# Science Literacy for All in the 21st Century

**As the roles of science, mathematics, and technology grow in our society, the corresponding school curriculums must emphasize depth of knowledge, not breadth of information.**

**George D. Nelson**

In general knowledge of science and mathematics, U.S. 12th graders were among the lowest scoring students from the 41 nations that participated in the Third International Mathematics and Science Study (TIMSS). And US students taking advanced placement mathematics and physics courses ranked even lower when compared with their non-U.S. counterparts. The TIMSS study is compelling evidence of what we have known for decades: Most US students, even the brightest, are failing to learn much that is useful in science, mathematics, and technology (Schmidt, McKnight, & Raizen, 1997). These symptoms point to a chronic condition that ultimately threatens the health and well-being of both our nation and its citizens.

## The Need for a Science-Literate Population

As the world becomes increasingly scientific and technological, our future grows more dependent on how wisely humans use science and technology. And that, in turn, depends on the effectiveness of the education we receive. With the exploding impact of science and technology on every aspect of our lives, especially on personal and political decisions that sustain our economy and democracy, we cannot afford an illiterate society.

For our species to thrive in the next century, we must, through deliberate education, create a universally literate society. And the definition of literacy must expand to include not only reading and arithmetic, but also science, mathematics, and technology. The life-enhancing potential of science and technology cannot be realized unless everyone understands the nature of these subjects and acquires basic scientific habits of mind. Without a science-literate population, the outlook for a better world is not promising.

## Our Current Condition

So, how are we doing? Not well, I'm afraid, especially in science, mathematics, and technology. A classic video made at a Harvard University graduation illustrates what I mean (Private Universe Project, 1989). In the video, young graduates and faculty--still in their caps and gowns-- answer this question: Why is it warm in the summer and cold in the winter? Twenty-two out of 25 got the answer wrong. The typical answer was that it's warmer in the summer because the earth is closer to the sun. (The correct answer is that it's warmer then because the tilt of the earth, which remains constant as the earth orbits the sun, puts each hemisphere at an angle to receive maximum sunlight during the summer. The distance from the earth to the sun varies very little--actually, the earth is a little closer to the sun in January.)

More than half of the US population doesn't know that the earth orbits the sun or how scientists figured out that it does. Almost no one can explain what the phrase "orbits the sun" even means. Worse still, few can distinguish between an evidence-based explanation of how the physical world works and an opinion-based one.

The science-literate population is a tiny minority. Not until the few upper-division or graduate students majoring in science or engineering begin taking serious science and mathematics courses do they face learning the ideas, concepts, and habits that are so important to literacy. Unfortunately, this leaves out most people--including most future science and mathematics teachers.

Those of us in education must take most (if not all) of the blame for our nation's deficiencies in science literacy. We've become burdened by the overwhelming amount of new knowledge and the perceived need to lay it all out. Over the last 50 years, K-12 science, mathematics, and technology curriculums have become ever-expanding accumulations of facts, vocabulary, and hollow activities. As long as some students can absorb and emit this information--usually without much mental processing--we call it "learning." But what should students be learning? How should students be taught? How can we improve science and mathematics education?

## In Pursuit of Science Literacy

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 considered 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--what would make them science literate. In two major reports, *Science for All Americans* (AAAS, 1990) and *Benchmarks for Science Literacy* (AAAS, 1993), Project 2061 describes that knowledge and recommends learning goals for elementary, middle, and high school students as they progress toward science literacy.

## Guidelines for Reform

*Science for All Americans* and *Benchmarks* are based on the premise that the science-literate person 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 helped establish science literacy as an important national goal for all students. It both captured and influenced the growing national consensus on what constitutes science literacy and suggested 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:

- The first priority of science education is basic science literacy for all students, including those in groups that have traditionally been poorly served by science education.
- 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 and motivated to pursue further education in scientific fields.
- Science literacy consists of a 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 the 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 work.

But many obstacles lie on the way toward science literacy for all. The nation's curriculums, textbooks, and teaching continue to lack focus and to emphasize quantity over quality. As the data from TIMSS indicate, the nation's approach to science and mathematics education is "a mile wide and an inch deep."

## Improving the Science Curriculum

Today's 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, reading rather than doing. They fail to encourage students to work together, to share ideas and information freely with one another, or to use modern instruments to extend their intellectual capabilities.

