



Scientific Literacy: What Is It, Are We Teaching It, and Does It Matter?

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Lately, my perusal of the scholarly literature has been focused largely on scientific literacy, inspired by several concomitant events: overhaul of the General Education curriculum at my university, the ensuing faculty senate deliberations on scientific literacy and its woeful state among our undergraduates, and personal reflections on student learning in my own courses. Service on my university's General Education Committee, charged with revising the current undergraduate curriculum, further motivated me to delve into the literature, and thus was my naïveté revealed. What I expected to be a brief foray turned into a protracted expedition, as scholars have been articulating educational aims, devising pedagogies and measures, and debating the very concept of scientific literacy for decades.

Many readers of *American Entomologist* teach scientific literacy through one or more activities, such as instruction of college-level entomology courses that target non-science majors, involvement with K-12 science education, or informal science teaching through museum exhibits, insect expos, or other venues. In this paper, I highlight the history of science education, present various definitions and measures of scientific literacy, and discuss scientific literacy data for the United States. I do not aim for a comprehensive review; my intention is to provide enough background information and context for thought to inspire other entomologists to become proactive regarding scientific literacy.

A Historical Overview

"Speculative rubbish" and the Two Cultures. Through many public addresses and essays, T.H. Huxley (Fig. 1), known famously

as "Darwin's Bulldog" and no shrinking violet, took up the gauntlet of what might now be termed scientific literacy. In Huxley's day, the British educational system—of which Charles Darwin was a product—focused on mathematics and the classics (Greek and Latin language and culture). Not only was science absent from the curriculum, but to quote Huxley, some regarded it as "speculative rubbish" and averred that "the scientific habit of mind is an impediment...in the conduct of ordinary affairs" (Huxley 1882, p. 4). In an address commemorating the landmark opening in Birmingham, England, of Sir Josiah Mason's Science College, Huxley reproved those who believed that "continual devotion to scientific studies tends to generate a narrow and bigoted belief in the applicability of scientific methods to the search after truth of all kinds" (Huxley 1882,

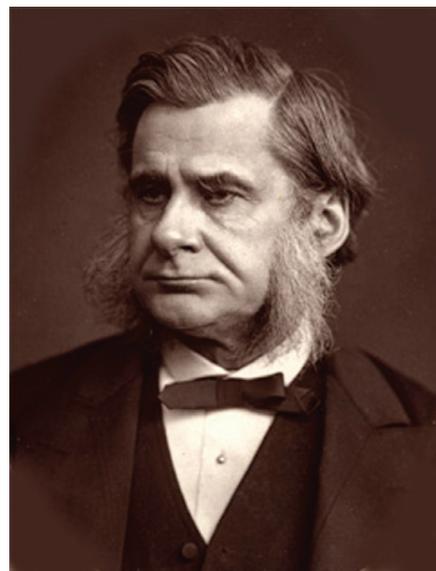


Fig. 1. Thomas Henry Huxley (1825-1895), early proponent of science education. <http://tinyurl.com/7qc8bxx>

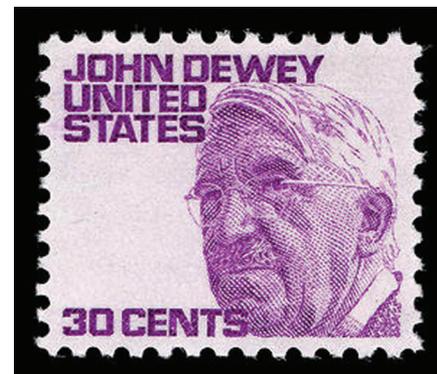


Fig. 2. John Dewey (1859-1952), featured on 30-cent stamp issued in 1968 as part of the Prominent American Series. <http://tinyurl.com/7xl6wp5>

p. 7). Huxley's call for incorporating science training into the British educational system was echoed several decades later, when scientist and novelist C.P. Snow delivered his famous Rede lecture on the "Two Cultures," in which he lamented the communication divide between science and the arts. Snow (1959) argued that improving education in the sciences and building bridges between the two intellectual domains would better prepare citizens to solve the problems of the modern world.

"Scientific attitude" and the pre-Sputnik era. Many historical reviews of scientific literacy begin with a reference to John Dewey (1859-1952) (Fig. 2), an American visionary in education, pedagogy, psychology, and social reform. Writing at the turn of the 20th century, Dewey argued, "Contemporary civilization rests so largely upon applied science that no one can really understand it who does not grasp something of the scientific methods and results that underlie it..." (Dewey 1909, p. 291). He called for educators to train all students to develop a "scientific attitude" or "habit of mind," such

that they would exhibit “open-mindedness, intellectual integrity, observation, and interest in testing their opinions and beliefs” (Dewey 1934, p. 3). Dewey believed that the tax-paying public was justified in requiring a type of science education that benefited the intellect of the individual and thus society at large; his contemporary, I.C. Davis, shared that belief. Based on a survey of science teachers across the U.S., Davis (1935) articulated the characteristics of a student with a “scientific attitude” [see Box 1]. He also organized a group of 350 Wisconsin science teachers who, after a year’s work, produced a list of fourteen unranked science objectives for students [see Box 2]. Although generated 75 years ago, these two lists have stood the test of time remarkably well.

“Scientific attitude” in the sense used by Dewey and Davis is quite different from public attitude toward science, which is today an active field of research. Predicting peoples’ attitudes toward science is complex and can vary depending on culture, educational background, socioeconomic conditions, and country (Miller 1983, 2004; Sturgis and Allum 2004, Allum et al. 2008). To complicate matters, the public’s general attitude toward science can be a poor predictor of its attitude toward specific scientific applications or areas of research (Evans and Durant 1995, Allum et al. 2008).

