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Scientific Literacy

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Just how knowledgeable are you about science? Can you correctly identify which of the following statements are true and which are not?

> The center of the earth is very hot.
> Lasers work by focusing sound waves.
> All radioactivity is man-made.
> Electrons are smaller than atoms.
> Antibiotics kill viruses as well as bacteria.

Obtained from the National Science Foundation (NSF) document *Science and Engineering Indicators 2006*, these questions are a sampling of those used in surveys designed to assess scientific literacy. Countries participating in these surveys include: the United States, 25 European Union countries, Russia, China, South Korea, Japan and Malaysia.

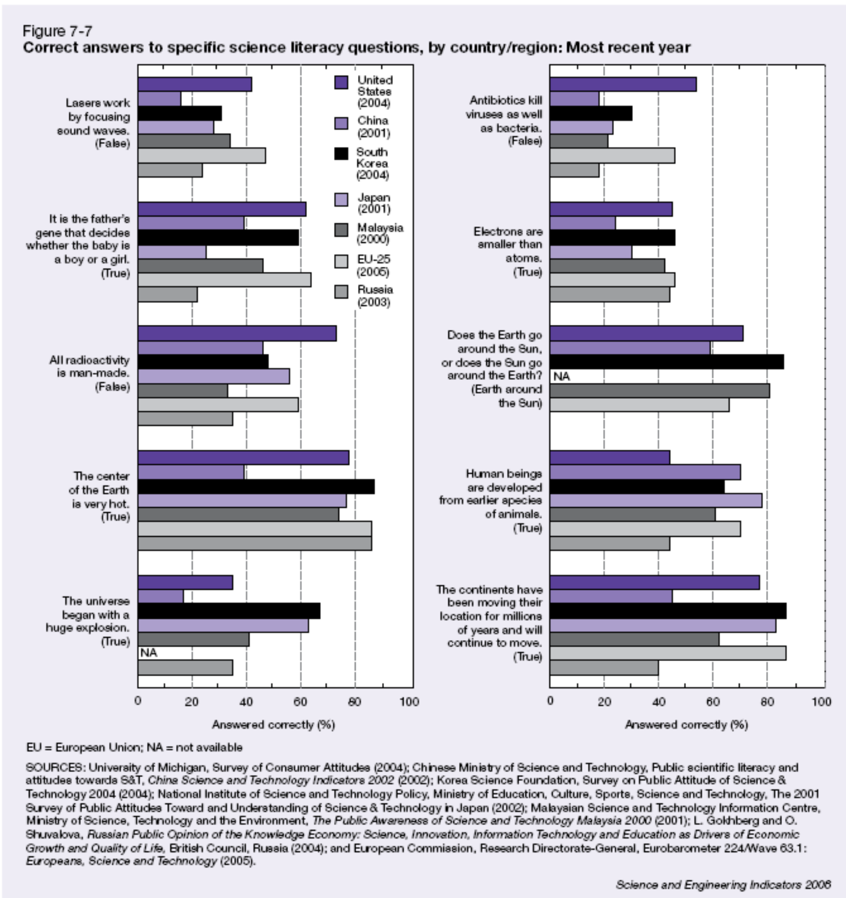

Figure 1: Survey questions from *Science and Engineering Indicators 2006.*
National Science Foundation
http://www.nsf.gov/statistics/seind06/pdf/c07.pdf

The results of such surveys have not been encouraging. The majority of respondents from all countries except China correctly identified the first statement about earth's core temperature as true. However, less than 50% of respondents from all countries correctly identified the second statement about lasers as false and the fourth statements about electrons as true. Only respondents from the United States, the European Union, and Japan scored higher than 50% in correctly identifying question three regarding radiation as false. The United States was the only country to score higher than 50% in correctly identifying that antibiotics do not kill viruses.

