of it is that lesson study is all centered on what the kids are saying. So it takes a lot of pressure off the teachers, who are pretty apprehensive about being observed."

Lesson study also pushes teachers intent on pursuing inquiry-based science to question whether they really listen to students or just "tell them

what we want them to learn," Shapiro observes. At the same time, teachers start questioning their own assumptions about a topic. For example, after observing a research lesson on helping students decide when to choose a line plot and when to choose a bar graph to represent data, teachers debated the question themselves during the debriefing session. They then decided that students should be given the same opportunity to defend their graph choices in class and increased the number of data points called for to help students better see the strengths and weaknesses of each type of graph. Shapiro suggests the following tips for schools embarking on lesson study:

• **Planning the research lesson.** Align lessons with local and national science standards, but don't waste time belaboring details. Use the time to focus on observing, debriefing, and refining the curriculum. Concentrate on one concept/misconception or skill to address for each research lesson.

• **Observing the research lesson.** Let students take the lead and use observation time just for listening to the students. Teachers should ask probing questions that encourage students to reflect more fully on what they have seen.

• **Debriefing.** Reassure teachers that the focus of observation is on students and what happens in a lesson, not on the individual's abilities as a teacher.

The Benefits of Collegiality

In San Mateo, California, the benefits of collegiality promoted through lesson study are as practical as they are professional. In preparation for its curriculum's transition to a rigorous Primary Years Programme as part of the International Baccalaureate program, Sunnybrae Elementary School adopted lesson study as an ideal form of ongoing teacher preparation.

"Every time I have taught a lesson as part of a lesson study cycle, I have been amazed at how much I don't see going on with the students. It's invaluable to have so many data collectors in the room. Data becomes the impetus behind the lesson changes instead of the teachers' feelings or

guesses," says Sunnybrae 5th grade teacher Linda Bauld, who takes part in lesson study with four other teachers.

In one of her lessons, Bauld had been pleased by how well her students were doing. But she didn't realize how many students had been chatting about anything but science until her colleagues let her know of the off-task behavior. Bauld reconfigured the lesson to allow for more student choice in developing questions for investigation and choosing the related materials. The result: "a quantum leap in science dialogue" among students, says Bauld. "I was so amazed at their high level of discussion and utter absorption in the investigation that I ran to get my colleague who had observed my class in the earlier lesson," she remarks. Her students, so intensely focused on their work, hadn't even noticed that the two teachers had temporarily switched places, her colleague later told her.

Bauld and her colleagues continually discuss their understanding of the research lesson, so they're "hungry" for content that will answer their questions. As a result, Bauld concludes, new content "sticks." And the benefits of lesson study go beyond the personal satisfaction gained from acquiring content and instructional knowledge: the opportunity to observe and appreciate fellow teachers' full range of talents in the classroom fosters a mutual trust. "I feel a sense of pride in myself and my profession when I'm acting as a teacher researcher," Bauld notes. "Our discussions, analysis, and reflections demand my best thinking, and I love the mental challenge. I also love the camaraderie and the deep appreciation we develop for each other as professionals."

Essential Science: The Power of the Moving Image

Science education experts agree that elementary teachers need to have a solid background in content knowledge to teach science well. Alan Colburn notes that "the exemplary science teacher should have knowledge of content deeper than the students'—not only to make connections among the different ideas, but also to make them feel more comfortable in what they are teaching."

For do-it-yourself educators or schools on a shoestring budget, Annenberg Media offers a variety of free online video courses and supporting materials. Among its most recent video workshops is *Essential Science for Teachers,* targeting K–6 educators. Produced by the Harvard-Smithsonian Center for Astrophysics, the series features three courses, each consisting of eight one-hour videos, aimed at increasing science teachers' content understanding in earth and space science, life science, and physical science. A downloadable professional development course guide outlines a detailed plan of readings, experiments, and discussion questions that groups of teachers in a school can follow together.

One goal of the video series is to help elementary teachers pay close attention to ideas about science that students have when they enter the classroom, says Nancy Finkelstein, project manager for the Annenberg Channel's professional development offerings. For that reason, videos often begin with engaging scenes of young children confronting their own thinking about such fundamental questions as "What is life?" and "What is soil?" In one physical science video, 1st and 2nd graders discuss the nature of matter to arrive at a working definition. It's not easy. One boy says you have to see it, feel it, or pick it up. "Air is not matter," he declares. Except in the winter, when you can see it, adds another boy. A girl posits that matter is "what matters"; therefore, because we need air to live, air is "matter."

Through young children's frank debates on science, as well as through more focused student interviews, the *Essential Science for Teachers* videos help teachers confront their own lack of content knowledge or possible misconceptions so that they can gain more confidence in teaching science, Finkelstein notes. She further suggests that the delivery of content by working scientists "humanizes the science and makes it much more interesting," and classroom footage "reflects the kind of teaching we think will be helpful" for elementary-level science teaching.

The videos and professional development activities are linked to appropriate national science education standards and to *Benchmarks for Science Literacy*. According to Finkelstein, the courses were designed to provide teachers with the content they need to know to meet the standards. Some teachers wanted to address only the concepts that they were

teaching for their grade: "They didn't understand, for example, why we were presenting a unit on DNA when they were teaching 1st grade, where DNA wasn't addressed," Finkelstein says. But because elementary teachers may be teaching different grades over their careers, understanding the science concepts at a number of levels will pay off, Finkelstein suggests. And, she hints, teachers might also be better prepared when students, who are exposed to sophisticated science topics through the news media and TV, throw teachers curveball questions.