For historical context, it should be noted that the formal educational attainment of Americans looked vastly different in the time of Dewey and Davis compared with today’s landscape. In 1940, more than 50% of the U.S. adult population (25 years old and over) had no more than an 8th-grade education, and only 6% of males (and 4% of females) had completed four years of college. By 1960, the numbers had improved—40% of males had completed high school and 10% had completed college, but 42% of adult males still had no formal schooling beyond 8th grade (NAAL). Thus, for Davis and his contemporaries, “scientific attitude” was something the great majority of adults would have acquired in primary and/or secondary school, not college. Deliberations about scientific literacy at the tertiary educational level are relatively recent.

Dewey (1934) and Davis (1935) laid the groundwork for science in the curriculum aimed at instilling an understanding of the nature of scientific inquiry, or the “nature of science,” as it is often termed (Miller 1996). Both men believed that sound science instruction would result in a more

Box 1. Fourteen specific objectives (unranked) for the student (Davis 1935)

1. Command of factual information
2. Familiarity with laws, principles, and theories
3. Ability to distinguish between fact and theory
4. Concept of cause-and-effect relationship
5. Ability to make observations
6. Habit of basing judgment on fact
7. Ability to formulate workable hypotheses
8. Willingness to change opinion on the basis of new evidence
9. Freedom from superstitions
10. Appreciation of the contributions of science to our civilization
11. Appreciation of natural beauty
12. Appreciation of man’s place in the universe
13. Appreciation of the possible future developments of science
14. Possession of interest in science

Box 2. Characteristics of a student with a “scientific attitude” (Davis 1935)

1. Willingness to change opinion on the basis of evidence
2. Search for the whole truth regardless of personal, religious, or social prejudice
3. Concept of cause-and-effect relationships
4. Habit of basing judgment on fact
5. Power or ability to distinguish between fact and theory
6. Freedom from superstitious beliefs

scientifically educated American public, but empirical research on the country’s “scientific attitude” was still two decades away.

The first attempt at measuring the “scientific attitude” of the U.S. public occurred in 1957 with a survey commissioned by the National Association of Science Writers (NASW). As fate would have it, the NASW survey results appeared just before Sputnik I (Fig. 3) was launched, and as such, represent a baseline of public understanding of and attitude toward science prior to the space race (Miller 1983, 1996; Trefil 2008a). The survey revealed that while American adults placed great confidence in scientific and technological achievements, their knowledge regarding science was low (Withey 1959, Hurd 1982). Today the NASW survey serves to underscore the need for durable survey questions when timeline comparisons are of interest. In the 1957 survey, respondents were asked about four issues then dominating the headlines: strontium 90 (radioactive fallout), fluoridated drinking water, the polio vaccine, and space satellites. In 2011, these topics hardly raise eyebrows,

precluding any meaningful longitudinal comparisons with today’s adult populace.

Sputnik. The impact of the first Sputnik launch on the American educational system cannot be overstated. Stunned by the Soviet Union’s achievement, which conceivably could be translated into ballistic missiles carrying nuclear weapons from Europe to the U.S., our government responded by pouring billions of dollars into science education. The goal was to produce a bumper crop of young adults in STEM careers (Science, Technology, Engineering, and Mathematics), rather than to improve science education for students whose academic interests lay outside of these disciplines (Trefil 2008a). This watershed episode in U.S. educational history stands as a reminder that “scientific literacy” can mean very different things depending on context and historical timeframe.

NAEP, U.S. Science and Engineering Indicators. Some healthy debate currently surrounds the concept and definition of scientific literacy (discussed more fully below), but U.S. leaders in the field (Miller 1983,

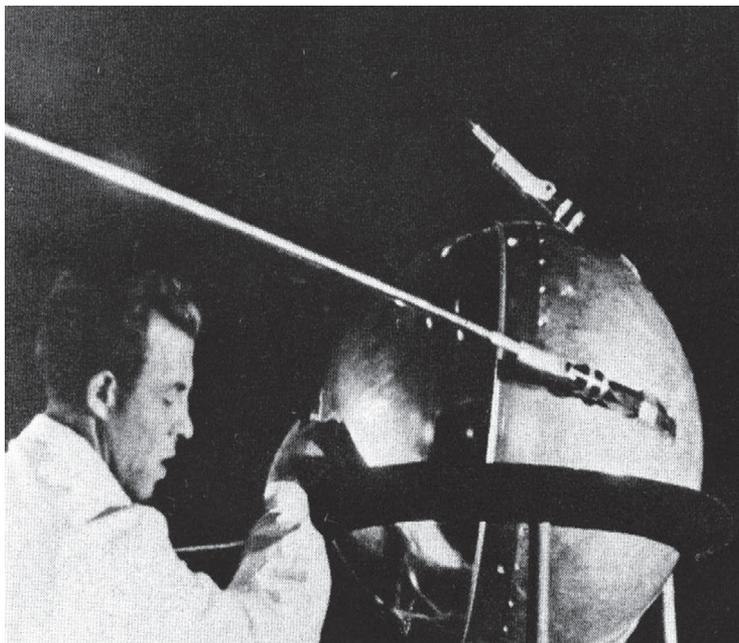


Fig. 3. Sputnik 1. Image from NASA web site shows a technician “putting the finishing touches” on Sputnik 1, launched by the former Soviet Union on 4 October 1957, initiating the space age. <http://tinyurl.com/27egk6>

1996, 1998; Trefil 2008a) and nationally sponsored committees on science education (AAAS 1989; NSES 1996) generally identify three key dimensions of scientific literacy to be met at a minimal (not ideal) level: 1) content knowledge (familiarity with basic science terms and concepts); 2) understanding of science as a process (akin to Dewey’s “scientific attitude”); and 3) impact of science on the individual and society. For American pupils, data on the first two dimensions appeared in 1969, as reported by the National Assessment of Educational Progress (NAEP) for 9-, 12-, and 17-year-old students. By 1986, five NAEP assessments had been conducted that together showed declining achievement scores for all three student age groups (Miller 1983, 1996).