In the United States and Europe, correct responses regarding the inability of antibiotics to kill viruses have been increasing since the 1990s. In the United States in 1995 only 40% of people surveyed correctly answered the question. By 2001 correct responses were up to 51%, and by 2004 they had increased to 54%. In Europe in 1992 only 27% of people correctly answered the question. Correct responses increased to 40% in 2001 and 46% in 2005. This increase in knowledge is attributed to public heath campaigns, including media coverage and doctors' warnings, in both the United States and Europe, aimed at promoting awareness of over-prescription and the rise of antibiotic resistant diseases. Any increase in general knowledge, particularly regarding health issues, is a positive outcome. Still, even completely random responses to true/false questions should yield correct answers approximately half of the time. In Asia correct responses ranged from 18% in China to 30% in South Korea. Such low figures suggest not simply ignorance but misinformation.

What is Scientific Literacy, and why does it matter?

There is substantial agreement in the academic community that levels of national and international scientific literacy among the general public are undesirably low for our technologically driven society. However, when it comes to actually defining scientific literacy, the discussion becomes more complex. Some metrics focus on facts, concepts, and vocabulary, while other definitions emphasize the scientific process and reasoning skills (SEI, 2006 and Miller, 2006). Miller (2006) uses the following working definition of scientific literacy for a survey conducted in 2005 in the US and Europe: "A level of understanding sufficient to read science and technology stories written at the level of the *New York Times* Science Times section or an article in *Science et Vie* [a French science magazine]." Hazen (2002) makes a distinction between being able to do science and being able to use science. He states that "scientific literacy, quite simply, is a mix of concepts, history, and philosophy that help you understand the scientific issues of our times." Other academics argue for a deeper knowledge of science, but this overview uses the less demanding definitions provided by Miller and Hazen.

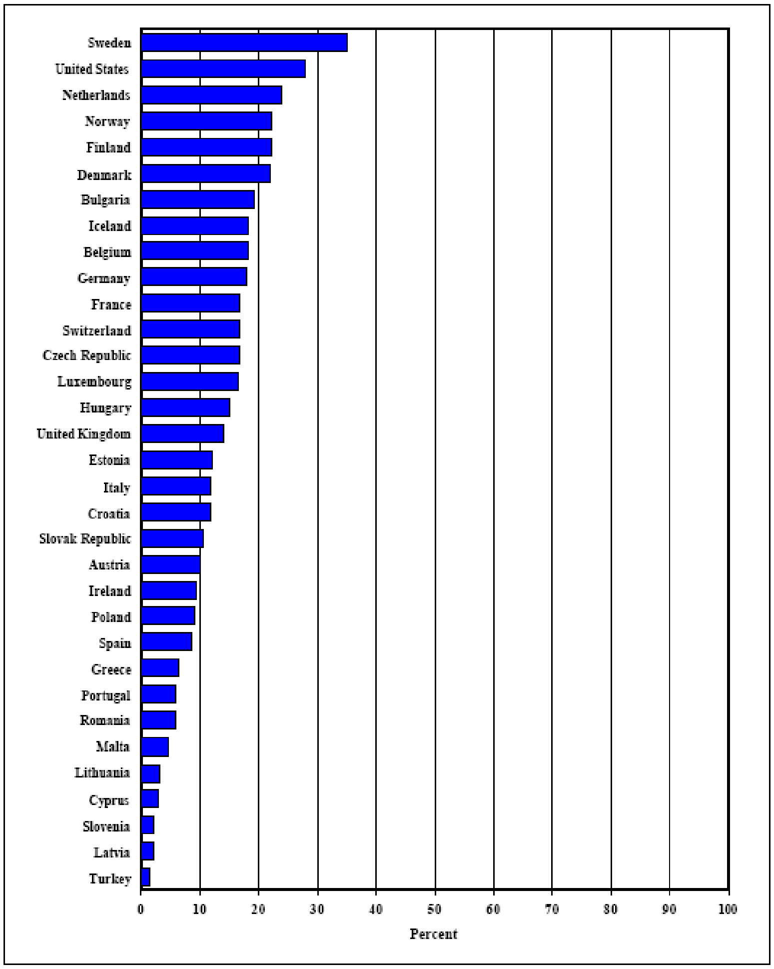

Figure 2: Assessment of Adults considered Scientifically Literate according to Miller (2006).
ARCS Foundation, Inc.
http://www.arcsfoundation.org/Pittsburgh/JMiller.pdf

