Essays of an Information Scientist: Science Literacy, Policy, Evaluation, and other Essays, Vol:11, p.251,1988 Current Contents, #31, p.3-9, August 1,1988

Current Comments®

EUGENE GARFIELD
INSTITUTE FOR SCIENTIFIC INFORMATION®
3501 MARKET ST., PHILADELPHIA, PA 19104

Science Literacy. Part 1. What Is Science Literacy and Why Is It Important?

Number 31 August 1, 1988

This two-part essay examines issues concerning science education and literacy in the US and elsewhere. A scientifically literate person possesses an understanding of the nature and limits of science, a mastery of basic conceptual knowledge in the major disciplines, and a sense of the social, cultural, and ethical implications of science and technology. Since science education is a necessary precursor to science literacy, its quality at all levels in the US is reviewed.

Despite the fact that American scientists have won more than half of the Nobel Prizes awarded in science in the past 10 years, the US has, ironically, lost ground in overall science literacy. A survey of American adults conducted in 1985 assessed public understanding of common scientific terms, such as "molecule" and "radiation." Jon D. Miller, Public Opinion Laboratory, Northern Illinois University, De Kalb, found that only 5 percent of those surveyed could be considered scientifically literate.[1] Moreover, the percentage had declined from the 7 percent found in his 1979 survey.[2]

Even worse, science achievement in our schools is quite low. On standardized science tests given in 17 countries by the International Association for the Evaluation of Educational Achievement (IEA), US students ranked near the bottom in almost every category.[3] And with the total college-age population shrinking, so is the pool of available scientific talent.[4] (p. 2, 11),[5] (p. 195)

Scientists and teachers are not the only ones alarmed by these reports. Business and political leaders have expressed concerns about the lack of technologically skilled American workers; policymakers and legislators lament the misapprehension of science-related issues among voters. According to observers like Herbert J. Walberg, Department of Education, University of Illinois, Chicago,[6] and D. Allan Bromley, Department of Physics, Yale University, New Haven, Connecticut,[7] the scientific and technological illiteracy of the American public threatens our economic competitiveness and the vitality of our universities and research institutions. Others, such as Miller, suggest that it may even threaten the survival of our democratic form of government.[1]

Concerns about the level of science literacy in the US are not new; however, we seem to focus on these concerns only periodically, usually in times of crisis. In 1945 President Franklin D. Roosevelt, wishing to continue the scientific gains made during World War II (as in the Manhattan Project), asked Vannevar Bush, then director of the Office of Scientific Research and Development, Washington, DC, to recommend a course of action. Bush's report, *Science: The Endless Frontier*,[8] proposed an increased role for government in the funding of science. It laid the groundwork for an unprecedented expansion in basic research.

Then, in 1957, the Soviet launch of Sputnik fueled an all-out effort to improve US science and science education. While the space program excelled and many scientific advances were made in the ensuing years, efforts to improve US science education, and thereby produce a more scientifically literate public, were not sustained.

Robert E. Yager, University of Iowa, Iowa City, suggests a number of reasons for declining science literacy in the US, including decreased political support for science research, cuts in funding, and cancellation of key science-education programs.[9] Thirty years after Sputnik we face a deeper crisis: we must try to understand why, despite impressive US achievements in science and technology, our society is not producing enough scientifically and technologically literate citizens. Indeed, what novelist C.P. Snow described as the rift between the "two cultures" (intellectuals in science versus intellectuals in other fields) may be but one of many socioeconomic factors involved.[10]

In a previous essay, I discussed the need to encourage undergraduate science.[11] Also, a recent editorial in *THE SCIENTIST*® examined the need to revitalize mathematics education.[12] This essay will discuss what is meant by "science literacy" and review the evidence that science illiteracy is widespread and increasing in America. Part 2 will examine the small amount of relevant research on this subject and consider strategies for combating science illiteracy.

Defining Science Literacy

A key problem in considering this matter is that it is difficult to arrive at a single definition or set of criteria for the term "science literacy." In his essay "Nothing to fear, much to do," Stephen R. Graubard, Department of History, Brown University, Providence, Rhode Island, and editor of *Daedalus* (which devoted a special issue to science literacy), suggests that the very concepts of "science literacy" and "science illiteracy" are so imprecise as to be meaningless, and that these terms are used "principally to sound a political tocsin." Objecting to the atmosphere of panic that surrounds these terms, Graubard urges Americans to respond not out of fear, but out of an understanding of what our society really needs to achieve in terms of literacy.[13] Are these concepts, then, useful only as a way of convincing the public that we have a problem, or can they also help us devise solutions? What do citizens here and abroad really need to know about science?