With funding from the National Science Foundation, Jon Miller and the National Science Board (NSB) turned their attention to American adults, developing survey instruments to measure all three dimensions of scientific literacy (basic content, scientific process, science and society). Known as the U.S. Science and Engineering Indicators (Fig. 4), these data have been referred to as the “gold standard” for assessing scientific literacy over time (Trefil 2008a). To generate the indicators for a given year, data from all three dimensions are analyzed and combined to yield a measure of scientific literacy. For 1979, 1985, 1988, 1990, and 1992, the data show that an astonishingly few American adults qualified as scientifically literate—between 7-9% of the popula-

tion (Miller 1996).

The NSB generated additional survey data from the 1990 and 1992 indicators to determine the demographic distribution of scientific literacy and gain insight into parameters that influence it. Using those data, researchers constructed a Science-Math

Education Index, which revealed a strong positive correlation between respondents’ scientific literacy and their exposure to biology, chemistry, physics, and mathematics in high school or college (Miller 1996). For example, only 1% of adults with low exposure to science and math education (≤ 4 courses) were scientifically literate, compared to 7% with medium exposure (5-8 courses) or 24% with high exposure (≥ 9 courses).

A Nation at Risk, Project 2061, National Science Education Standards. In 1983, the U.S. National Commission on Excellence in Education published their report, *A Nation at Risk*, alerting America that its educational foundation was being “eroded by a rising tide of mediocrity” (NCEE 1983). Average achievement by high school students on most standardized tests was lower than when Sputnik I was launched. Further, our students were being outcompeted by their peers in other industrialized nations, “threatening our very future as a Nation and a people.” Understandably, the report pointed an accusing finger at the much fewer science and math requirements for American students compared with their international counterparts. At the time, 35 states required only one year of mathematics and 36 required only one year of science to graduate

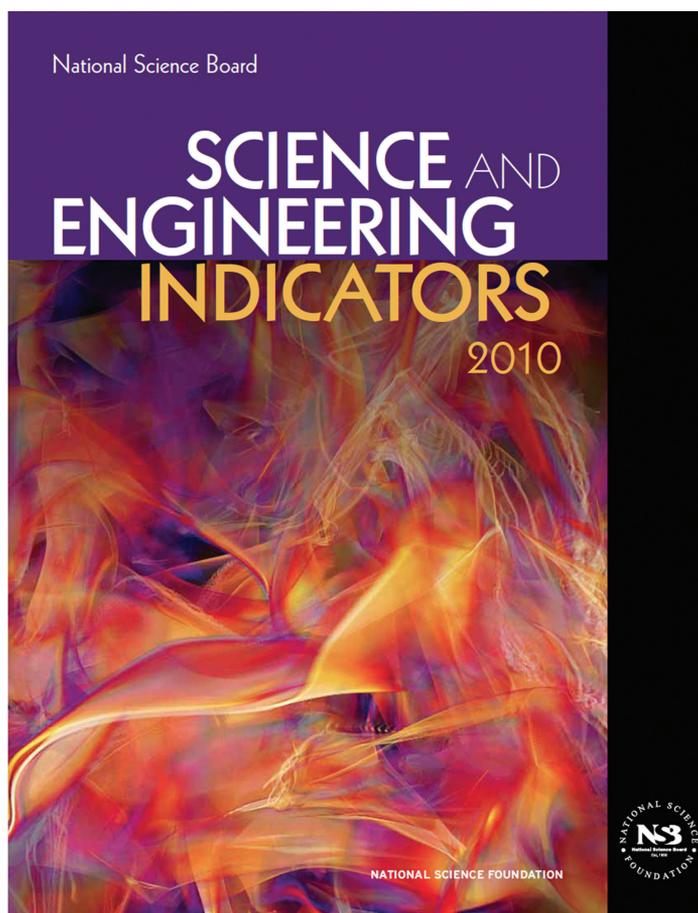


Fig. 4. Science and Engineering Indicators. Chapter 7 of the Indicators for 2010 reports data on public understanding and attitudes about science and technology.

from high school. In the wake of the report, U.S. high school graduation requirements and college entrance requirements became more stringent. Nevertheless, students' test scores have remained approximately flat since the 1970s (Trefil 2008a).

A few years after *A Nation at Risk* appeared, the American Association for the Advancement of Science (AAAS) established Project 2061, a three-phase, long-term plan to improve scientific literacy for all students by reforming education in the sciences (including social sciences), mathematics, and technology. Phase I, outlined in *Science for All Americans* (AAAS 1989), provides recommendations for students' "knowledge, skills and attitudes" and includes emphases on cross-disciplinary integration, paradigm shifts, and habits of mind; Phase II, outlined in *Benchmarks for Science Literacy* (AAAS 1993), lists specific scientific literacy goals and outcomes for students completing grades 2, 5, 8, and 12; Phase III calls for collaboration among scientific societies, institutions, and other interested groups to implement Phase II reforms (AAAS 1989). The Entomological Foundation supports Phase III through its educational resources and programs for grades K-12 (http://www.entfdn.org/about_why_exist.php).