"Elementary teachers are being asked to know a lot of content in six or seven subjects, including science, which is hard. But we thought we had the responsibility to present certain things in science that they ought to know," she says.

Shedding Light on Content

Tyngsborough Public Schools in northeastern Massachusetts wanted to increase elementary teachers' science content knowledge, in part to fulfill NCLB's call for "highly qualified" teachers. The district's professional development coordinator, Joyce Croce, turned to several Annenberg Media video workshop series, including *Science in Focus: Shedding Light on Science*, which focuses on the theme of light across all the sciences, and *Essential Science for Teachers: Earth and Space Science*. According to Croce, "The videos do a wonderful job of connecting concepts to the classroom." Her district bought the videos, rather than using the free Web-based programs, but they are still cost-effective professional development, she says.

Although Tyngsborough teachers were comfortable using a kit-based curriculum, the videos helped them gain deeper content knowledge, thus enabling them to ask probing questions and bring students to a higher level of understanding, Croce says. The videos also gave teachers a leg up on understanding science vocabulary and using it more effectively in class.

The videos cover a range of material, from basic to advanced, but teachers can still selectively focus on what they need for their grades. *Shedding Light on Science* begins with the electromagnetic spectrum,

which got 2nd grade teachers giving Croce a "you're-beyond-me" look. Yet those teachers brought back important ideas about how the human eye works—how it sees reflected light and why it sees certain colors, for example—even if they were not so absorbed by wavelength and energy differences, Croce recalls.

Prior to viewing, teachers take part in hands-on activities and discussion to tease out their own understanding. For example, before watching *Shedding Light on Science*, teachers use flashlights in a darkened room to create shadows with different materials and study the angles of shadows. After watching the videos, teachers meet in groups to review what they have learned.

Teachers may also check out the videos for use at home, documenting their learning through set homework assignments, a reading journal, a reflective paper showing how their understanding of a concept has changed, or a lesson plan that applies their deeper understanding of content. "It's not just popping in the video and watching," Croce notes.

Croce also uses the video workshops to introduce helpful instructional techniques. For example, while viewing the videos on earth and space science, teachers created their own concept maps, revising or adding to them as they watched successive videos. Workshop participants then shared their maps to help them understand others' reasoning or examine their own misconceptions. Concept maps are "a way to clarify how things fit together" that teachers will also find helpful for their instruction or assessment, Croce says.

The videos answer elementary teachers' questions like, "Why do I need to know this?" and "What does it look like in the classroom?" The video footage of actual classrooms enables them to see for themselves how to apply the content, Croce emphasizes. "That is extremely beneficial."

Professional Development Leadership

As a 3rd grade science consultant—one of four in a large suburban district serving more than 160,000 students—Tanya Siwik meets with new teachers four times a year. Between meetings, she maintains an e-mail dialogue with colleagues to exchange ideas for science content

and teaching strategies. She tells teachers, "At a meeting, we spend the majority of the time problem solving. At the beginning of the year, I do so much with teachers about how you set up the classroom so that you can teach science. Then you get that trust going in your classroom, and have strong expectations, high expectations of your kids, and then you look at content."

With regard to content, Siwik continues, "science is so kinetic—students can do so much with hands-on activities. We're going to go through the whole food chain, the food web. Somebody gets to be a mushroom, a hawk, a bear that just dies, somebody's going to be salmon that got eaten by the bear, somebody will be the fish eggs that get eaten by other fish in the stream—and somebody is going to get to be fecal matter." Siwik predicts that at least two boys are going to fight over the prize of that last role.

Hands-on science does not begin and end with investigation, however. One of the issues Siwik faces as a consultant is veteran teachers convincing new teachers that science is just about "teaching the kit," with the help of the district-designed, step-by-step lesson plan. But teaching the kit isn't much better than filling out worksheets, if students' work is limited to following steps to get an expected result. As Siwik points out, "The kit is nice, but it's supplemental." Science is really about teaching big ideas, such as living systems and life processes, and developing crucial skills, such as investigating and observing.

Sometimes teachers tell Siwik that they taught students from the hands-on kit but that the students didn't do well on the standardized tests. Siwik counters such limited notions about teaching science by showing teachers a bull's-eye chart of targeted expectations, with the national or state standard in the center (see Figure 6.1). Surrounding this inner circle are several concentric circles, each representing the wider and more demanding curriculum that moves beyond a standard. The wider curriculum encompasses the following elements: program of studies; what the school expects; what the teacher demands of herself/himself; and what the student needs from the teacher. Siwik points out that if a teacher strives to serve his or her students' needs, then all the expectations of the smaller concentric circles will be met—and worrying

FIGURE 6.1
Targeted Expectations

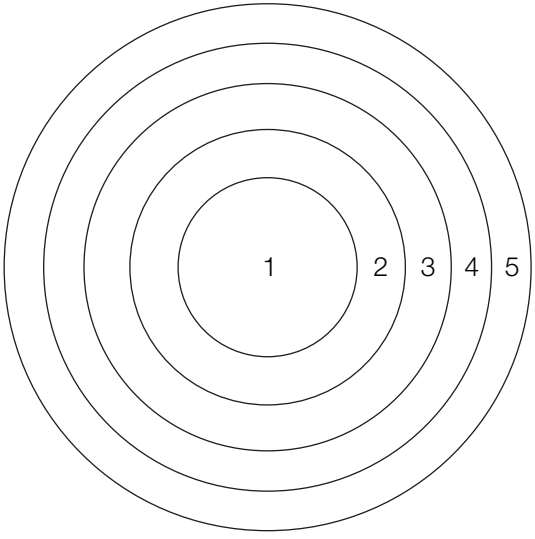
Innermost Ring: State or National Level Standards
The innermost ring, or bull's eye, is the lowest or most simple expectation of student learning. This is the level of learning that all students should be able to achieve.

