Making Science Happen

We can improve learning in science if we emphasize depth over breadth, link concepts to instructional themes, and engage students through direct experiences and cooperative learning.

The many reports decrying the sorry state of science education leave no doubt that, while science is a high priority for international competitiveness, it is a low priority in terms of what really happens for students. Our students are not achieving even the most modest goals of information acquisition, and they spend less time learning science than their peers in other technologically advanced countries.

There is no doubt that the public wants—even demands—better science education for all students, not just for those bound for advanced work in science and technology. But do we as educators have the will and ability to make science happen for all Americans?

Surprisingly, a consensus is emerging on what needs to be done, how to do it, and where to get started. Here I describe some recent developments in science education that might make scientific literacy a reachable goal. The best news is that this set of reforms holds the possibility for bringing along all students, not just the science elite, as happened in the 1960s.

Curricular and Instructional Fusion

All too often, in content debates science educators compromise by including every person's favorite scientific tidbit or "factoid." Factoids are the terms, definitions, facts, and trivia that form the lowest level of the learning hierarchy. (For example, "*Turgor pressure* is the pressure created against the cell wall when water enters the plant cell.") Concentrating on the teaching of factoids wastes students' time and erodes their motivation. Finally, among science educators there is consensus—though not unanimity—that factoids have to go. During the precious time we have with students, we must concentrate on things that really matter. Most science educators agree

Photograph by Vladimir Sinyuk and Geoffrey McDonald

Direct experiences, such as examining a live snake at a nature center, arouse students' curiosity about the world and engage them in their learning.

that learning science content (concepts, not factoids) is still the central mission of developing scientific literacy. But we want teachers and students to concentrate on depth over breadth.

Science educators also largely agree that science lessons need to be made more relevant to students' daily lives. Often, this means drawing connections between basic science concepts and their technological applications. This curricular trend is referred to as "Science, Technology, and Society" (STS). Of course, some aspects of science can be best connected to students' sense of aesthetics. For instance, while we can argue for maintaining tropical rain forests on the grounds that their resident species may hold some medicinal or agricultural utility for humankind, most students would appreciate these forests for their arboreal splendor. Science educators further agree that we need to integrate the disciplines of science and to integrate science with other areas of inquiry.

Defining the Curriculum

We are still early in the process of defining this new core science curriculum for all students. The AAAS report, *Science for All Americans* (Rutherford et al. 1989), is one of the first efforts. The National Center for Improving Science Education report, *Science and Technology Education for the Elementary Years* (Bybee et al. 1989), is similar in scope and style. The new California Science Framework[1] also moves in this direction. These new science curriculums provide in-depth study of important topics and seek to engage students by emphasizing meaning and relevance to everyday life.

Fortunately, the National Science Foundation has played a central role in the formulation of new conceptions of the science curriculum and has funded the development of 11 new instructional programs, some of which are already available for use in schools. One I recommend is Kids' Network, a joint project of the Technical Education Research Center and the National Geographic Society. Kids' Network is a nationwide (in fact, international) telecommunications network for upper elementary students. The telecommunications aspect is trendy, but the real action is in the classroom, where students do group investigations that can take up to six weeks. In "Acid Rain," for example, they study pH, measure acid content in rain samples, and compare data nationally. This is the kind of science curriculum that students want and teachers find compelling.

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Changing Instruction

How we learn science shows a lot about what science is. There are three aspects to instructional reform in science that are having major implications for the development of new materials and appearing in numerous teacher training programs as well. These are (1) thematic science teaching, where concepts are built upon a structure of the major ideas that connect the science disciplines; (2) constructivist science teaching, where teachers take account of students' prior experience to build rigorous conceptual models; and (3) interactive science learning, where students converse and collaborate about an issue or event.

Thematic teaching. Thematic teaching isn't new. We tried it in the sciences in the 1960s, gave up on it, and went back to the tried and true—factoids. Thematic science teaching mirrors the way science itself proceeds: the instructional themes we use in classrooms are analogous to the theories scientists use to build new knowledge. Scientists look for new discoveries within the bounds of a theory-driven paradigm, so students should not be taught factoids outside the context of a theme-driven curriculum. For as Jules-Henri Poincaré observed, "Science is constructed of facts, as a house is of stones. But a collection of facts is no more a science than a heap of stones is a house." Using themes in learning science will develop the intellectual habit of connecting ideas, which is helpful not only within the broad fields of science but also in bridging from them to other subjects.