The standards established by AAAS's *Project 2061* essentially align with the National Science Education Standards (NSES) (Fig. 5) proposed by the National Research Council. The NSES emphasize inquiry as a key pedagogical tool to develop and strengthen student understanding of science and the natural world. Standards for teaching, professional development, and educational assessment also are delineated in the NSES (NSES 1996).

Multifarious Dimensions and Definitions of Scientific Literacy

While reading the scholarly literature on scientific literacy, I was reminded of U.S. Supreme Court Justice Potter Stewart's famous quip about pornography—that he might not be able to define it, but he knew it when he saw it. Miller (1983) observed, "scientific literacy" is one of those terms often used but seldom defined." To preclude confusion, any serious discourse on scientific literacy should be framed within a clear and precise definition of the term because its meaning has evolved over time and, as will be discussed, it means different things to different stakeholders, including education scholars. Laugksch (2000) provides a

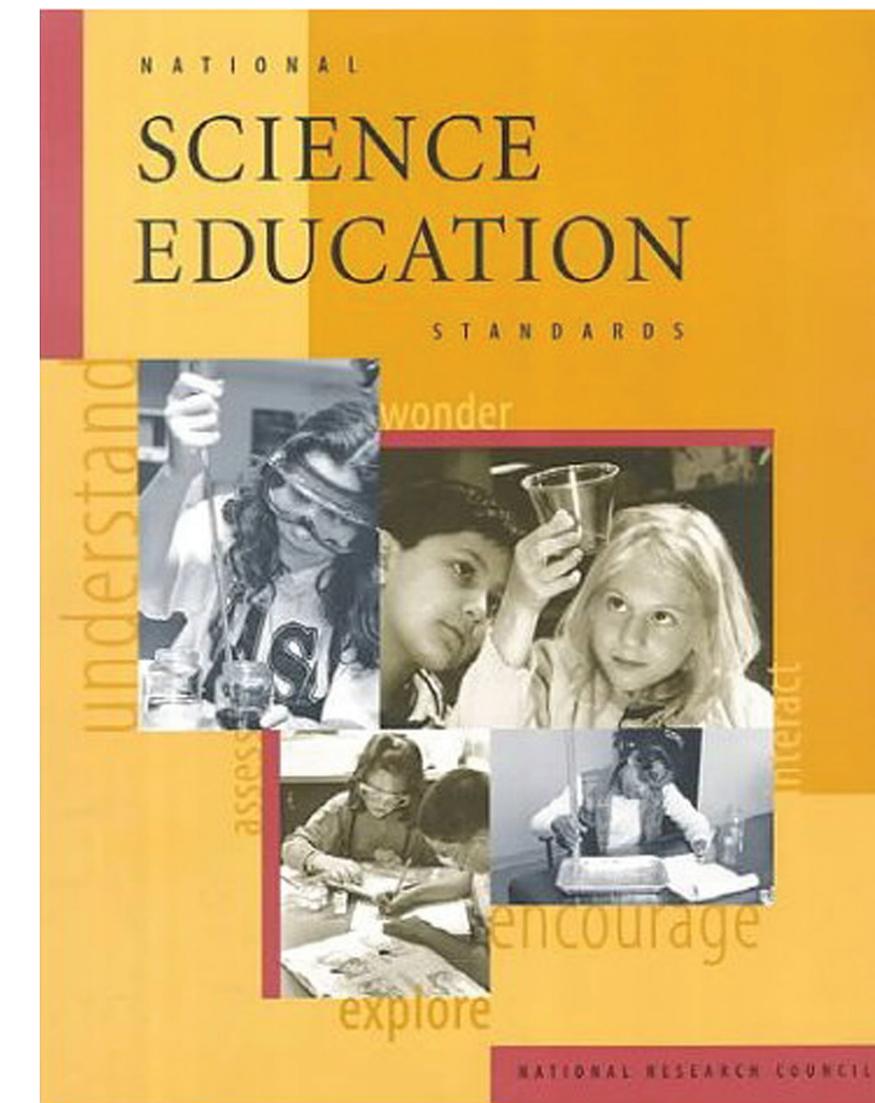


Fig. 5. National Science Education Standards, established under the auspices of the National Research Council, articulate science standards for K-12 students.

detailed model of various stakeholders and their motivations, target audiences, conceptions, etc. Further, assessment and evaluation of scientific literacy varies depending upon the group being examined and the measures and analyses being employed. (As an aside, "scientific literacy" in Great Britain is generally used interchangeably with "public understanding of science," and in France, it is referred to as "la culture scientifique" (Laugksch 2000)).

Scientific literacy: Dateline 1958. According to DeBoer (2000), the term scientific literacy has eluded precise definition ever since it was coined in 1958. That year, in light of the astonishingly swift changes that had occurred by mid-century (e.g., the splitting of the atom, space exploration, and various advances in biological research), three publications appeared that made reference to scientific literacy: 1) a report by

the Rockefeller Brothers Fund, which called for a larger technically trained workforce to safeguard our economic and military strength, and a more scientifically literate public able to execute civic responsibilities intelligently; 2) a publication by prominent Stanford University education researcher, Paul Hurd, who exhorted curricula leaders to develop pedagogies that promoted both the cultural and practical aspects of science; and 3) a published address by the president of Shell Chemical Corporation, who called for new curricula emphasizing the fundamentals of science, its history, and its significance for active citizenship and everyday life. As DeBoer (2000) noted, all three 1958 publications used broad brushstrokes to define scientific literacy, shrouding it in ambiguity. However, all three singled out its importance on individual and societal grounds. In contrast, when scientists and

science educators of the time were asked how they interpreted “scientific literacy,” most replied in terms of content knowledge and the scientific process (Miller’s first two dimensions), with very few mentioning the relationship between science and society (Miller’s third dimension) (DeBoer 2000). This single example of disparate notions of scientific literacy among contemporaries is not atypical and underscores the need for clear definitions and fully articulated goals. In the next few sections, I summarize perspectives from scholars in the discipline to provide a sense of the conceptual spectrum of scientific literacy.