In 1963 Robert H. Carleton, now retired as executive secretary of the National Science Teachers Association (NSTA), asked a number of leading scientists to define "science literacy." Two common themes emerged: that scientific literacy requires an understanding of the process by which a scientific study is carried out and an understanding of basic science concepts rather than an accumulation of scientific "facts." "It is better to have a thorough understanding of Newton's laws in physics or the role of the cell in biology than to know the galaxy of space vehicles," commented M.H. Trytten, then director, Office of Scientific Personnel, National Academy of Sciences, Washington, DC.[14]

Another observer, A.B. Arons, professor emeritus of physics, University of Washington, Seattle, notes the importance of comprehending the limits of scientific inquiry—that is, to recognize what questions "are neither asked nor answered by science." He also stresses the need to understand the true nature of scientific concepts (such as velocity, acceleration, force, and energy), which are "created by acts of human intelligence and imagination," not discovered accidentally, like a fossil.[15]

Miller, mentioned earlier, adds to the traditional view of scientific literacy another idea: "But if scientific literacy is to become truly relevant to our contemporary situation, one additional dimension must be added: awareness of the impact of science and technology on society and the policy choices which must inevitably emerge."[2] The critical importance of this idea is clear. Toxic waste, nuclear safety, genetic engineering, AIDS—each of us is affected by issues that require judgments to be made on the basis of scientific evidence. Many science-related issues, such as acid rain and depletion of atmospheric ozone, both of which were discussed in past essays,[16,17] also have worldwide impact. We must be able to make informed decisions and communicate about these issues with other nations.

Dana L. Zeidler, Delaware State College, Dover, adds that scientific literacy ought also to include an awareness of, or ability to deal with, the ethical questions raised by these issues.[18]

To be scientifically literate, then, one ought to have an understanding of the nature—and limits—of science, a familiarity with the processes of scientific inquiry, a mastery of basic conceptual knowledge in the major disciplines, an awareness of how the different specialties of science are related, and a sense of the social (global), cultural, and ethical implications of science and technology. This raises an interesting point: Applying this definition, one can't help but wonder how many *scientists* would be considered scientifically literate. With the high degree of specialization in science today, how many scientists follow developments in other fields? And how many scientists take into account the social, cultural, and ethical impact of their work?

Science Literacy in the Adult Population

Although this definition of scientific literacy may seem quite demanding to some, to others it may seem barely adequate preparation for making decisions in this technologically sophisticated age. Representative George E. Brown, a Democrat from California, clearly articulated the need for greater public comprehension of science-related issues: "New technologies will make existing laws and regulations obsolete. Policymakers and legislators will be able to replace them with more appropriate instruments only to the extent that an informed public will give its consent."[19] Brown, who was interviewed last year for *THE SCIENTIST*, serves on the House Committee on Science and Technology and has played a significant role in formulating science policy. The question he and others raise is, How can we, as a nation, make knowledgeable decisions in scientific and technological matters if the majority of Americans lack basic science literacy?[20]

In an attempt to gauge the scientific literacy of the general population, in 1979 Miller surveyed 1,635 American adults. Those surveyed were asked to assess their understanding of what a scientific study is and to supply a definition, to assess their understanding of basic scientific terms (in this case, "radiation," "GNP," and "DNA"), and to demonstrate an understanding of science-policy issues (food additives, nuclear power, and the space program).

Only 14 percent of those surveyed could supply a minimally acceptable definition of what a scientific study is. Only half of those polled thought they had a clear understanding of the term "radiation"; a third, of "GNP"; and only one in five, of "DNA." In the test on policy issues, those surveyed were asked to list two possible harms and two possible benefits related to each issue. Only 41 percent of respondents were able to provide 6 out of 12 possible responses.[2]

In his analysis Miller defined "scientifically literate" as having minimally acceptable answers in each of these three tests. Only 7 percent of all respondents and only 26 percent of those with graduate degrees (not specified) were deemed scientifically literate.[2] We could not determine how many of the latter were scientists, engineers, or physicians. Given that the survey relied substantially on self-assessment and self-identification, one should be guarded against drawing sweeping conclusions. But Miller's tests do provide interesting indications of how respondents view their understanding of science and scientific issues.