The Second Ring: POS or County/District Level Standards
The second ring depicts the level of expectations often outlined by individual counties or districts. This includes the state or national standards.

The Third Ring: School Level Standards
The third ring illustrates the level of expectation that many schools expect. This includes the state/national and the county/district expectations.

The Fourth Ring: Classroom Standards
The fourth ring exemplifies best practice. It shows that strong teachers go above and beyond national, state, district, and even school-level expectations to ensure that their students have the most enriching experiences.

The Fifth Ring: Student Standards
The fifth ring is the optimal ring. It shows the expectations that the student sets for him- or herself. If the teacher scaffolds each student's learning successfully, then the student will inherently seek to obtain an even higher level of learning. This is often evident by students doing independent research or study beyond classroom expectations.



Source: Tanya Siwik, Fairfax County Public Schools.

about whether students will pass standardized tests won't be an issue. On the other hand, Siwik warns, "if you just teach the standard, you're going to sink, and the kids are going to be bored—and you're going to be bored."

Siwik advises teachers to talk to their students both to find out what they know about a science topic and to find out what's important to them. "Even if what students want to know [about a topic] doesn't have anything to do with the objectives that you need them to meet, you still need to value that and respect that. Look for ways to tie objectives to what's important to them," advises Siwik. A good science teacher will use what's important to students as the starting point for engaging them with the content. For example, youngsters thrilled about *Star Wars* movies will be more motivated to learn about the solar system or the names of famous astronomers if the teacher kicks off the lesson with *Star Wars* music or reads aloud a science fiction book. Then, during the course of study, the teacher can challenge students to compose their own song about the planets to make their learning more meaningful to them.

In their study of plants and flowers, Siwik's students zeroed in on the parts of the flower connected to the terms *nectar, pollen,* and *bees barfing*, all of which they had previously heard on a CD of science songs played in class. It's important to know about nectar and pollen to meet the standards, but Siwik gives students opportunities—during a reading workshop, for example—to find out more on their own or to ask questions about how bees regurgitate nectar and enzymes to produce honey for the hive. A teacher can take a variety of paths into the content.

Reflections ◆ ◆ ◆

Many elementary school teachers begin to see themselves as teachers of science after taking their first steps in professional development and realizing how much they can do with some extra effort and training. Often, teachers relearn that wondering about "stuff" and then investigating it is worthwhile fun—an insight their students instinctively share. Training in how to use such resources as science kits can orient teachers to new content and to a deeper way of seeing the natural world, whether

in everyday life or in the more distant phenomena probed in life science, earth and space science, and physical science. Support from districts and from science advocacy groups can give science professional development the boost it needs, but collegial approaches that pool diverse talents and perspectives within a school or district can also be the catalyst that stimulates ongoing standards-based reform in science education.

Appendix A
Inquiry in Practice: Kindergarten

Examining Zachary's Fish: Demystifying Science for Children

Sheri Leafgren

My kindergartner Zachary once smuggled a frozen fish into the classroom and attempted to dissect it with a pair of children's safety scissors and a toothpick. The fish, stored by his mother in the freezer, was Zachary's keepsake from his first fishing trip, waiting to be mounted and displayed as a trophy.

Motivated by curiosity about biology and by some recent mysterious deaths of a number of fish and a turtle in our indoor classroom pond, Zachary already had some experience making discoveries at our classroom "take-apart" center. This is a place where children use screwdrivers, saws, pliers, and sometimes hammers to dismantle cast-off small household appliances, such as telephones, speakers, and toasters. In this spirit of investigation, Zachary was determined to take apart his special fish to see "how it works."

Children come to school with a natural curiosity and enthusiasm for making sense of the world around them. In the science classroom, how can we keep open the avenue for children to inquire, discover, and pose and solve problems that not only make the world understandable but also have an impact on it?

First, it's important to both encourage and direct children's sense of wonder. This includes helping them to pose a problem, investigate it, and use the proper tools to carry out their search for meaning. In early

childhood education, the technology for science often operates at a simple but critical level. A magnifying glass, a microscope, forceps, or medicine droppers can help children extend the use of their five senses and sharpen their ability to gather information. Of course, young children need to be taught how to use these—and all science tools—properly.

Kindergarten students at Stewart Africentric Elementary School in Akron, Ohio, prepare a microscope slide for observation. (Photo courtesy of Sheri Leafgren)

Seeking Science Role Models

Because the tools available in the take-apart center were obviously unsuitable for his investigation, I had to cut short Zachary's impromptu fish experiment, but his attempt inspired me to invite a biochemist friend to give my kindergarten classes their first chance to meet a real scientist. The next day, the biochemist—armed with scalpel, probe, and forceps—carefully dissected Zachary's fish under the intense scrutiny of 28 kindergartners and the watchful eye of our video camera, which projected the operation onto a TV monitor. The biochemist described how important it is to use the right tools and appropriate techniques

for gathering scientific information. Our guest scientist explained that taking the fish apart was necessary to see inside but that some precision and knowledge are required to uncover—without mutilating—the parts of the fish that can inform and inspire further inquiry.