There are a number of reasons why scientific literacy is considered important. The society we live in depends to an ever-increasing extent on technology and the scientific knowledge that makes it possible. We live in a nation with a rich, but not inexhaustible, supply of natural resources. We live in a world with a rapidly growing population. Decisions we make every day have the capacity to affect energy consumption, our personal health, natural resources, and the environment—ultimately the well being of ourselves, our community, and the world. Individual decisions may not seem to be critical, but when they are multiplied by 300 million nationwide, or nearly 7 billion worldwide, they have the power to change the face of the planet.

Miller (2002), who has been involved in assessing scientific literacy for over three decades, emphasizes the importance of "civic scientific literacy" in a modern society that relies heavily on technology. He believes that 21st century society requires a populace knowledgeable about scientific and technological issues for the democratic process to function properly. From the early 1990s to 1999, levels of adult scientific literacy in the US increased from 10% to 17%, as measured by the standards discussed earlier in this section (Miller, 2002). A further assessment in 2005 showed that scientific literacy had increased to 28% (Miller, 2006). While these increases are encouraging, Miller still believes they are insufficient for the requirements of modern democracy. For democracy to flourish, a voting populace must have the capacity to attain at least a general understanding of the issues they are called on to decide. With barely more than a quarter of the adult population equipped with the basic comprehension required to evaluate scientific and technological issues, it is unlikely informed decisions will guide the political process.

In a democracy, the populace exercises both indirect and direct influence on the creation of public policy. During elections citizens elect politicians and vote on individual ballot items. Ballot choices can include matters that pertain to science, such as natural resources, energy, conservation, pollution, and funding for education and research. Between elections the public can exercise political pressure and influence legislative and executive decisions through public opinion. Many factors help shape public opinion including upbringing, education, personal politics, regionalism, and individual experiences. While such factors have their place, when politics intersects with scientific and technological issues, basic scientific literacy is required for an informed decision making process.

Currently, two issues that have come up frequently in political debate involve human influence on climate change and the utility and ethics of stem cell research. To understand the science behind such matters requires not only acquaintance with climatology and cell biology but some familiarity with the scientific process. Hypothesis formation and testing provides a fundamental mechanism for the accumulation of scientific knowledge. Science does not always provide easy answers and can require a sophisticated understanding of statistical probabilities and mathematical modeling to interpret. Political debate often simplifies scientific issues to the point of irrelevance. Only an audience with the capacity to understand and evaluate the issues under debate can sift through the complexities in order to form well considered opinions.

Another aspect of the importance of scientific literacy is strongly emphasized by the *SEI 2006* report, which points out the importance of specialized knowledge in maintaining the U.S. economy and in enduring competition in the world market. For the past five decades the growth rate of Science and Technology (S&T) jobs in the U.S. has outpaced the rate of growth of citizens trained to fill these jobs. To this point, much of this shortfall has been filled by foreign born immigrants. Frequently, foreign born undergraduate and graduate S&T students in the U.S. have stayed on after completing their education to fill the gaps in the labor force. Over the course of the last decade or two, an increasing number of countries have been developing the technology, resources, and jobs to attract highly educated work forces to their own countries. Furthermore, after 9/1l the immigration policies that have allowed foreign students and workers to come to the U.S. became stricter. As a result, the U.S. workforce has received less supplementation from foreign born workers. Even though the laws have relaxed somewhat since 2001 and the rate of immigration of educated workers is on the rise again, it still falls below the rate prior to 9/11 (SEI, 2006). Beyond the S&T job market, workers from a variety of fields, such as health care support staff, educators, writers, and more, require a basic understanding of science and technology in order to acquire the skills necessary to fulfill the full potential of their individual professional development (Miller, 2002 and NSES, 1996).