In 1985 Miller carried out a similar survey and found that the level of science literacy had *decreased*; only 5 percent of all respondents, 12 percent of those with bachelor's degrees, and 18 percent of those with doctorates were found to be scientifically literate. When asked to agree or disagree with several scientific and pseudoscientific statements, 39 percent agreed that "astrology is scientific"; 40 percent said they believe in lucky numbers; 46 percent disagreed that humans evolved from earlier species of animals; and 53 percent agreed with the statement "Scientific researchers have a power that makes them dangerous." Of all respondents, 57 percent agreed with the statement "In this complicated world of ours, the only way we can know what is going on is to rely on leaders and experts who can be trusted."[21] Miller concluded that "the price of scientific illiteracy is erosion of the democratic principles on which our country was founded—in particular the tradition of informed citizen participation."[1]

Science Literacy in the Workplace

One of the driving forces behind the call for science literacy in the US is the complaint by industry leaders that US workers are not prepared to move into the high-technology jobs that are created as factories are modernized and service-sector businesses expand. The National Science Board's (NSB) 1985 *Science Indicators* report states that "...high school graduates who proceed directly to the workplace need very nearly the same education...as those going on to college."[22] (p. 137)

Science Literacy in US Schools

As noted at the beginning of this essay, the most recent report on the IEA standard science examination given in 17 nations shows that US students ranked very low in almost every age category tested. The 10-year-olds placed highest of any US group; they were 8th out of 15. Fourteen-year-olds from the US ranked a dismal 14th out of 17. A more selective group of 17-year-olds was tested in the US; only students enrolled in an elective second-year high-school science course took the IEA test. Unfortunately, selective testing did nothing to improve US performance. The US 17-year-olds placed 13th in biology, 11th in chemistry, and 9th in physics in a field of 13 nations tested.[3] (p. 3)

One criticism we often hear about such cross-cultural comparisons is that American education stresses understanding of basic principles and concepts rather than rote memorization of formulas and facts. However, a closer look at the 1970 IEA test results shows that US students scored substantially lower than their top-ranked Japanese counterparts, not only on the questions that relied on factual memory, but also on questions that measured broad comprehension of science concepts.[6]

We should not be surprised at this poor performance. The amount of class time devoted to math and science in the US is much less than in other developed nations.[5] (p. 33-4) One estimate suggests that US students spend as little as one-third to one-half as much time studying science and math as do their counterparts in the USSR, Japan, the People's Republic of China, the German Democratic Republic, and the Federal Republic of Germany. (This estimate takes into account days of instruction per year, attendance patterns, length of schoolday and of schoolweek, fraction of total schooltime allotted to science, and amount of homework assigned.)[22] (p. 133)

Science & Engineering Indicators—1987, published by the National Science Foundation (NSF), cites additional reasons for the poor performance by American students on comparative math exams. Math textbooks for kindergarten through the eighth grade contain relatively low percentages of new content from year to year. Moreover, a comparison of average instructional hours spent on math subjects in the eighth grade showed that US schools devote much more time to teaching measurement (7 hours), fractions (18 hours), and ratios and percentages (14 hours) than do Japanese schools (a total of 8 hours). By contrast, Japanese schools devote an average of 18 instructional hours to geometry and 37 to algebra in the eighth grade. US schools devote an average of 15 hours to geometry and 20 to algebra. In the 12th grade, Japanese schools emphasize calculus (an average of 56 instructional hours). Although US schools also emphasize calculus in the 12th grade, they devote less than half as many hours to its instruction (on average, 24).[5] (p. 34-6)

In the US science teaching at the elementary-school level is almost nonexistent (often as little as one or two minutes a day, on average)[23] and in high schools science is treated as an elective course.

The obvious solution to this problem—increasing the science requirements in our schools—may not be easy to accomplish. Another problem at the heart of the crisis in science literacy is the growing shortage of qualified science teachers.[22] (p. 134) The NSTA predicts that if the present decline in the number of science graduates entering teaching continues, we will see a net loss of secondary-school science teachers of 35 percent by 1992.[24]

Our universities are not making up for omissions at the secondary-school level. Last year, Frank H. Westheimer, Department of Chemistry, Harvard University, Cambridge, Massachusetts, stated: "Many of the most prestigious American colleges and universities require the equivalent of only about two half-courses in science for graduation, and some of these courses are special, watered-down courses at that.... We tell our students, by our requirements, that science is all but irrelevant to education, and then we are surprised when they do not seem particularly enthusiastic about it."[25]