My students' experience with the biochemist inspired me to seek ways to create more opportunities for students to meet with practicing scientists who could lead them in authentic inquiry. The inner-city school where I taught at the time—Stewart Africentric Elementary School in Akron, Ohio—embraces a holistic philosophy of learning and living that emphasizes students' health and well-being as a crucial part of their development.

To reach the dual goals of having students examine their nutrition and of demystifying the scientific world and demonstrating its attainability to young children of color, our school applied for and won a $10,000 Toyota Tapestry Grant through the National Science Teachers Association. Our winning project—"If We Are What We Eat, Then We Must Have Eaten a Scientist!"—was an inquiry-based exploration of the nutritional value of the foods we ate daily in school-provided lunches and in lunches brought from home.

Dissecting Meatballs

My goal in the project was to encourage the curiosity of 5-year-olds and lay out in a natural way the elements of the scientific method. My students investigated their environment and their diets by gathering samples, helping with analysis, drawing conclusions, determining effective and accurate means of representing their findings, and, finally, sharing what they found with their families.

As teachers, we know that authentic inquiry stems from questions robust enough to provoke a need to know and to stimulate more "how and why" questions. Too often, the default mode of thinking is to take the world for granted. At Stewart, students relearn to wonder, to embrace the skepticism of the scientist, to look at the world with soft and receptive eyes, and to see the world as a place that they themselves can affect in a meaningful way.

Just as Zachary "dissected" his first catch, the students in my later class dissected a school lunch. First, we just named the foods: meatballs with sauce, fruit cup, Italian bread, butter. Then we began to look more closely; using probes and small forceps, for example, we deconstructed a meatball and found what looked like four different kinds of food. The students' comments, although not marked by typical scientific vocabulary, were accurate expressions of their observations: "Eeww! What's this hard thing?" "I think I see some bread in there!" "Some parts are roundy and some are flat." Using magnifying glasses, we found lots of colors in the sauce: black, green, and some yellow, as well as the red color we thought it was. Some of the fruit pieces we couldn't identify. Lunch was never the same for us.

Demystifying the Lab

Through this project, teachers in our school hoped to show students that the science laboratory is not a mysterious separate world. French scientist Bruno Latour (1999) writes,

> The only way for a scientist to retain the strength gained inside his laboratory . . . is not to go outside where he would lose it. . . . Does that mean that they are stuck in the few places where they work? No. It means that they will do everything they can to extend to every setting. . . . If this means transforming society into a vast laboratory, then do it. [If people believe] that science stops or begins at the laboratory walls . . . [they are missing that] . . . the laboratory is much trickier than that. (p. 272)

As we worked with our kindergartners, we kept in mind that learning doesn't stop or begin at the classroom walls—that learning, to borrow from Latour, is much trickier than that. Worlds collide when 5-year-olds visit working commercial laboratories to see practiced on a large scale what we practice on a very small scale in our classroom.

Children bring fresh eyes to what we adults often miss. During past visits to labs, my students have spotted and commented about the common functions shared by the classroom and laboratory work: "They use that to look really, really close at something!" "They use those to pick up teeny tiny things!" "Their goggles are littler than ours!" As my student Jamal excitedly pointed out during one visit, "Look! They keep track of their observations, too!" Classroom and science labs share vocabulary as well as procedures.

Being Scientists

As students seek answers to their own questions, they are discovering the importance of real evidence. The use of lenses to extend the senses, of precise tools to carefully gather samples, and of a laboratory to analyze their samples extends their understanding of "evidence." They are learning to no longer passively accept another's claim but to become equipped to challenge it or build on it.

With the help of professional role models, my students gained confidence in their abilities to ask questions that helped them explore the world and understand it better. They began to view the world and themselves with new eyes: scientist eyes!

It came as no surprise when I learned that Zachary introduced himself to his 1st grade teacher with the words, "I'm a scientist." He had achieved an understanding of himself, fortified by a biochemist who had shared his enthusiasm for science with a curious little boy.

Like Zachary, my kindergartners at Stewart not only discovered that they wanted to become scientists, but also recognized in themselves the qualities indicating that they already were scientists. As they examined their lunches, they learned how to frame questions, plan and conduct a simple investigation, use simple tools to gather data and extend the senses, and use data to construct explanations and communicate and critique their work and findings (National Research Council, 1996, p. 122). The students did not merely learn *about* inquiry and scientific technology, but *lived* it.

Perhaps the most important concept students carried away with them was the great pleasure that can be derived from doing science. As a teacher, I attribute my own experience with Zachary as the crucial event that prompted me to see children's natural inquiry abilities and innate engagement with science. Zachary taught me to see the "nature of science" within the "nature of children" (National Research Council, 1996).

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Source: Adapted from "Examining Zachary's Fish: Demystifying Science for Children," by S. Leafgren, 2003, *Curriculum-Technology Quarterly*, *12*(4).

Appendix B
Using Assessment to Deepen Students' Science Knowledge

Frederick Erickson, Laura Weishaupt, Sharon Sutton, Donna Elder, Raul Alarcón, and Lisa Rosenthal Schaeffer

We don't leave science learning to chance at Corinne A. Seeds University Elementary School (UES), the laboratory school of the University of California, Los Angeles. We don't make our budding botanists, zoologists, and geologists wait until the end of the lesson or term to clarify any misconceptions they may have. Instead, our teachers use in-class assessment to make immediate adaptations in instruction, reteaching concepts for individual children or, when necessary, for the entire class. It's an approach that is perhaps best illustrated through the following scenarios.