A further reason for attaining scientific literacy discussed by Hazen (2002) is for the development of intellectual coherence. The scientific discoveries made by our society often have a strong influence in how people define themselves and view the world in which they live. Terms such as “relativity” and “chaos” acquired new meaning over the last century with the discoveries of Einstein in the early 1900s and the complex geometrical forms of fractals in the 1970s. Discoveries regarding genetics, neuroscience, and health continually reshape our understanding of the human body and personal identity. This touches on the broader issue of cultural literacy. In the 1980s Hirsh discussed the importance of a culture maintaining a shared core vocabulary and knowledge base in order for members of a society to effectively communicate with one another. In his book *Cultural Literacy*, Hirsh pointed out scientific literacy as a weak point in the knowledge of most otherwise well educated people in the U.S.

Since the 1980s there has been considerable discussion of how to fill the gap in scientific understanding in our society. K-12 education has frequently been pointed to as key in effectively addressing this issue (Nelson, 1999 and Hazen, 2002). It has been pointed out that science education reform is a challenging endeavor that will take considerable time and investment to fulfill. In the mean-time college education (Hazen, 2002) and alternative sources of science information (SEI, 2006) also fill a large portion of the efforts to expand scientific literacy.

K-12 Science Education

Halley’s Comet passed by the earth in 1985. In the same year the American Association for the Advancement of Science (AAAS) started work on Project 2061 which focuses on the reform of science, mathematics, and technology education. The project title refers to the year Halley’s Comet will return, anticipating changes in science and technology that society will undergo in the life-span represented by the comet’s return, and emphasizing the need for long-term vision in education reform. The project identified deficiencies in K-12 education, including curriculums attempting to cover too much information with too little depth, unsatisfactory text books, and methods of instruction that did not adequately promote the learning process (Nelson, 1999). Fruits of Project 2061 included a number of documents, such as the texts *Science for All Americans* published in 1990 and *Benchmarks in Science Literacy* in 1993. These texts made recommendations regarding the progress that students should attain over the course of K-12 education and provided aid in developing curriculums.

Starting in the late 1980s, support for the development of national education standards helped drive the production of science education standards. The National Academy of Sciences and the National Research Council worked on the development of the standards, with funding provided by the Department of Education and the National Science Foundation. The National Committee on Science Education Standards and Assessment (NCSES) built on the base provided by Project 2061. The NCSES released the *National Science Education Standards* in 1996.

Figure 3: Science Education Standards for K-12 students emphasize inquiry based learning.
National Academies Press
http://books.nap.edu/html/inquiry_addendum/images/jpg/ch3_f1.jpg

The *National Science Education Standards* is an ambitious project that many people were involved in developing. The guidelines place emphasis on inquiry based education. The process of inquiry involves describing objects and events, asking questions, testing explanations, and communicating ideas. This process is aimed at helping students develop critical thinking skills and logic, consider alternative explanations, and learn to use science knowledge and logic to acquire further knowledge (NSES, 1996). The NSES does not intend to dictate a specific curriculum, leaving curriculum decisions in the hands of states, communities, schools, and teachers. The NSES is meant to provide guidance in defining what students should know by different stages in their academic development and providing guidance on effective teaching methods. The standards specifically cover the following subject matter: teaching, professional development for teachers, student assessment, science education content, education program standards, and education system standards. Developers of the NSES anticipate it will take many years to implement the reforms outlined in the document.