Practical, cultural, and civic scientific literacy. In an oft-cited publication, Shen (1975) (reviewed in Miller 1998, Laugsch 2000) proposed three categories of scientific literacy: *practical scientific literacy*, or the application of scientific principles and technology to improve living standards; *cultural scientific literacy*, or the appreciation of science as a major human achievement; and *civic scientific literacy*, or the level of understanding needed for informed engagement with contemporary science-related issues. More recently, physicist James Trefil essentially expounded on these three categories (Trefil 2008a). He advanced an “Argument from Culture” on the grounds that that science has been a dominant force in Western society for the past 300 years; an “Argument from Aesthetics,” which aligns with Shen’s (1975) cultural scientific literacy definition; and an “Argument from Civics,” posited for civic scientific literacy, which Shen (1975) considered a cornerstone of informed public policy in a democracy. Even scientists, Trefil argues, require some generalized scientific knowledge to engage in rational debate when an issue falls outside their professional bailiwick. Both Trefil and Jon Miller, a social scientist and pioneering researcher on scientific literacy, identify civic scientific literacy as being most critical for people in today’s modern society.

Civic scientific literacy. Jon Miller (1983, 1998) conceptualized civic scientific literacy as a multi-dimensional construct involving three related dimensions, noted earlier: 1) basic science content, 2) science as a process, and 3) the impact of science and technology on society. In practical terms, he defines civic scientific literacy as the level of understanding needed to be able to read and comprehend the Tuesday science section of The New York Times, or to comprehend and follow debates about science and technology

in the media (Miller 1998, 2004, 2007a). Trefil (2008b) concurs, stating that college students “should be able to read the newspaper on the day they graduate.” He adds, “...we should think about the way our students will use their science education in later life, and then adopt goals that support those uses” (Trefil 2008b, p. 8).

Readers seeking a lucid, engaging resource on science education and scientific literacy would do well to peruse the book, *Why Science?* (Trefil 2008a). The author insists that scientific literacy is “not about math and not about doing science,” and remains adamant that active citizenry requires only a minimal amount and type of scientific knowledge because the “real” question is always about something other than science. Citing as an example the debate over stem cell research, Trefil (2008a) argues that once a person comprehends a few basic facts, the real question comes down to one’s own moral and ethical standards. He provides an operational definition: “Scientific literacy is the matrix of knowledge needed to understand enough about the physical universe to deal with issues that come across our horizon, in the news or elsewhere.” (Trefil 2008a, p. 28)

Functional scientific literacy. Both Miller and Trefil embrace a functional conception of scientific literacy. The latter asserts, “...no matter how technological the economy becomes, it remains a fact that most people will never need to do science for a living. Everyone, however, will have to function as a citizen, and they will need to be scientifically literate to do so.” (Trefil 2008a, p. 155). Miller (1996, 2007a) contends that functional literacy is relative to the character of the society and that its threshold is a judgment call made by those knowledgeable about the subject. He terms “functionally literate” those adults who possess the minimum skills required to function in a contemporary industrial society.

At first glance, Miller and Trefil’s pragmatic view appears equivalent to that of Feinstein (2011, discussed below), who argues for scientific literacy that is “useful” to the citizenry in everyday life. But this is hardly the case. To Miller and Trefil, scientific literacy requires a foundational understanding of science. Indeed, Trefil (2008a) avers that one “cannot think critically about nothing” and advances a “Great Ideas” approach to literacy, which entails basic comprehension of 19 fundamental principles that explain how the universe

works. He envisions these as an indispensable framework for civic scientific literacy, unlike Feinstein (2011), who asserts that needing to know something because it is “good to know” (e.g., that the earth is a sphere) is different from needing to know something because it is “useful.”

Fundamental and derived scientific literacy. For purposes of theorizing and setting educational goals, Norris and Phillips (2003) find it helpful to differentiate between fundamental vs. derived senses of literacy, but they see both as inextricably intertwined and comprising scientific literacy. They argue that fundamental scientific literacy has been simplified and narrowed to mean reading, writing, and retrieving and summarizing information, when it should also include the ability to interpret, infer from, analyze, contextualize, and critique science-related texts. The authors point out that scientific statements encompass an array of intent—e.g., an observation, a causal relationship, a generalization, a hypothesis, an assumption, an assertion, a conclusion, supportive evidence, a prediction, a conjecture, etc.—and that students need practice differentiating among them to construe text accurately. To buttress their argument, Norris and Phillips (2003) cite studies indicating that high school and college students who achieve the highest grades in their science courses nevertheless perform poorly when asked to interpret mass media science reporting or to interconnect separate pieces of scientific information. If students are not grappling with texts that carry the content, the authors argue, they will not become literate in the fundamental sense and cannot achieve derived scientific literacy. This they define as being “knowledgeable, learned, and educated in science” (Norris and Phillips 2003, p. 224), which they believe has been overemphasized by educators at the expense of fundamental literacy.

