Science Literacy For All: An Achievable Goal?

By George D. Nelson

“What the future holds in store for individual human beings, the nation, and the world depends largely on the wisdom with which humans use science and technology. And that, in turn, depends on the character, distribution, and effectiveness of the education that people receive.”

-Science for All Americans, AAAS, 1989.

In a well-known study of science learning, education researchers asked a group of young Harvard graduates—still in their caps and gowns—to explain the change in seasons. Most responded confidently that the warm weather of summer occurs because the earth is closer to the sun during those months. In the same study, researchers quizzed bright high school students about the phases of the moon. Most attributed these changes to shadows or clouds blocking the moonlight. Where did such explanations come from? Surely we are not teaching our children erroneous ideas in school. Why, then, do even the most capable learners leave high school and college with such basic misconceptions about the natural world? Some might ask, is it valuable that they know the correct explanation for those events? Is science literacy important for all?

Alarming reports

In 1983, the National Commission on Excellence in Education, a special government committee, stunned a nation by declaring that the U.S. educational system had failed to meet the nation’s needs. Its report, A Nation at Risk: The Imperative for Educational Reform, became one of many studies conducted in the 1980s to focus attention on serious problems in American education. Most of the reports grew out of concerns about America’s seeming economic decline, particularly in areas dependent on scientific and technical know-how. Trends in U.S. public education were also troubling: poor test scores, low enrollment in science and mathematics.
courses (especially among girls and minorities), schools and teachers without adequate resources or support, and much more. Most recently, the disappointing performance of U.S. students in the Third International Mathematics and Science Study (TIMSS) emphasizes the need for change.

Rather than a crisis in American education, these symptoms point to a chronic condition, one that ultimately threatens the health of the nation and the wellbeing of each of its citizens. Short-term, quick fixes won't cure this condition. Only a long-term commitment to system-wide reform in science, mathematics, and technology education will do.

The scientific community responds
In 1985, the American Association for the Advancement of Science (AAAS) launched a long-term effort to reform science, mathematics, and technology education. With Halley's comet in view that same year, the project's originators found themselves considering all the scientific and technological changes that a child entering school in 1985 would witness before the return of the comet in 2061. They chose the name "Project 2061" to suggest that meaningful reforms to education depend on a long-term vision of the knowledge and skills that today's students will need as adults in the 21st century.

With expert panels of scientists, mathematicians, and technologists, Project 2061 set out to identify what was most important for the next generation to know and be able to do in science, mathematics, and technology—what would make them science literate. In two major reports, Science for All Americans and Benchmarks for Science Literacy, Project 2061 describes that knowledge and recommends learning goals for elementary, middle, and high school students as they make progress toward science literacy.

Science literacy: A national goal
Science for All Americans and Benchmarks for Science Literacy are based on the premise that the science-literate person is one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes. Project 2061 helps to establish science literacy as an important national goal for all students. It both captures and influences the growing national consensus on what constitutes science literacy and suggests some guidelines for successful reform.

In a joint statement issued in February 1996, AAAS, the National Academy of Sciences, and the National Science Teachers Association affirmed their commitment to science literacy and to the guiding principles that have directed Project 2061's work for more than a decade. Points include

- The first priority of science education is basic science literacy for all students, including those in

What is science literacy?
Project 2061 defines science literacy broadly, emphasizing the connections among ideas in the natural and social sciences, mathematics, and technology. Both Science for All Americans and Benchmarks for Science Literacy include specific recommendations in the following areas

- The Nature of Science focuses on three principal subjects: the scientific world view, scientific methods of inquiry, and the nature of the scientific enterprise.
- The Nature of Mathematics describes the creative processes involved in both theoretical and applied mathematics.
- The Nature of Technology considers how technology extends our abilities to change the world and the considerations necessary for its prudent use.
- The Physical Setting describes basic knowledge about the content and structure of the universe (on astronomical, terrestrial, and submicroscopic levels), and the physical principles on which it seems to run.
- The Living Environment delineates basic ideas about how living things function and how they interact with one another and their environment.
- The Human Organism characterizes living systems through a focus on the human species as one that is in some ways like other living things and in some ways unique.
- Human Society considers scientific principles of individual and group behavior, social organization, and the process of social change.
- The Designed World reviews principles of how the world can be shaped and controlled in some key areas of technology.
- The Mathematical World gives an account of basic mathematical ideas that together play a key role in almost all human endeavors.
- Historical Perspectives illustrate the science enterprise with 10 historical examples of exceptional significance in the development of science.
- Common Themes present general concepts that cut across science, mathematics, and technology.
- Habits of Mind sketches the attitudes, skills, and ways of thinking that are essential to science literacy.