In addition, the NSB, the policy-making arm of the NSF, reported in March 1986 "serious problems of quality" in science teaching in US undergraduate institutions, including poor laboratory instruction, unimaginative curricula and classroom instruction, and teachers who were not up-to-date on the latest developments in their fields.[4] (p. 1-2) It is not surprising, then, that the quality of teacher preparation in science is also under fire. In 1985 science and math graduates who planned to teach school scored well below the mean on the Graduate Record Examination, the standardized achievement test required for admission to most graduate schools in the US.[22] (p. 136) If we are producing poorly trained science and math teachers, we will simply perpetuate the current problem. Part of the blame for this lies with the science leadership. As science journalist Deborah Shapley and Rustum Roy, director, Science, Technology & Society Program, Pennsylvania State University, University Park, pointed out in *Lost at the Frontier*, in the early 1980s the NSF drastically cut the portion of its budget allotted to science education, even while the organization's total budget was growing steadily.[26] (p. 111) However, as we've reported in *THE SCIENTIST*, legislators have begun to address this problem, granting the NSF's science-education program a 40 percent increase for 1988, to approximately $140 million.[27] (Roy, incidentally, is editor-in-chief of the *Bulletin of Science, Technology & Society*, which in 1986 and 1987 devoted special issues to technological and scientific literacy.[28,29])

Has substandard precollege and undergraduate science education had a detrimental effect on graduate-level science? *Science & Engineering Indicators—1987* reports that, despite a decline in population in the age group most likely to attend college and graduate school, the number of doctorates awarded in science and engineering in the US has been increasing in recent years. The total number of doctorates in science and engineering awarded by US universities reached a peak of 19,000 in 1972. Following a brief period of decline from 1974 to 1978, this number has gradually climbed each year, reaching approximately 18,250 in 1985 and 18,800 in 1986.[5] (p. 202) This increase is attributed largely to increasing numbers of foreign students earning degrees in the US. In 1985, for example, 26 percent of science and engineering doctorates awarded went to foreign-born students.[5] (p. 198)

In a previous essay, I discussed a group of 50 liberal arts colleges that produce high percentages of graduates who go on to receive doctorates in the sciences.[11] Their success in this area has been attributed, in part, to excellent faculty mentors and to the opportunities these schools offer for students to do active scientific research as undergraduates. For years teachers and scientists have been recommending that we adopt a hands-on approach to teaching science at all educational levels, especially for very young children. A number of recent reports indi-

Table 1: Selected list of organizations and associations worldwide involved in promoting public understanding of science and technology and in integrating studies of science into existing cultural and educational systems.

Association for the Education of Teachers in Science
315 Claxton Addition
University of Tennessee
Knoxville, TN 37996

Committee on the Public Understanding of Science
Royal Society
6 Carlton House Terrace
London SW1Y 5AG
United Kingdom

Commonwealth Association of Science, Technology and Mathematics Educators
Education Programme
Marlborough House
Pall Mall
London SW1Y 5HX
United Kingdom

Federation for Unified Science Education
231 Battelle Hall of Science
Capital University
Columbus, OH 43209

International Council of Associations for Science Education
Department of Professional Studies in Education
University of Hong Kong
Hong Kong

National Assessment of Educational Progress
CN 6710
Princeton, NJ 08541

National Association for Research in Science Teaching
c/o Glen Markle
401 Teachers College
University of Cincinnati
Cincinnati, OH 45221

National Science Teachers Association
1742 Connecticut Avenue, NW
Washington, DC 20009

School Science and Mathematics Association
126 Life Science Building
Bowling Green State University
Bowling Green, OH 43403

Science Talent Search
Science Service
1719 North Street, NW
Washington, DC 20036

Scientists' Institute for Public Information
355 Lexington Avenue
16th Floor
New York, NY 10017

Young Scientists of America Foundation
P.O. Box 9066
Phoenix, AZ 85068

cate that this approach is being implemented in test programs around the country, from elementary to high schools.[30,31]

Although I have emphasized the US thus far in my discussion, it must be noted that these issues—science literacy, science education, the image of science and of scientists—are being scrutinized and discussed in many nations. A recent report in *Chemical & Engineering News*, for example, noted that Mexico is currently dealing with problems similiar to those of the US. These include a shortage of qualified science teachers and, consequently, a decline in the quality and depth of science education. There are also indications that students, along with a large part of the public, harbor "negative feelings" about science.[32] In contrast, a survey of 10- to 15-year-old French schoolchildren, by Goéry Delacôte, CNRS, Paris, indicated favorable perceptions about science and scientists.[33] And in the UK, a report by the Royal Society, London, entitled *The Public Understanding of Science*, discussed science education and related issues. The report pointed out the need for the media, industry, and scientists themselves to become more involved in promoting public awareness and understanding of science.[34] Table 1 is a list of worldwide organizations involved in improving science education and increasing public understanding of science.

In Part 2 of this essay, I will consider some of the strategies that have been proposed for reversing the trend toward science illiteracy, most of which begin with the call for earlier, better, and more science and math education in the schools. I will also review the 1986 and 1987 research fronts related to science literacy and discuss some of the core publications for these clusters.