Useful scientific literacy. In sharp contrast to mainstream thinking, Feinstein (2011) argues that science education should focus on the “usefulness aspect” of scientific literacy; i.e., the degree to which science education actually helps people solve personally meaningful, everyday problems and make important science-related decisions. He decries the assumption that students who are taught general scientific principles will be able to magically extend and apply them to specific situations in daily life, and asserts rather heretically that science educators have made rhetorical claims about the

usefulness of science education without providing evidence. Finding inspiration in research on public engagement with science, which emphasizes “real-life” connections with science, Feinstein (2011) argues that the goal of educators should be to help students become “competent outsiders” with respect to science—i.e., teach them how to recognize moments when scientific information would be useful and enable them to locate it, integrate it with their own experiences, and reach an informed opinion or decision. He alleges that traditional education instead produces “marginal insiders,” whose scholastic experiences and rudimentary understanding of science often dampen their interest and impede their confidence in dealing with scientific information.

Summary of science education goals. I trust that the reader has gained some sense of the complexity involved in defining (and, it follows logically, measuring and assessing) scientific literacy. If not, consider the range of science teaching goals advanced over the decades and compiled by DeBoer (2000) in his review of the history of science education (Box 3). In the final analysis, he concluded that although the concept of scientific literacy is a general one and has varied over time, it “usually implied a broad and functional understanding of science for general education purposes” as opposed to preparation for careers in the sciences or technology. He proposed a pragmatic approach (DeBoer 2000, p. 594):

“... we should accept the fact that scientific literacy is simply synonymous with

the public’s understanding of science and that this is necessarily a broad concept. We also need to realize that we cannot do everything. From a wide range of valuable knowledge and experiences, choices have to be made, and these choices will very likely vary from person to person and place to place.”

The Current Status of Scientific Literacy

First, the good news: in the United States, approximately 28% of adults qualify as scientifically literate, an increase from about 10% in the late 1980s and early 1990s (Miller 2007a). Scientific literacy measures for American adults are as good as or better than those for adult residents in other developed countries (Indicators 2010). In addition, a broad consensus of support exists for scientific literacy in the U.S. (Miller 2004), and NSF has funded research in this area for decades and continues to do so. Attitude-wise, thirty years of data show that Americans consistently support government-funded science research and see value in past and future scientific and technological accomplishments (Indicators 2010). Americans also perceive quality education in science and mathematics as crucial at the individual and societal levels. Moreover, 70% of adult respondents feel that the quality of education in these areas is inadequate, and about 74% believe that the government is spending too little money to improve education (Indicators 2010). (These responses were compiled before the current global economic crisis.)

Now for the bad news, stated succinctly

by Miller (2007a): “We should take no pride in a finding that 70 percent of Americans cannot read and understand the science section of *The New York Times*.” Public understanding of science and technology has not changed much from 2001 to 2008; responses to questions posed in various surveys are illustrative. Consider, for example, the most recently available Indicators (2010) data, showing that 53% of male and 71% of female respondents knew that the father determines the sex of the baby; 47% of males and 60% of females knew that antibiotics kill bacteria, not viruses; and 64% of males and 34% of females knew that lasers do not work by focusing sound waves. Or, consider data on U.S. public acceptance of organic evolution, which indicate that one-third of American adults believe that evolution is “absolutely false” (Miller et al. 2006). As Weissmann (2006) put it, “We’re ahead of Turkey, but behind Iran.” Not only is the U.S. behind, Iran, but 31 other countries as well, including Cyprus, Latvia, Lithuania, Bulgaria, Greece, Romania, and Croatia. Moreover, the percentage of American adults who were “not sure” about evolution rose from 7% in 1985 to 21% in 2005 (Miller et al. 2006). On a related note, consider adult understanding of human evolution. According to a Gallup poll conducted in December 2010, 40% of Americans believe that God created human beings in their present form about 10,000 years ago (Newport 2010). Recent survey data show that less than 43% of Americans knew (or guessed correctly in a multiple-choice format) that the earth is billions of years old, and only 30% agreed that the universe is billions of years old (Bishop et al. 2010).

Are we teaching scientific literacy? As I ponder this, a couple of thoughts come to mind. First (and not to be doctrinaire or evasive), whether we are teaching it or not clearly depends on one’s conception and definition of it. That said, the standards established by AAAS (1989) and the National Research Council (NSES 1996) are comprehensive and laudable, and students who achieve them would be considered scientifically literate by any rational measure. This begs the question: how widely are the standards being adopted by primary and secondary public school teachers, and how well are students meeting them? We could ask similar questions about science courses, curricular design, implementation, and their impact on scientific literacy of non-science majors at the tertiary level. The majority of

Box 3. Summary of science education goals in the scholarly literature (DeBoer 2000)

1. Teaching and learning about science as a cultural force in the modern world
2. Preparation for the world of work
3. Teaching and learning about science that has direct application to everyday living
4. Teaching students to be informed citizens
5. Learning about science as a particular way of examining the natural world
6. Understanding reports and discussions of science that appear in the popular media
7. Learning about science for its aesthetic appeal
8. Preparing citizens who are sympathetic to science
9. Understanding the nature and importance of technology and the relationship between technology and science

employers believes that an undergraduate college education should provide a balance between the knowledge and skills needed for a specific field *and* a well-rounded education (AAC&U 2006). Nevertheless, obstacles and resistance to general education and science teaching persist at all levels.