For years K-12 assessments of science and mathematics knowledge have shown that U.S. students frequently lag behind their peers in other industrialized countries. A 2003 survey of mathematical skill has shown some improvement over the past decade; however, a 2000 science assessment has not shown similar improvement (SEI, 2006). We have yet to see the results from the implantation of the NSES, and there are substantial barriers in the process of improving science education. The SEI assessment of Elementary and Secondary Education found a number of factors that negatively affect the teaching of science and mathematics. Science and mathematics majors who go on to teach at the K-12 level frequently show lower academic performance then their peers who go on to jobs in science and technology. Frequently teachers are assigned teaching jobs outside the scope of their college majors. Schools commonly contend with low retention rates for science and mathematics teachers, as teachers move to new schools or leave teaching for more lucrative jobs or better working environments. With the current shortcomings of K-12 education, our society must continue to rely on colleges and outside sources of science information to help promote scientific literacy.

Undergraduate Science Education

U.S. undergraduates must take general education requirements not included in the curricula of other first world countries. College students in Japan and Europe majoring in the humanities do not need to take university level science courses. U.S. non-science majors frequently take from one to three science courses in college. The single biggest factor affecting levels of scientific literacy among adults who did not major in science is the number of science courses taken in college (Miller, 2002). As a result, even though younger U.S. students lag behind their contemporaries in other countries, the level of science literacy among U.S. adults is frequently greater than most European and Asian countries. Only Sweden outperformed the U.S. in the 2005 assessment of scientific literacy (Miller, 2006).

U.S. colleges frequently find it difficult to resolve how best to teach science to non-science majors. To offer one prominent example, in 2001 the president of Harvard University, Lawrence Summers, made a point of emphasizing the need to effectively teach science to undergraduates. However, in the five years Summers served as Harvard's president, the university failed to overhaul the core curriculum (Dizikes, 2006). A committee formed in 2004 failed to come to a consensus on the definition of scientific literacy. While some faculty members believed an understanding of scientific literacy required lab work, other faculty members emphasized knowledge of relevant contemporary issues, such as cloning and stem cell research, or understanding of the history and philosophy of science.

At George Mason University professors James Trefil and Robert Hazen joined forces to develop an undergraduate course focused on introducing non-science majors to an overview of science knowledge. Together they wrote *The Sciences: an Integrated Approach*, a text that has since been adopted by many U.S. colleges. Regardless of the approach taken by individual universities, Miller's results have demonstrated the value of teaching science courses at the undergraduate level. College enrollment has been on the rise over the past few decades, but still over one-third of high-school graduates do not enroll in college promptly after graduation (SEI, 2006). A disproportionate number of students from low income families do not attend college. For those who never attend college, and those for whom college serves only as a distant memory, non-academic sources of science information provide increasingly important sources of knowledge.

Science Information and Popular Culture

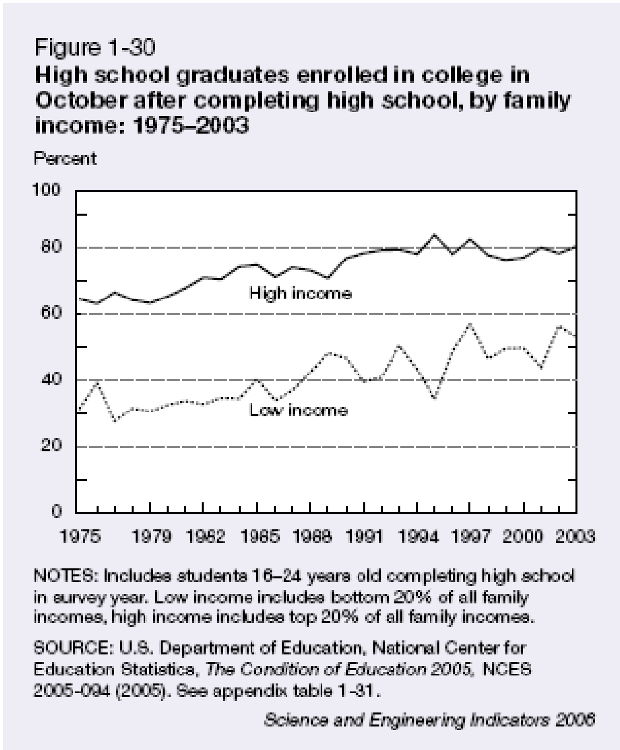

Figure 4: College enrollment rates have increased over the past 3 decades, however gaps exist between social and economic groups.
National Science Foundation
http://www.nsf.gov/statistics/seind06/pdf/c01.pdf