One theme that is absolutely essential to students' understanding of biology is evolution. Textbook authors have been driven away from this organizing concept by a small, vocal faction of the religious right; consequently, they are now forced to organize life science programs around ecology, molecular biology, cellular biology, or taxonomic categories. None of these approaches makes sense, however, outside the explanatory theme of evolution.

Constructivist teaching. The push toward thematic understanding is closely linked to the constructivist models of learning that educators are borrowing from cognitive psychology. Constructivist teaching begins by taking into account the prior ideas students have. For example, when students begin to study gravity in the upper elementary grades, they often have the misconception that heavier objects fall at a faster rate. Not only are these prior ideas often incomplete or inaccurate (the literature calls them "misconceptions" or "naive theories"), they are extremely resistant to challenge or change. In fact, we can't make any valid diagnostic decisions without first hearing from students about their worldviews.

Fortunately, cooperative learning techniques provide a perfect instructional starting point for constructivist teaching. Heterogeneously grouped students can discuss their ideas about how gravity works and then design and conduct experiments to test their ideas,

such as replicating the famous (but apocryphal) Tower of Pisa experiments.

Interactive learning. The power of interactive learning, known since the Socratic dialogues, is only now being exploited. Educational technology and cooperative learning provide settings where interactive learning can be emphasized. But interactivity means more than responding to some low-level query with a single key stroke. New softwares, of all formats and media, offer exploratory ways for students to interact with machines or other users in more meaningful ways. Educational technology also holds the promise of delivering those instructional events that are too dangerous, too small, too distant, or too *anything* for students to experience directly.

Cooperative learning is another technique to get kids sharing ideas about science and technology. We are finding that there are no slow learners in science; all students want to share their views on how our world works. The teacher is the most vital resource. He or she needs to decide when and how to help students see the "correct" conceptual model. Those of us in science are finding that, contrary to the linear textbook approach, it is okay to have students follow different routes or find multiple solutions.

In sum, the trend is toward a structured sequence of instructional events where students collaborate to build new ideas on existing intellectual foundations. Teachers not only create the blueprints for such learning, they monitor the execution of the design. If our science curriculums focus on a few powerful concepts, students will be eager to work for extended periods on units that have direct meaning to their everyday lives. And, as teachers can implement these techniques with minimal training and assistance, such reforms should be relatively easy to put into practice.

School-level Change in California

In developing science literacy, we should be prepared to put reforms into practice school by school. In California, we are developing school-level plans for restructuring the science curriculum.

I must make two important points before describing a system comprising over 8,000 schools and 4.5 million students. First, we begin by targeting lighthouse districts that are ready for change. In most cases, including the three I will outline below, we begin with about 100 schools with an overrepresentation of high-minority urban schools. We choose these schools partly because of the demographic imperative (the program has to work for all students) and partly because of their district leadership and support. Second, we assume from the start that there is no single model of effective implementation. Each school modifies the general characteristics of the plan to fit the local clientele.

Elementary level. At the elementary level, we have created a California Science Implementation Network (CSIN). Under the direction of Kathy DiRanna of the University of California at Irvine, 75 staff developers in science have been trained in the canons described above, along with peer coaching, craft sharing, and other professional development techniques. Each of these 75 establishes direct ties to elementary science mentors. Each mentor, along with his or her principal and several other teachers, outlines a scope and sequence for the entire school. They select three to five major areas for science investigation in each grade. Teachers of that grade jointly plan extensive, in-depth units of instruction that range from 10 to 30 days. This simple organization creates a science curriculum that significantly treats the 35 big ideas in elementary science. Students don't get science every day, but when they sink their teeth into one of these engaging units, they love it!