Carl Sagan, who did so much to communicate the wonder and beauty of science through the popular media, once reflected, "... I was lucky enough to go through a general education program... where science was presented as an integral part of the gorgeous tapestry of human knowledge... The status of teachers in [that] curriculum had almost nothing to do with their research; perversely—unlike the American university standard of today—teachers were valued for their teaching, their ability to inform and inspire the next generation" (Sagan 1996, pp. xiv-xv). Trefil shares Sagan's view, stating that teaching is "simply not very important" in today's universities because the reward system neither promotes nor values it. He adds that scientists who teach non-majors face daunting barriers: "Activities designed to raise the country's stock of scientific literacy do little to add to anyone's research; they will not help you publish; they are normally considered in the noblesse oblige category of 'real' science courses; and they certainly don't bring in research money. Given the current situation, it would be foolhardy indeed for faculty members to become involved in dealing with scientific literacy" (Trefil 2008a, p. 139). Scientists, he says, can exacerbate the situation by denigrating or refusing to teach non-majors science courses.

If some faculty at my university are representative of others across the nation, general education can be seen as a waste of time, money, and effort. In a press-release interview, Miller (2007b) acknowledges this viewpoint, but underscores the positive outcomes: "Although university science faculties have often viewed general education requirements with disdain, analyses indicate that the courses promote civic scientific literacy among U.S. adults despite the disappointing performance of American high school students in international testing." Consistently, studies demonstrate that formal science education shows a strong positive correlation with scientific literacy. In 1992, 18% of adults reported having taken biology, chemistry, and physics in high school, and their scientific literacy rate was 15%, compared with less than 1% for

adults who had taken none of these high school courses. Of high school graduates who had taken three or more college-level science courses, 22% were scientifically literate, and the number of courses taken accounted for 80% of variance in scientific literacy (Miller 1996). This pattern of formal education in science as a predictor of scientific literacy level continues to hold true (Indicators 2010).

In addition to faculty, university students often question the value of general education requirements, as anyone who has taught or advised undergraduates can attest. According to a survey conducted for the American Association of Colleges and Universities (AAC&U), senior high school students readily identified "expanded understanding of science" as their least significant college learning goal (AAC&U 2006). Trefil (2008a) traces the origin of the problem to middle school, where students become disinterested in (or worse, disenchanting with) science, and then they move on to high school, where they encounter compartmentalized science courses. These educational experiences hamper scientific literacy, he claims: "The fragmentation of science into mutually exclusive domains (physics, chemistry, biology, astronomy, and so on), coupled with the idea that students need to study only a few of them to learn science is a phenomenon that first surfaces in high school. It reappears, in more virulent form, at the university level" (Trefil 2008a, p. 137).

Does Scientific Literacy Matter?

Given increasingly rapid changes brought about by advances in science, technology, and biotechnology, Miller anticipates an escalating demand for scientific literacy in the workforce, global economy, and public policy issues at all governmental levels. He cautions that the scientific community should find "little consolation" in the fact that science courses at the tertiary level somewhat compensate for inadequate science education at the primary and secondary levels, and bemoans "...the truth... that no major industrial nation in the world today has a sufficient number of scientifically literate adults" (Miller 2004).

Miller is one of several experts who provide compelling arguments for the importance of scientific literacy; by and large, their views are commensurate with the National Science Education Standards (NSES), founded on the belief that all students deserve the opportunity to become

scientifically literate. In a nutshell, the NSES state that because science and technology pervade our world, students need a certain level of science-related understanding to make sound personal choices, engage in rational debate on key issues, develop essential workplace skills (e.g., reasoning, thinking creatively, problem solving), compete in the global marketplace, and enjoy the natural world on a personal level (NSES 1996).

Many scholars (Miller 1996, Sagan 1996, Trefil 2008a) characterize as vital the need for students and the public to be able to distinguish between scientific versus pseudoscientific claims. A series of questions in the Science and Engineering Indicators focus on this ability, which appears to be strengthened by formal science education. For example, in 2008, 78% of college graduates stated that astrology is not at all scientific, compared with only 60% of high school graduates (Indicators 2010).

According to the most recent data, 88% of the sources that Americans use for science and technology information come from television (40%), the Internet (28%), and newspapers (20%) (Indicators 2010). Nisbit and Mooney (2007) point out that the public does not necessarily use such media reports as a scientist would, e.g., by asking whether one side of the issue has garnered strong support from the scientific community. Instead, they contend, the public uses news outlets whose viewpoints match their own, thereby reducing exposure to alternative views and the likelihood of becoming better informed. Of related concern is that tentative "frontier science" is what makes headlines—not established, uncontroversial "textbook" science (Zimmermann et al. 2001). This consideration illustrates that greater public understanding of the scientific enterprise (Miller's second dimension) is not, by default, an esoteric or excessive goal.

Laugksch (2000) reasons that higher levels of scientific literacy would tend to increase support for science and provide the public with a more realistic expectation of science and its capabilities. He also claims it would soften people's view of science as "the epitome of specialization and technology," which tends to elicit a response of "adulation and fear" (Laugksch 2000).

Politics and ideology can significantly influence public attitude and viewpoint, and thereby have major impacts in a democracy. Based on results from a 1979 NSF survey, Miller (1983) concluded that about 70%

of the public who were deemed “attentive” to science policy nevertheless did not meet minimal criteria for science literacy. To interpret scientific information, the attentive public relies on science journalists and reporters as “translators” of scientific information. This concerns Miller on two fronts. First, in his words, a given journalist’s “personality or philosophical perspective may become as important—if not more so—than the substance of the scientific arguments.” Second, because of their willingness to contact their representatives and make their voices heard, special interest groups target members of the attentive public—all the more reason that they be well informed on public policy issues (Miller 1983).