The second biggest factor contributing to levels of adult scientific literacy is informal science education resources (Miller, 2002). Such sources include science articles in newspapers and magazines, science web sites, museums, public libraries, and science books. According to surveys in the *SEI* 2006, television has been and continues to be the largest contributing source to science knowledge in the U.S. and many other countries world wide. Much of this information is obtained inadvertently, either through news stories or entertainment programming.

In recent years the internet has become the second largest information source Americans turn to for science and technology news. The internet is the only information source that has been steadily attracting larger audiences to science and technology information in the past few years. According to a 2004 survey, 73% of respondents had a computer in their household, up from 31% a decade earlier. In the same year 70% of households had internet access, up from 59% in 2001 (SEI, 2006). Internet users are more likely to search for specific information. Topics of great interest among this audience include the weather, technology, and health issues. The internet audience tends to be younger, better educated, and more affluent than the public at large. This can be dramatically observed in trends in internet use. Approximately 50% of college graduates use the internet on a regular basis, compared to fewer than 20% of high school graduates and fewer than 10% of those who failed to finish high school. Another factor affecting patterns of internet usage is access to broadband. Broadband internet users spend more time on the internet, seek a greater variety of information, and are more likely to participate in activities such as distance learning.

U.S. residents are more likely to visit museums, zoos, aquariums, and public libraries than their European and Asian counterparts. Results from a 2001 survey showed that 30% of U.S. residents had visited a museum in the last twelve months, compared to 16% of

Europeans and 14% of Japanese residents. 58% of U.S. residents had visited either a zoo or aquarium in the past year, while only 9% of Europeans and 32% of Japanese residents had visited zoos or aquariums in the same time frame (SEI, 2006). There is a modest increase in rates of scientific literacy for those who participate in such activities.

Conclusion

Science literacy has been increasing in the U.S. over the last 15 years. Still, we are a long way from the vision of universal scientific literacy. K-12 education still offers the greatest hope at reaching the largest audience for upcoming generations. But we are still waiting to see the results of the reforms anticipated in movements such as Project 2061 and the National Science Education Standards. Issues these reforms must address include attracting and keeping qualified teaching staff and confronting the discrepancies in education among differing social, economic, and ethnic groups.