* * * * *

My thanks to Marsha Hall and Pat Taylor for their help in the preparation of this essay.

REFERENCES

1. **Miller J D.** The five percent problem. *Amer. Sci.* 76(2):[iv], March 1988.
2. ——————. Scientific literacy: a conceptual and empirical review. *Daedalus* 112(2):29-48, Spring 1983.
3. **International Association for the Evaluation of Educational Achievement.** *Science achievement in seventeen countries.* New York: Pergamon Press, 1988. 125 p.
4. **National Science Board.** *Undergraduate science, mathematics and engineering education.* Washington, DC: National Science Foundation, 1986. 61 p.
5. ——————. *Science & engineering indicators—1987.* Washington, DC: National Science Foundation, 1987. 353 p.
6. **Walberg H J.** Scientific literacy and economic productivity in international perspective. *Daedalus* 112(2):1-28, Spring 1983.
7. **Bromley D A.** The other frontiers of science. *Science* 215:1035-44, 1982.
8. **Bush V.** *Science: the endless frontier.* Washington, DC: US Government Printing Office, 1945. 184 p.
9. **Yager R E.** Prologue. (Harms N C & Yager R E, eds.) *What research says to the science teacher.* Washington, DC: National Science Teachers Association, 1981. p. 1-4.
10. **Snow C P.** *The two cultures and the scientific revolution.* New York: Cambridge University Press, 1961. p. 2.
11. **Garfield E.** Research and dedicated mentors nourish science careers at undergraduate institutions. *Current Contents* (33):3-9, 17 August 1987.
12. ——————. Let's revitalize math education. *THE SCIENTIST* 1(24):9, 2 November 1987.
13. **Graubard S R.** Nothing to fear, much to do. *Daedalus* 112(2):231-48, Spring 1983.
14. **Carleton R H.** On science literacy—a symposium. *NEA J.* 52(4):32-5; 57, April 1963.
15. **Arons A B.** Achieving wider scientific literacy. *Daedalus* 112(2):91-122, Spring 1983.
16. **Garfield E.** Acid rain. Parts 1 & 2. *Essays of an information scientist: ghostwriting and other essays.* Philadelphia: ISI Press, 1986. Vol. 8. p. 77-95.
17. ——————. Ozone-layer depletion: its consequences, the causal debate, and international cooperation. *Current Contents* (6):3-13, 8 February 1988.
18. **Zeidler D L.** Moral issues and social policy in science education: closing the literacy gap. *Sci. Educ.* 68:411-9, 1984.
19. **Brown G E.** Biotechnology and science literacy: a federal perspective. *Amer. Biol. Teach.* 46:447-8, 1984.
20. Rep. Brown: a department of science and technology? *THE SCIENTIST* 1(6):14-5, 9 February 1987.
21. **Miller J D.** The scientifically illiterate. *Amer. Demogr.* 9:26-31, 1987.
22. **National Science Board.** *Science indicators: the 1985 report.* Washington, DC: National Science Foundation, 1985. 314 p.
23. **Simpson R D.** National attentiveness to science: an educational imperative for the eighties and beyond. *Education* 104(1):7-11, 1983.
24. **Marcuccio P.** Responding to the economic Sputnik. *Phi Delta Kappan* 64:618-20, 1983.
25. **Westheimer F H.** Are our universities rotten at the "core"? *Science* 236:1165-6, 1987.
26. **Shapley D & Roy R.** *Lost at the frontier.* Philadelphia: ISI Press, 1985. 223 p.
27. **Mervis J.** Budget cuts trim NSF's hopes. *THE SCIENTIST* 2(1):3, 11 January 1988.
28. **Roy R,** ed. Technological literacy. (Whole issue.) *Bull. Sci. Technol. Soc.* 6(2/3), 1986. 205 p.
29. ——————. Technological literacy. (Whole issue.) *Bull. Sci. Technol. Soc.* 7(1/2), 1987. 366 p.
30. **Solovitch S.** Schools look to teach science by doing science. *Philadelphia Inquirer* 10 April 1988. p. 30.
31. **Lyman R.** Breeding scientists in the Bronx. *New York Times* 15 March 1987. p. 19A.
32. **Worthy W.** Science image needs help in Mexico, too. *Chem. Eng. News* 66(26):39, 27 June 1988.
33. **Delacôte G.** Science and scientists: public perception and attitudes. (Evered D & O'Connor M, eds.) *Communicating science to the public.* Chichester, UK: Wiley, 1987. p. 41-8.
34. **Royal Society.** *The public understanding of science.* London: Royal Society, 1985. 41 p.