From Seeds to Flowers

In a K–1 classroom, students studied the life cycle of plants and insects by conducting experiments with seeds, taking field trips to gardens to witness pollination firsthand, and dissecting flowers and insects to learn about their parts and the function of each part.

The children were then asked to show what they learned about a plant's life cycle (from seed to flower) by drawing the stages in a flipbook format. To do so, the children had to reflect on each stage, think about how to draw each one, focus on the details, and consider how they worked together as a whole.

In examining their students' work, the teachers saw that an illustration of germination was missing from some of the flipbooks. Some of the

children did not show the seed coat opening and the embryo beginning to develop. So the teachers decided to review the concept by looking at germination firsthand. With the children, they opened up seeds, examined the parts of a seed, and planted lima beans to watch how germination occurred.

After the lima beans had begun to sprout, the teachers asked the children to make a slide show to demonstrate their understanding of germination. These representations included a clear depiction of the opening of the seed coat and the root and shoot beginning to emerge—information that had been missing from the flipbooks.

Observing and Writing About Snails

To study animal behavior, a class of 3rd and 4th grade students collected about 80 snails, placed them in a large aquarium, and observed them closely, using a magnifying glass and a photographer's loupe. They generated questions about the snails and grouped them into three broad categories—physical characteristics, behaviors, and reproductive habits—which they used to guide their research.

The teacher then asked the class to create detailed drawings of the snails. She reviewed the drawings to be sure students included four tentacles—two on the top and two on the bottom. Rather than simply tell students when their drawings didn't depict the tentacles accurately, she asked them to further observe the snail and then make new drawings. This was important because it allowed students who needed extra time for observing to take that time.

Next, the students researched the reproductive characteristics of garden snails. They read books and searched for Internet articles; they also observed the snails' mating habits. The students then wrote stories about snails using the information they had gathered. After reading the stories, the teacher determined that several, but not all, students had incorrect or missing information about the snails' reproductive habits. One student wrote that snails are "asexual," even though the teacher had used the correct term: *hermaphrodite*.

Because not everyone in the class misunderstood snail reproduction, the teacher decided to give the students who needed to bolster their understanding a chance to revise their work. She underlined any incorrect information in their stories, attached a note explaining the information they had missed or misunderstood, and gave them copies of a short article on snail reproduction. When the teacher was satisfied that these students had self-corrected their misconceptions, she had them revise their stories, adding new information and correcting inaccuracies.

Solidifying Students' Knowledge of Earth Science

In their study of earth science, 2nd and 3rd graders explored the characteristics of igneous, sedimentary, and metamorphic rocks. They engaged in firsthand experiences, such as examining rock specimens and then characterizing and labeling the specimens by their different properties, including color, texture, and size. They also discussed their observations, watched educational videos and took notes on what they learned, and analyzed information from books and appropriate Web sites.

The teacher then asked the students to represent what they knew about the characteristics of the different types of rocks in a two-dimensional form and a three-dimensional form. He provided a variety of materials, including poster paper, pencils, markers, clay, sand, pebbles, paint, cardboard, and yarn. The students then worked in cooperative groups to develop their representations.

For the two-dimensional representations, the students chose to create Venn diagrams, concept maps, and charts. For the three-dimensional representations, most groups made models of rocks, two groups created models of the earth's crust, and one group created a clay volcano and used it to show the relationship of rocks to volcanoes.

After analyzing the representations and discussions, the teacher realized his students didn't have a clear understanding of the process by which rocks become metamorphic. Some of the students were not able to describe the process, saying only that igneous and sedimentary rocks "change into" or "become" metamorphic rocks.

He surmised that the gap in understanding might be because students engaged in multiple hands-on experiences with the igneous and sedimentary rocks, whereas their experiences with the metamorphic rocks were mostly through text or video. In addition, the process by which metamorphic rocks form takes place beneath the surface of the earth under tremendous heat and pressure. Thus, it is an abstract concept for young children because they cannot observe it.

To adapt his instruction, the teacher reviewed the concept of the changing states of matter and how heat and pressure may cause solids to change from one state to another. Then he and his students conducted an experiment using pancake batter and other food items—such as chocolate chips, raisins, coconut slices, marshmallows, and hard candy (some of which can melt)—to observe what happens to the batter after it is heated and pressed by a spatula. He and his students also discussed how, as the earth's crust moves down, rocks in the crust may change because of the intense heat of the magma and the pressure of being forced downward.

The teacher integrated his reassessment of the students' knowledge of metamorphic rocks with his preparation of their year-end final projects. To prepare, the students wrote outline notes, which the teacher collected and checked for evidence of understanding. He found that the students' work included more detailed descriptions of the process by which metamorphic rocks form.

Helping Students Achieve Their Best

Just as students begin school at UES with different skills and background knowledge, they graduate with different levels of understanding about the concepts addressed in the curriculum. Some children do learn more than others. Still, by integrating assessment with teaching, by adapting instruction to immediately address misconceptions, and by offering students opportunities to demonstrate their learning in a variety of ways, teachers increase their opportunities to reach every student. Reaching students in this way increases the likelihood that each child will achieve at a personally high standard—in science and in other subjects, as well.

Source: From "Using Assessment to Deepen Students' Science Knowledge," by F. Erickson, L. Weishaupt, S. Sutton, D. Elder, R. Alarcón, and L. R. Schaeffer, 2005, *ASCD Express, 1*(4).