Today's science and mathematics curriculums are overstuffed and undernourished. Over time, they have grown with little restraint, overwhelming teachers and students and making it difficult to keep track of what science, mathematics, and technology are truly essential. Some topics are taught over and over 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 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 a 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 given educators in every state and school district a powerful tool for fashioning their own local curriculums.

## A New Approach to Teaching

Project 2061's work has also brought 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,* for example, that "learning is not necessarily an outcome of teaching." Cognitive research reveals that even with good instruction, many students--including academically talented ones--understand less than we think that they do. For example, although 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 students' understanding is limited or distorted, if not altogether wrong. This finding suggests that parsimony is essential in setting out educational goals: Schools should pick and emphasize the most important concepts and skills 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, and doing things over; 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 need to deal with the questions at hand; time for asking around, reading, and arguing; time for wrestling with unfamiliar and counterintuitive ideas and for coming to see the advantage in thinking differently.

Moreover, any topic in science, mathematics, or technology that is taught in only a single lesson or unit is unlikely to leave a trace by the end of schooling. To take hold and mature, concepts must not be presented to students just from time to time, but must be offered to them periodically in different contexts and at increasing levels of sophistication.

## Classroom Implications

Imagine for a moment that our Harvard graduates who failed to answer correctly the question about the seasons 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?

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 by identifying students' preconceptions and commonly held ideas about seasons and then addressing those that reflect faulty thinking. If he or she ignores or dismisses students' intuition and misconceptions out of hand, their original beliefs are likely to win out in the long run.

Next, the teacher engages the students with the topic. Young people 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 our Harvard graduates learn about seasons, for example, the teacher might ask small groups of students to build models that illustrate the relationship between the sun and the earth and then to demonstrate and explain the physical phenomena that produce seasons. To assess whether the students genuinely understand the phenomena and to give them an opportunity to reflect on their own understanding, our teacher might ask them about the seasons in Australia or even on Uranus. If we expect students to apply ideas in novel situations, then they must practice applying them in novel situations.

The teacher's guide to the video *A Private Universe* describes how this approach works.

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. (Private Universe Project, 1994)

The timing and sequence of learning are also important. As illustrated in *Benchmarks,* teaching about the earth's rotation and axis with regard to the planet's seasons is specifically targeted for grades 6 through 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 these grade levels; a more complete picture comes with the benchmarks assigned to grades 9 through 12. A forthcoming Project

2061 publication, the *Atlas of Science Literacy,* will graphically depict the interconnections among benchmarks as they contribute to a student's growth of understanding over time.

## Science Literacy Goals

Science literacy is a necessary and achievable goal for all students. Teachers, administrators, parents, and reformers have an opportunity to use the TIMSS data to make an even stronger case for science literacy efforts designed to

- Implement national and state benchmarks and standards that will help students of all backgrounds, abilities, and interests achieve science literacy;
- Encourage textbook publishers and developers to align their work with benchmarks and standards;
- Prepare educators to assemble standards-based curriculum materials into coherent programs;
- Provide teachers with the time, resources, expertise, and preparation needed to understand and apply national and state standards in their classrooms; and
- Build support for benchmarks and standards among families, community and business leaders, higher-education faculty, and policymakers.

This kind of change takes time and collaboration. Patience and realistic expectations are crucial. But so is urgency; if we don't start down the path to improvement today, we'll find ourselves in the same place with the same problems and the same learning next year--and the world is not waiting for us. The United States cannot meet the challenges of the future unless today's children have a better understanding of the world and how it works. Literacy in science, mathematics, and technology is not an option for the citizens of the 21st century.

## References


American Association for the Advancement of Science (AAAS). (1990). *Science for all Americans.* New York: Oxford University Press.

American Association for the Advancement of Science (AAAS). (1993). *Benchmarks for science literacy.* New York: Oxford University Press.

Private Universe Project, (1989). *A private universe* [Videotape]. Cambridge, MA: Harvard-Smithsonian Center for Astrophysics.

Private Universe Project. (1994). *A private universe: Teachers' guide.* Cambridge, MA: Harvard-Smithsonian Center for Astrophysics.

Schmidt, W. H., McKnight, C. C., & Raizen, S. A. (1997). *Splintered vision: An investigation of U.S. mathematics and science education.* Norwel, MA: Kluwer Academic.




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