Optics at Georgia Institute of Technology
Georgia Tech's traditionally strong optics program (roughly 18 faculty members) has been augmented by the hiring of Stephen E. Ralph in EE and Rick Trebino in Physics. Ralph brings to Tech an established research program in optoelectronic devices and systems initiated at Emory Univ. Trebino, who comes from Sandia National Labs, is well known for his development of powerful new techniques for measuring ultrashort laser pulses.

To develop strong international research collaborations in the optoelectronics area, Georgia Tech, jointly with the French Centre National de la Recherche Scientifique (CNRS), has opened a new research laboratory, GTL-CNRS Telecom, at Georgia Tech Lorraine, Georgia Tech's European platform in Metz, France. The laboratory's program in optical encryption, quantum optics, soliton pulse modulation, and microwave-optics is being conducted by a team of French and American researchers under the direction of Jean-Pierre Goedgebuer of the CNRS and William T. Rhodes of Georgia Tech.
groups that have traditionally been served poorly by science education, so that as adults they can participate fully in a world that is increasingly shaped by science and technology.

- Education for universal science literacy will, in addition to enriching everyone’s life, create a larger and more diverse pool of students who are able to pursue further education in scientific fields and are motivated to do so.

- Science literacy consists of knowledge of certain important scientific facts, concepts, and theories; the exercise of scientific habits of mind; and an understanding of the nature of science, its connections to mathematics and technology, its impact on individuals, and its role in society.

- For students to have the time needed to acquire essential knowledge and skills of science literacy, the sheer amount of material that today’s science curriculum tries to cover must be significantly reduced.

- Effective education for science literacy requires that every student be frequently and actively involved in exploring nature in ways that resemble how scientists themselves go about their work.

But there are many obstacles on the way toward science literacy for all (see “What Is Science Literacy?” sidebar, page 43). The nation’s curricula, textbooks, and teaching continue to lack focus and emphasize quantity over quality. As the newly released data from TIMSS indicate, the nation’s approach to science and mathematics education is a “a mile wide and an inch deep.”

**Overstuffed and undernourished**

The present science textbooks and methods of instruction, far from helping, often actually impede progress toward science literacy. They emphasize the learning of answers more than the exploration of questions, memory at the expense of critical thought, bits and pieces of information instead of understandings in context, recitation over argument, and reading rather than doing. They fail to encourage students to work together, to share ideas and information freely with each other, or to use modern instruments to extend their intellectual capabilities.

The present curricula in science and mathematics are overstuffed and undernourished. Over the decades, they have grown with little restraint, thereby overwhelming teachers and students, making it difficult for them to keep track of what science, mathematics, and technology is truly essential. Some topics are taught over and over again in needless detail; some that are of equal or greater importance to science literacy—often from the physical and social sciences, and from technology—are absent from the curriculum or are reserved for only a few students.

**Benchmarks for Science Literacy** challenges the status quo in science education by providing a coherent set of specific learning goals (or benchmarks) for grades K–2, 3–5, 6–8, and 9–12. The recommendations at each grade level suggest reasonable progress toward the adult science literacy goals laid out in Science for All Americans. Benchmarks can help educators decide what to include in (or exclude from) a core curriculum, when to teach it, and why. The sequence of benchmarks for any given topic reflects a logical progression of ideas, with early-grade benchmarks anticipating the more advanced benchmarks for later grades.

Benchmarks has had a significant impact on the reform movement. Its recommendations have helped shape the National Science Education Standards and have provided educators in every state and school district with a powerful tool to use in fashioning their own local curricula.

**Effective learning and teaching**

Project 2061’s work has also helped to bring attention to the growing body of research about the nature of learning and teaching when science literacy is the goal. Consider the assertion in Science for All Americans that “learning is not necessarily an outcome of teaching.” Cognitive research reveals that even with what is taken to be good instruction, many students—including academically talented ones—understand less than we think they do. For example, while students taking an examination...
may be able to identify what they have been told or what they have read, careful probing by teachers often shows that their understanding is limited or distorted, if not altogether wrong. This finding suggests that parsimony is essential in setting out educational goals: Schools should pick the most important concepts and skills to emphasize so that they can concentrate on the quality of understanding rather than on the quantity of information presented.