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Index

achievement
  feedback and, 81, 82–83
  formative assessment and, 82
  science fair example, 31–32
  teacher effectiveness and, 100
Allen, Woody, 18
Animal Lives (Tagholm), 43
Annenberg Media, 106–109
Ansberry, Karen, 42–45
Apsell, Paula, 73
Archimedes, 95
Asia, educational reform efforts, 2, 103
assessment. *See also* tests
  Australia, high-stakes testing, 83
  comments versus grades for, 82
  NCLB requirements, 2, 15–17, 19, 96
  peer judging, 82
  pre-assessment strategies, 84–87, 85*f*
  reflective, 8
  standards alignment with, 16–17
  storylines, aligning with, 25–28, 26*f*
  student self-assessment, 82
assessment, formative
  example of, 123
  feedback in, 81, 82–83
assessment, formative (*continued*)
  in inquiry-based instruction, 13–14, 15–16
  practices to improve standards and achievement, 13–14, 82
  problems with, 81
  tools for
    concept cartoons, 84–87, 85*f*
    science notebooks, 87–93, 88*p*
assessment, summative, 82
Atlas of Science Literacy (Project 2061 & NSTA), 29
Australia, high-stakes testing in, 83

backward design, 20–22
Ballard, Robert D., 70
Banilower, E. R., 98
Bar Harbor bay testing, 71
Bauld, Linda, 105–106
Benchmarks for Science Literacy (AAAS), 4, 17, 18–19, 29, 107
Bertenthal, Meryl, 15–16
big ideas concept, 7–8, 16–19, 23, 27–28, 84
Billy B., 45
Black, Paul, 81, 83
Bodanis, David, 72
Boyd, S. E., 98
Bransford, J. B., 6, 7–8, 84
Bubblicious versus Bubble Yum, 55–56
Building Academic Vocabulary (Marzano & Pickering), 67
Butternut Hollow Pond (Heinz), 43

Carle, Eric, 44
Chaplin, Bob, 34, 55–58, 73–74
Châtelet, Émilie du, 72
classroom, building trust in the, 36
Colburn, Alan, 1, 2, 11–14, 36, 55, 60, 106
collaboration, 37–38, 38*p*
concept cartoons, 84–87, 85*f*
Corinne A. Seeds University Elementary School (UES), 83, 121–125
Croce, Joyce, 108–109
Curie, Marie, 81
curriculum
  backward design approach, 20–22
  engaging students, elements of, 30
  kit-based
    variation in, 14
    Fairfax County Public Schools, 23–25
    El Centro Elementary School District, 25–27, 26*f*
    storylines with, 25–28, 26*f*

curriculum (*continued*)
Lynden School District 504, 29
advantages of, 33–34
students involved in, 33*p*
Valle Imperial Project in Science, 87–88, 90
standardized testing and, 110–112, 111*f*
promoting understanding, elements of, 31
storylines strategy, 25–28, 26*f*
successful, elements of, 30–32
typical, problems with, 20
typical standards-based, problems with, 18–20
variety component in, 34–35

Dabell, John, 86–87
De Fronzo, Ron, 27–28
dialogue, 47, 67
Donovan, S., 6, 7–8, 84
Duron, Alfred, 88

$E = mc^2$ (Bodanis), 72
Earle, Janice, 4–5, 8, 84
earth, rotation of the, 86–87
East Bay Educational Collaborative, 27
Education Trust, 100
eggs supported by straws, 37–38, 38*p*
Einstein, Albert, 1, 72
"Einstein's Big Idea" (*NOVA*), 72
El Centro Elementary School District, 25–27, 26*f*, 88–92
Elementary CORE Academy, 97
Emerson, Ralph Waldo, 33
English language learners, 64–70, 92–93
environment, inquiry into the
Bar Harbor bay testing, 71
Middle Carson River monitoring, 70–71, 71*p*
Nature Trail experiences, 48–49, 49*p*
Esker, Sharon, 79
Essential Science for Teachers (Annenberg Media), 106–108
estimates, making, 47
evergreens, revealing, 39–41, 40*p*
experimental design, 51–52, 62–63, 101–103

Fairfax County Public Schools, 23–25
families, engaging, 66, 75–79, 77*p*, 79*p*
Faraday, Michael, 73, 73*f*
Feasey, R., 101
feedback, role in assessment, 81, 82
Feynman, Joan, 75–76
Feynman, Richard P., 75–76
Finding the Titanic (Ballard), 70
Finkelstein, Nancy, 107
5Es model of instruction, 42–45
flowers, from seeds to, 121–122
flowers as problems, 45–48, 46*p*
food, nutritional value of, 117–118
Frisch, Otto Robert, 72
Full Option Science System (FOSS), 14, 29