The politicization of science contributes to our staggeringly low numbers for evolution literacy, assert Miller et al. (2006). These authors contend that in the U.S., the conservative wing of the Republican Party has politicized the concept of evolution, a phenomenon not seen in Europe or Japan. On a related note, the Gallup poll cited earlier showed that a significantly higher percentage of Republicans (52%) opt for the 10,000 year-old view of human origins compared with 34% of Democrats and 34% of Independents (Newport 2010).

What Can Be Done?

Concern over what appear to be deplorable levels of scientific literacy among U.S. students and adults has yielded many proposed changes to improve the situation. The strong correlation between literacy scores and formal science and math education provides rationale for increasing these requirements in high school and college. American high school students receive less formal education than their counterparts in any other industrialized nation: only 23% of our students take as many as three years each of math and science, and fewer than 10% ever take a physics course (Trefil 2008a, p. 136). Miller (1996) calls for high school graduation to require three years of lab science and three of mathematics, and Miller et al. (2006) advocate teaching basic evolutionary concepts in middle school, high school, and college science courses. Cell biologist Ken Miller (2010), a zealous advocate for evolution education, recently appealed to his scientific colleagues to speak out against inclusion of scientific creationism or intelligent design as alternatives to evolutionary theory in public school science curricula.

Many contend that focusing on content and process (Miller’s first two dimensions), as is traditionally done in science courses, provides inadequate preparation for students to deal with future science and technology issues. Indeed, to those involved in the Science/Technology/Society (S/T/S) education reform effort initiated in the 1980s, it is wholly erroneous to assume that once students learn scientific vocabulary, principles, and fundamentals, they will “naturally” be able to apply them and understand their impact (Yager 1996). In S/T/S pedagogy, students connect scientific learning to previous experiences and knowledge; consider personal values, ethics, and civic responsibility; and engage in educational experiences that explicitly illustrate how science, technology, and society influence one another. Recently, Krajcik and Sutherland (2010) outlined key approaches to foster science literacy through inquiry, many of which are emphasized in S/T/S pedagogy.

Feinstein (2011) declares that “making science relevant” should be reconceptualized from a teaching tool to a measurable student outcome. Indeed, allowing students to pose their own personally relevant questions can be critical for engagement. Lutz (1996) contends that the primary job of the S/T/S teacher is to engage and retain student interest by employing relevant, “real-world” context. She envisions the instructor as facilitator and guide, while students are fully responsible for identifying a question or problem, procuring the necessary information to address it, and constructing their own knowledge and applying it. Presumably, Lutz (1996) would find fault with Trefil’s “Great Ideas” approach (discussed earlier). She strongly questions the value in requiring students to learn a list of essential science concepts, arguing that genuinely essential, relevant concepts will emerge during students’ information-gathering process.

Students may decide not to pursue a natural preference for a career in science if they experience bad science teaching and dull subject matter, according to findings from the Organisation for Economic Cooperation and Development, which measures students’ interest in science and technology across nations. It recommends flexible, more attractive science curricula with updated content, and pedagogy that employs best practices (OECD 2006).

Arguing that “the kinds of issues that

arise in public debate rarely involve scientific questions alone,” Trefil (2008b) seeks transformative changes in general education and proposes radical curricula for non-science majors (expounded on in Trefil 2008a). For example, he questions the typical “eight hours of science” requirement, saying that it tends to focus on content in a couple of scientific disciplines to the exclusion of others (instead he calls for teaching broadly applicable, basic principles that underlie today’s complex, interdisciplinary problems). He dismisses the notion that students must “do” science, e.g., in lab sections, to be able to appreciate it (reasoning that one need not learn to play a musical instrument nor paint a picture to appreciate a concert or fine art). And he scoffs at teaching the “scientific method” (maintaining that it is but a part of the scientific process and that teaching it will not benefit the future lives of non-majors).

To enter the debate on a science-related issue and reach an informed decision requires the ability to judge the expertise and credibility of the scientists involved (Norris 1995, Trefil 2008a, Zimmerman et al. 2001). This aspect of scientific literacy has not been given due attention, in this author’s opinion. It is rarely taught to science majors, let alone non-majors. Zimmerman et al. (2001) found that when asked to assess the credibility of science news briefs in the popular press, university students “generally failed” to seek expertise-related information. Trefil (2008a) rightly contends that non-experts are typically ill-equipped to evaluate the evidence associated with a particular claim and must instead make a judgment call; at such times, scientific credibility of the experts should be evaluated. How might one teach this? Norris (1995) recommends devising a scientific credibility exercise that focuses on a “real-world problem” currently impacting students’ lives. He believes that students should be taught to maintain a healthy dose of skepticism regarding scientific claims and given practice applying criteria to judge the credibility of the expert(s)—e.g., scientific consensus on the issue, the researcher’s reputation in the scientific community, and the publication in which the findings appeared. Readers might include additional criteria; I would add identifying funding sources and whether the reported findings are associated with a political agenda or involve a conflict of interest on the part of the researcher(s).

Concluding Remarks

Scientific literacy should matter to all entomologists because as scientists, we know better. We understand that science is a double-edged sword: with advances come trade-offs, often attended by environmental, ethical, moral, or other concerns. We also understand that evolutionary theory unifies all the biological sciences, and that application of its principles occurs daily and has improved and saved countless lives. Scientific literacy enables people to weigh options and make informed decisions as individuals and as citizens of a democracy. When experienced as cultural and aesthetic enrichment, it can promote better stewardship of the planet. It is incumbent upon us to give students in our courses, and adults through informal education, experiences that empower them to delight in the natural world, scrutinize sources and information, and deal responsibly with issues at our doorstep and those in the offing.

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