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There are real benefits to this organizational plan. First, within some very broad recommendations, the teachers create their own science programs. Second, the mentor and the staff developer are available to help find and adapt the units, provide on-site training assistance, and scrounge materials and equipment. Third, the teachers start with only three units and work their way to five. Fourth, students benefit from experience the teacher has had with other students: over time the themes become richer and more interconnected, teacher direction is based on earlier cohorts' misconceptions, and the activities become refined and more interactive. Making this network available to all 5,000 schools in California will take time and money, but it is a workable plan and early indications look promising.

High school level. At the high school level, we are just organizing a group of 100 schools to experiment with a bold new proposal by Bill Aldridge (1989), Executive Director of the National Science Teachers Association (NSTA), to copy the countries that are trouncing us in the International Science Study. The NSTA proposes establishing a concurrent high school program that treats biology, chemistry, physics, and earth/space science each week for 4 to 6 years. In the most robust 7–12 model, students take science every day for six years.

In California, 100 high schools are selecting from among four variations of the model in order to create laboratory-based science classes that are not driven by highly quantitative approaches to learning chemistry and physics. Department chairs are provided a small amount of funding to meet with the science faculty to discuss how to work together to teach concurrent science. Like the elementary program, this effort covers fewer concepts more deeply, connects science learning to overarching themes, and engages students in sharing what they learn through direct experience. And since the classes are lab-oriented,

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higher education looks favorably on them in terms of entrance requirements. Through this program, we hope to raise the participation of women and minorities in sci-tech fields by sparking their interest and building their confidence early.

Middle school level. The middle school science program is an extended version of the elementary school plan. Here, again, we have nearly 100 schools beginning to base the entire science program on "projects" that last from three weeks to three months. These projects are selected from among a set of alternatives created by the teacher to pique the interest of even the most jaded adolescent. The projects share the following characteristics: (1) they have a built-in sequence; (2) they have an almost endless set of options for side trips, detours, and other relevant exploratory inquiries; (3) they are as rich and intellectually stimulating as the students make them; and (4) they require small-group collaboration.

Taken together, these school-level efforts to restructure science hold the potential for a transformation of K-12 science learning to meet the needs of many more students. The focus is on teacher-led implementation, not training and accountability; though both play a part in the effort.

State and Federal Intervention

For the most part, state and federal agencies can help most by encouraging and allowing local efforts to reform science teaching. However, there are three areas where such agencies can play a significant positive role: texts, tests, and training. Texts and other instructional materials can be greatly improved. The National Science Foundation, for instance, has funded 11 instructional materials programs for grades K-8 known as the "Triad Programs" because they involve commercial publishers, university developers, and local schools in partnerships (see September 1988 *Educational Leadership*, p. 54).

In science testing, agencies including the National Science Foundation, U.S. Department of Education, and American Association for the Advancement of Science have created new visions of appropriate measurement techniques that can help lead the new reforms into classroom practice. Another National Center for Improving Science Education report (Raizen et al. 1989) discusses appropriate assessment measures. In addition, states such as Connecticut, New York, Florida, and, of course, California are beginning to experiment with a broader array of assessment techniques that more fully tap students' abilities to grasp science concepts and cope with technological issues. One such technique being piloted in California poses open-ended questions, such as "What are the pros and cons of offshore oil drilling?", and asks students to marshal arguments on both sides of the issue, drawing on their prior knowledge.

With regard to training programs, the National Science Foundation and the U.S. Department of Education are providing millions for teacher training opportunities for K-12 teachers of science. Unfortunately, the content and methods for such training do not vary much from the summer institutes of the 1960s. But new designs, such as those suggested by Shulman (1986) and Loucks-Horsley (1989), offer training techniques that focus on teacher-led programs already successful in regular classroom settings.

A Sense of Optimism

Many of us in science education feel a real sense of optimism. National efforts to set a new agenda are bold, but not so foreign as to frighten the more conservative elements in the education and public sectors. National and state-level initiatives are aligning tests, texts, and training so that the reforms are fully supported. And best of all, teachers are feeling a renewed sense of power, which makes the implementation of science reforms possible. When teachers are committed to improving the style and substance of science and technology education, and when administrators create the conditions for change to occur, then all students in America will develop the literacy that will serve them and society well into the 21st century.□

[1] "Science Framework for California Public Schools, 1990" is available in final draft from the author at the address below.

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