Gelman, Rita Golden, 43
goatheads, the problem with, 49–51, 50*p*
Goldsworthy, A., 101
Groeneweg, Nicole, 38–42

hands-on, minds-on. *See* inquiry
Heinz, Brian J., 43
Hendricks, Marj, 28–30, 32, 101–103
heroes, scientists as, 72–74
Himmelman, John, 44
How Students Learn (Donovan & Bransford), 6, 84

inquiry
assessing, 13–14, 15–16
encouraging, 36, 58–60
guided, 12, 27
inquiry (*continued*)
open, 12–13
questions and, 60–63
scaffolded, 27, 91–92
standards measuring, 9–11
structured, 12
inquiry boards, 31, 101–103
inquiry in practice
analysis and reflection, 54
Bar Harbor bay testing, 71
Bubblicious versus Bubble Yum, 55–56
changing seasons, 56–58, 57*f*, 58*p*
eggs supported by straws, 37–38, 38*p*
embedding reading, 42–45, 70
experimental design, 51–52, 62–63
famous scientists, 73–74
flat rocks, speed and distance, 62, 70
flowers as problems, 45–48, 46*p*
flowers, from seeds to, 121–122
"If We Are What We Eat, Then We Must Have Eaten a Scientist!", 117–120
leaf models, 41–42
learning to love nature, 38–39
let's grow yeast, 52–55
making estimates, 47
Middle Carson River monitoring, 70–71, 71*p*
modeling observation, 53–54
Nature Trail experiences, 48–49, 49*p*
nutritional value of foods, 117–118
the problem with goatheads, 49–51, 50*p*
revealing evergreens, 39–41, 40*p*
rock characteristics, 123–124

inquiry in practice (*continued*)
rotation of the earth, 86–87
snails, observing and writing about, 122–123
toilet-tissue tube, 37
vibration and pitch, 104
Zachary's fish, 115–117
instruction
concept cartoons, 84–87, 85*f*
English language learners, 64–70
5Es model, 42–45
vocabulary, 67–68, 70
instruction, inquiry-based
age-appropriate, 9–11
assessment in, 13–14
class management, 55
foundation of, 12–13
implementing, 11, 13, 14–15
starter lessons, 37–38
students involved in, 10*p*, 11*p*, 38*p*, 71*p*, 116*p*
instructional strategies
addressing preconceptions, 6–7
cooperative dialogue, 67
data interpretation, 14
devising scientific procedures, 13
focus on big ideas, 7–8, 16–19, 23, 27–28, 84
genre-transforming exercises, 67
hands-on experiences, 69–70
metacognitive, 8–9
reflection, providing time for, 23–24
role playing, 67
teaching scientific thinking, 6–7
using questions, 13, 60, 61–63, 82, 105
Internet, benefits from, 24, 34, 48
IQWST (Investigating and Questioning our World through Science and Technology) project, 21–22
Japan, 103

Kass, Leon, 4
Keogh, Brenda, 84, 85*f*, 87
Klentschy, Michael, 27, 90–91
Krajcik, Joseph, 21–22

language-minority students, 64–70
Latour, Bruno, 118
Leafgren, Sheri, 115–120
leaf models, 41–42
learning
discovery-based, 36
by experts versus novices, 7–8
independent, 12
learning goals–driven design, 21
learning progressions, 16–17
lesson study, 103–106
Lessons from a Decade of Mathematics and Science Reform (Banilower, Boyd, Pasley, & Weiss), 98
literacy, scientific
characteristics, 3–4
economics of, 65, 69
English language learners, 64–70
literature, integrating with science, 42–45, 70
Local Systemic Change through Teacher Enhancement initiative, 98
Lynden School District 504, 29–32, 103
Lyon County School District, 70–71, 71*p*

Madison Elementary School, 103–105
Mains Elementary School, 92–93
making estimates, 47
Making Sense of Primary Science Investigations (Goldsworthy & Feasey), 101
Martinez-McDonald, Pita, 35–36, 48–51, 62–63, 69–70, 96
Marzano, R., 67, 68
McTighe, J., 20
Meitner, Lise, 72
metacognitive strategies, 8–9
Middle Carson River monitoring, 70–71, 71*p*
Molina-De La Torre, Elizabeth, 27, 91–92, 93
moon, phases of the, 6, 44
Morgan, Emily, 42–45
motivation
community research projects, 70–72
engaging families, 66, 75–79
English language learners, 64–70
scientists as heroes, 72–74
service learning projects, 70–72
Moulding, Brett, 19–20, 97

National Science Education Standards (NRC), 3, 9, 18–19
National Science Teachers Association (NSTA), 29
nature, inquiry into
Bar Harbor bay testing, 71
evergreens, revealing, 39–41, 40*p*
flowers, from seeds to, 121–122
flowers as problems, 45–48, 46*p*
goatheads, the problem with, 49–51, 50*p*
leaf models, 41–42
learning to love nature, 38–39
Middle Carson River monitoring, 70–71, 71*p*
rock characteristics, 123–124
rotation of the earth, 86–87
snails, observing and writing about, 122–123
Naylor, Stuart, 84, 85*f*
Nelson, George, 18–19, 99–101
Newton, Issac, 72

No Child Left Behind (NCLB), 2, 3, 15–17, 19, 96
North Cascades and Olympic Science Partnership (NCOSP), 18–19, 29–30, 99–105
notebooks
  for assessment, 87–93, 88*p*
  interactive, 23–24

Ohana, Chris, 9, 14
Ortega, Claudia, 92–93

Padilla, Michael, 65–66
Papa, Please Get the Moon for Me (Carle), 44
Pasley, J. D., 98
Piaget, J., 43
Pickering, D., 67, 68
Picture-Perfect Science (Ansberry & Morgan), 42
preconceptions, addressing, 6–7
principals and professional development, 98
professional development
  collegiality with, 105–106
  curriculum reform with, 28–30
  Elementary CORE Academy, Utah, 97
  funding efforts, 3
  increasing content knowledge, 106–109
  for inquiry-based instruction, 14–15
  inquiry boards, 101–103
  leadership in, 109–112
  lesson study, 103–106
  Lynden School District 504, 28–32
  online video courses, 106–109
  partnerships, 99–101
  promoting enjoyment of science, 95–97
  sustained, improvements with, 98–99
  teacher-led, 103–106
professional development (*continued*)
  Teacher On Special Assignment (TOSA) program, 29–30
Project 2061, 29

questions
  clarifying, 61–63
  in formative assessment, 82
  in lesson study, 105
  open-ended, 13, 60
  wait time following, 60, 82