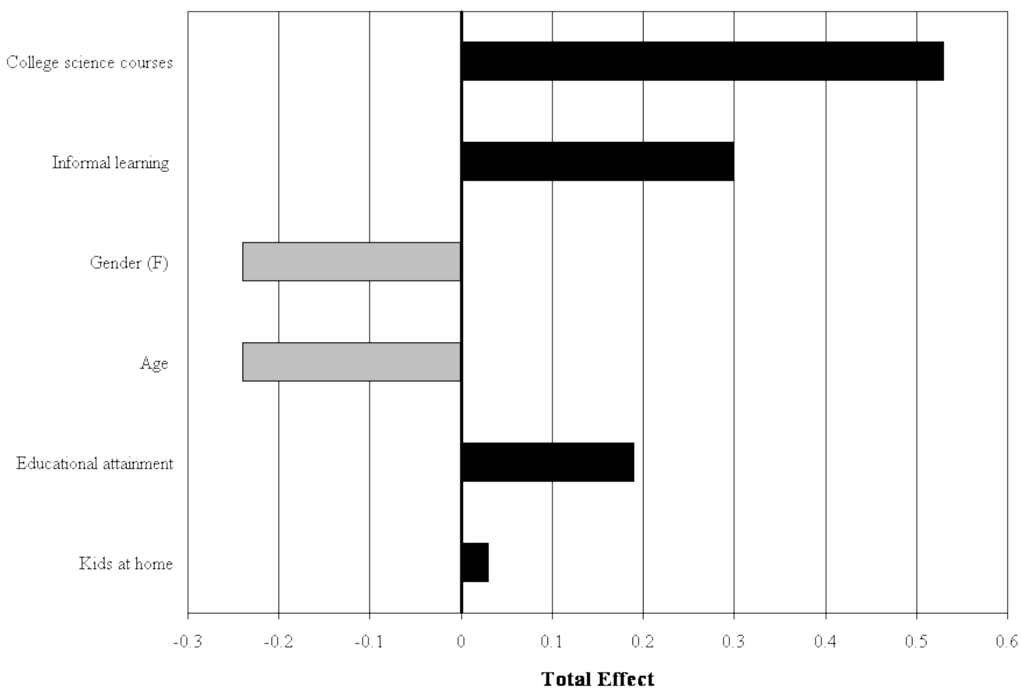

Figure 5: Factors contributing to public scientific literacy.
Federation of American Scientists
http://www.fas.org/faspir/2002/v55n1/scilit.htm

College education can help relieve some of the slack through the teaching of science courses to non-science majors. However, college classes provide no benefit to those who do not attend college. Many of those groups who already lag the farthest behind in knowledge of the sciences at K-12 level are also less likely to attend college. Furthermore, in order to help fill the growing need for a scientifically and a technologically literate work force, it is important to stimulate interest in science knowledge at an earlier age.

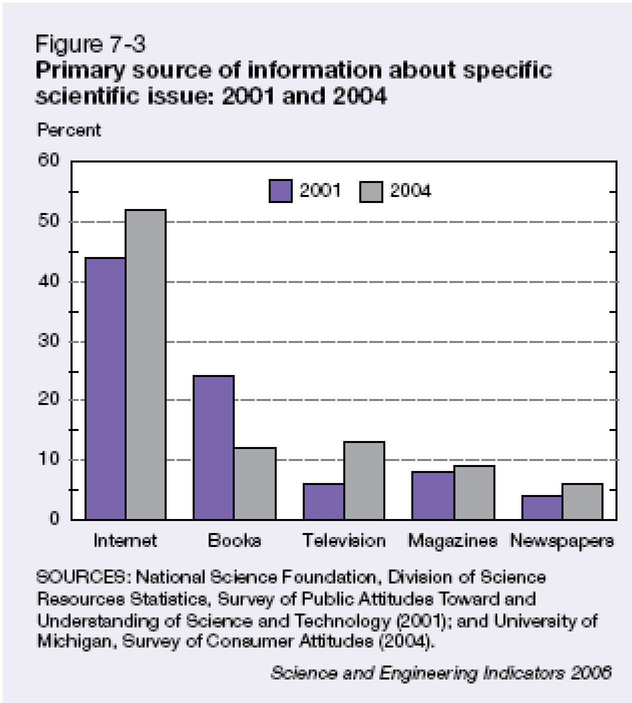

Figure 6: Sources used for attaining science information. National Science Foundation http://www.nsf.gov/statistics/seind06/pdf/c07.pdf

The internet is a promising resource for the promotion of scientific literacy. It is well worth the effort to capitalize on the interests of this growing audience. The internet is a versatile tool that can be used both in the class room, and as a resource for life-long learning. Since the internet has become an increasingly important research tool, it is important to provide easy to find, interesting, high-quality scientific material—in order to best promote scientific literacy. The internet and other distance learning technology can provide the capacity to bring together large audiences that would not otherwise easily communicate with each other. It can strengthen the bonds between formal education and outside institutional resources such as museums. And it can aid in forming the bonds of a community of learning.

The United States has demonstrated that a commitment to life-long learning can in part make up for the deficiencies of insufficient education. With the fast pace of information acquisition in modern society, the maintenance of scientific literacy requires an audience tuned in to new discoveries and new insights. Our best chance to create a society that is truly scientifically literate rests not on one education program, one resource, or on reaching one audience. It involves strengthening education at all levels, using all resources one can obtain, and capturing as broad an audience as possible.

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