In a classroom where science literacy is the goal, teaching should take its time. In learning science, students need time for exploring, making observations, taking wrong turns, testing ideas, doing things over again; time for building things, calibrating instruments, collecting things, and constructing physical and mathematical models for testing ideas; time for learning whatever mathematics, technology, and science they may need to deal with the questions at hand; time for asking around, reading, and arguing; and time for wrestling with unfamiliar and counter-intuitive ideas, and for coming to see the advantage in thinking in a different way. Moreover, any topic in science, mathematics, or technology that is taught only in a single lesson or unit is unlikely to leave a trace by the end of schooling. To take hold and mature, concepts must not just be presented to students from time to time, but must be offered to them periodically in different contexts and at increasing levels of sophistication.

The changing classroom
Imagine for a moment that our Harvard graduates are back in middle school. What might their classroom experiences look like if the teaching and learning are designed to achieve science literacy? How could their teacher help them better understand the physical phenomena that cause seasons? What would their teacher do to help them become more successful learners?

The University of Dayton Electro-Optics Program

Since 1983, through its School of Engineering, The University of Dayton has offered a multidisciplinary, stand-alone graduate program in electro-optics. The program has 22 faculty members who come from electrical and computer engineering, physics, and the Research Institute. A total of 50 M.S. and over 25 doctoral students are enrolled in programs known for their rigor and application orientations. The students have access to more than 25 stand-alone EO graduate courses. The EO facilities include a total of 16 research laboratories devoted to various aspects of optical information processing, materials, diagnostics, and communications. Located minutes from Wright-Patterson Air Force Base, opportunities are often available for EO students to work at one of the many government laboratories.
Research tells us that students come to school with their own ideas—some correct and some not—about almost every topic they are likely to encounter. With that in mind, our hypothetical teacher most likely begins a lesson about seasons by taking account of her students' preconceptions. She identifies commonly held ideas using various instructional strategies and then tries to address those that reflect faulty thinking. If students' intuition and misconceptions are ignored or dismissed out of hand, their original beliefs are likely to win out in the long run.

Next, the teacher engages the students with the topic. Like all of us, young people can learn most readily about things that are tangible and directly accessible to their senses. Over time and with experience, they grow in their ability to understand abstract concepts, manipulate symbols, reason logically, and generalize.

To help students learn about seasons, for example, the teacher might provide small groups of students with materials and ask them to build models that illustrate the relationship between the sun and the earth. Then she might encourage the students to demonstrate and explain to each other the physical phenomena that produce seasons. To assess whether the students genuinely understand the phenomena and to provide them with an opportunity to reflect on their own understanding, our teacher might ask the students about the seasons in Australia or even on Uranus. If we expect students to apply ideas to novel situations, then they must practice applying them that way.

How this approach works and propagates is described in a Teacher's Guide to A Private Universe. “If students are given the time to observe, explore, and understand the apparent motions of the sun and moon in the sky, to make models of the solar system based on their observations, and to test their predictions, they may miss out on some other topics. For the rest of their lives, however, these students will have a firm foundation for learning other ideas across the curriculum. They will have a head start in understanding gravity in physics, growing seasons in environmental science, and vision in biology. Understanding lunar phases may even benefit students in art, adding to their comprehension of light and shadows.”

The timing and sequence of learning is also important. As illustrated in Figure 1 (page 45), teaching about the earth's rotation and axis with regard to the planet's seasons is specifically targeted for learning at grades 6–8. The cause of the seasons is a subtle combination of global and orbital geometry and of the effects of radiation at different angles. Students can learn part of the story at this grade level; a more complete picture comes with the benchmarks assigned to grades 9–12.

Science literacy for all
As Science for All Americans reminds us, “Education has no higher purpose than preparing people to lead personally fulfilling and responsible lives.” But it will take more than a vision to achieve science literacy for all. Meaningful change will also require sustained effort to create the following conditions for success:

- clear and explicit standards and benchmarks for student learning
- knowledgeable and well-prepared teachers
- well-aligned textbooks and tests that support standards and benchmarks
- coherent curricula from kindergarten through high school
- strong support throughout the education system for high student achievement.

Through Project 2061, AAAS will continue to encourage and engage the scientific community to help make science literacy a reality for all students.

References
1. Research conducted by the Science Education Dept. at the Harvard-Smithsonian Center for Astrophysics, Cambridge, Mass., to produce an educational video titled A Private Universe (1988). The chapter “The Physical Setting” in Science for All Americans deals with some of the key concepts that eluded the Harvard graduates and high school students. “The motion of the earth and its position with regard to the sun and moon have noticeable effects. The earth's one-year revolution around the sun, because of the tilt of the earth's axis, changes how directly sunlight falls on one part or another of the earth. This difference in heating different parts of the earth's surface produces seasonal variations in climate. The combination of the earth's motion and the moon's own orbit around the earth, once in about 28 days, results in the phases of the moon (on the basis of the changing angle at which we see the sunlit side of the moon).”

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