Ramón y Cajal, Santiago, 64
reading, embedding in science instruction, 42–45, 70
The Real Value of Teachers (Education Trust), 100
Rice Is Life (Gelman), 43
Roche, Stephanie, 23–25
rocks
  characteristics of, 123–124
  speed and distance, 62, 70
role models, 116–117
role playing, 67

A Salamander's Life (Himmelman), 44
scaffolding, 27, 91–92
science, cookbook, 14, 36
Science and Technology for Children (STC), 14
science education reform
  cognitive research supporting, 5–9
  No Child Left Behind and, 2, 3, 15–17, 19
  North Cascades and Olympic Science Partnership (NCOSP), 18–19, 29–30, 99–105
  professional development role, 28–30
  public demand for, 2–4
scientific method
  analysis and reflection, 54
scientific method (*continued*)
  dialogue in the, 47
  experimental design, 51–52, 62–63, 101–103
  making estimates, 47
  observation, 53–54, 57*f*
  science notebook essentials, 89–90
  scientific thinking, 6–7
scientists
  as heroes, 72–74
  as role models, 116–117
seasonal change, 6–7, 56–58, 57*f*
self-regulation, 43
service learning projects, 70–72
Shapiro, Michael, 103–105
Shedding Light on Science (Annenberg Media), 108–109
Sierzant, Bobbie, 1, 35, 51–55, 58–59, 61
Siwik, Tanya, 36, 45–48, 95–96, 109–112
snails, observing and writing about, 122–123
standards
  aligning assessment with, 16–17
  backward design approach for meeting, 20–22
  Essential Science for Teachers workshop and, 107
  evaluation results at state level, 5
  for inquiry, 9–11
  kit-based curriculum and, 110–112, 111*f*
  learning progressions and, 16–17
  lesson study and, 105
  NRC-developed, 3–4, 9, 18–19
  problems with, 4–5
  streamlining, need for, 4–5, 15, 18–19
Standards of Learning (SOL), Virginia, 22–25

The State of State Science Standards 2005 (Fordham Institute), 5, 22
Stewart Africentric Elementary School, Ohio, 116–120, 116*p*
storylines, 25–28, 26*f*
students
  being scientists, 119–120
  building trust, 36
  curriculum engaging, elements of, 30
  peer assessment, 82
  promoting enjoyment of science for, 35–36, 59–60, 97
  self-assessment, 82
Sunnybrae Elementary School, California, 105–106
Systems for State Science Assessment (NRC report), 15, 16–17

Tagholm, Sally, 43
teacher leaders, 101–103
Teacher On Special Assignment (TOSA) program, 29–30
teachers
  effectiveness, determining, 100
  efforts to recruit, 3
  feelings about science, 1–2, 35–36
  involvement, importance of, 25
  NCLB qualifications requirement, 96
  promoting enjoyment of science for, 2, 35–36, 95–97
teacher training, 2, 99–101
tests. *See also* assessment
  preparing for, 82
  standardized, 110–112, 111*f*
Thomas B. Fordham Institute, 5
toilet-tissue tube, 37
Tomlinson, Carol Ann, 30–31, 64
Tyngsborough Public Schools, Massachusetts, 108–109

Understanding by Design (Wiggins & McTighe), 20
United Kingdom, 84

Valle Imperial Project in Science, 87–93, 88*p*
value-added systems, 100
vibration and pitch, 104
Virginia (state) public schools, 22–25
vocabulary instruction, 67–68, 70

Weiss, I. R., 98
Western Washington University, 99–101
Wiggins, G., 20
Wiliam, Dylan, 81, 83
Wilson, Terry, 34, 35, 37–38, 59–60, 61, 76–78
writing, integrating with science education, 87–93, 88*p*, 122–123

yeast, let's grow, 51–55
"Yo, I'm a Flower" (Billy B.), 45

Zachary's fish, 115–117

Related ASCD Resources: Science

At the time of publication, the following ASCD resources were available (ASCD stock numbers appear in parentheses). For up-to-date information about ASCD resources, go to www.ascd.org.

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Math and Science Revolution: New Teaching Methods That Work (#202154)
Reading Strategies for the Science Classroom (#505104)

Networks
Visit the ASCD Web site (www.ascd.org) and click on About ASCD. Click on Networks for information about professional educators who have formed groups around topics like "Problem-Based Learning" and "Service Learning/Experiential Learning." Look in the "Network Directory" for current facilitators' addresses and phone numbers.

Print Products
Teaching Reading in Science (*A Supplement to Teaching Reading in the Content Areas*) Mary Lee Barton, Deborah L. Jordan (#302269)
Improving Achievement in Math and Science (*Educational Leadership,* #104027)

Videotapes
The Lesson Collection Tape 10 Physical Science: Visual Tools (Middle School) (#400062)
The Lesson Collection Tape 37 Science (Density) (Intermediate School) (#403353)
The Lesson Collection Tape 42 Science (Observation) (Middle School) (#404459)
The Lesson Collection Tape 45 Lab Prep (Acids and Bases) (High School) (#404462)

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