Even while demanding improvements in science education because of a deplorable lack of scientific literacy, advocates do not agree about what they mean. "Scientific literacy" has become a buzz phrase to capture different things, a confusion that is useful at times because it allows people to think they agree when they really do not. Yet, hiding disagreements also keeps us from understanding how we might make things better. This commentary explores the most common meanings and distinguishes scientific literacy—or the democratic having of creative, scientific "habits of mind" by everybody—from science literacy—or the having of particular scientific knowledge by trained experts. Both are important, and we must not lose track of the more difficult and long-term goal of achieving scientific literacy for everybody in the urgency of producing short-term results in the form of scientific knowledge by the few.

Commentary: To the Future—Arguments for Scientific Literacy

JANE MAIENSCHEIN AND STUDENTS
Arizona State University

Scholars have discussed the basic idea of scientific literacy for a very long time; yet, we are left with unanswered questions about what scientific literacy is, its meanings for society, and how to achieve it. In the summer of 1997, a select group of fifteen undergraduates from Arizona began to explore these questions by reading a foot-deep pile of printed materials and then traveling to Washington, D.C., to examine past and contemporary arguments. We discovered a range of views, some consensus, some problems, and some new questions. Our collective perspective, as undergraduates with one faculty leader, offers a different view of the issues and, we hope, represents fresh thinking about old questions.[1]

Author's Note: This commentary was written with students David Borough, Ingrid Burger, Reza Enshaie, Marie Glitz, Arthur Kesh, Kate Kevern, Brent Maddin, Joseph Martinez, Mark Rivera, Diana Rutowski, Matthew Shindell, Pablo Tapia, Alon Unger, Nghi Vuong, and Susan Williams. Marie Glitz has served as editor and coauthor for this version of the article. Address correspondence to Jane Maienschein, Philosophy Department, Arizona State University, Tempe, AZ 85287-2004; phone: 480-965-6105; fax: 480-965-0902; e-mail: maienschein@asu.edu.

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Statements by the American Association for the Advancement of Science (AAAS), the National Academy of Sciences (NAS), and the National Science Foundation (NSF) motivated our study. These three groups have taken the lead in developing the contemporary notion of scientific literacy and promoting it. We expected considerable confusion because of the large number of people involved in each of the three groups' projects. Through the primary writings of all three, there nonetheless emerges the common theme that science is a vital endeavor to which "all Americans" must have access. Rather than simply acquiring separate scientific facts or isolated technical skills, students and adults alike should be able to integrate these scientific facts into a larger conceptual framework. This framework should allow humans not only to understand the processes of science that yield facts and results but also to see how science as a critical way of knowing fits into, and interacts with, other aspects of human society.

In 1985, the AAAS began Project 2061 to look at science and math education in order to develop "a set of tools to help local, state, and national educators redesign curriculum in these areas and insure its success." This points to the centrality of science education in discussions of scientific literacy. Five years later, the AAAS published *Science for All Americans*, which states that the "necessary first step in achieving systematic reform in science, mathematics, and technology education is reaching a clear understanding of what constitutes scientific literacy" (Rutherford and Ahlgren 1990). Project 2061 is the result—a long-range, multiphase effort designed to help the nation understand and achieve scientific literacy. In an attempt to clarify what constitutes scientific literacy, the AAAS describes a scientifically literate person as

> one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes. (Rutherford and Ahlgren 1990, ix)

The second major contributor is the NAS. In introducing the *National Science Education Standards*, the NAS says,

> Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. . . . Scientific literacy has different degrees and forms; it expands and deepens over a lifetime, not just during the years in school. (National Research Council 1996, 5)

Third is the National Science Foundation. Its report *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (*SMET*) asserts that, for scientific literacy,

> it is necessary that every student have an opportunity to learn what science (broadly defined) actually is; what SME&T professionals actually do; how to evaluate information presented as "scientific"; and how society should make informed judgments about science and engineering. (National Science Foundation 1996, 55)

Our careful review of this literature and discussions with representatives of the groups, as well as with congressional leaders addressing the same issues, revealed common goals and statements of what scientific literacy is. As Project 2061 director F. James Rutherford put it at a congressional hearing before the House Science Committee in 1998, there really is substantial consensus about goals and appropriate methods for achieving them. In principle, then, it should just take some work to extract the core agreement from the mountain of printed words.

Despite the apparent agreement, however, our study reveals that there actually is hidden ambiguity and even deep controversy. The NSF, for example, acknowledges that "there is no substantial agreement about what is meant by 'scientific literacy.'" Ph.D. historian of science and U.S. Congressman Bob Filner from California acknowledged this confusion when he suggested to us that "science literacy is like pornography. You know it when you see it." He pointed to the challenges in achieving it—whatever *it* is—especially given that Congress (like the public generally) does not really know much about science and they are even proud of that fact. So, while leaders in science education may agree superficially on a vague ideal of "scientific literacy," there is much work to be done just to be sure we know what we are talking about.

From our search through the written record and discussions with national leaders, we have extracted five basic principles concerning scientific literacy that underpin all these contributions. We lay out these principles and then challenge aspects of the consensus. We offer some insights into ways in which a superficial reading of these principles hides fundamental tensions and obscures important complexities that we need to address to achieve the goals embraced by all. We then make suggestions for moving toward a more scientifically literate future.

The five principles state that scientific literacy (defined as scientific "habits of mind") is (1) a desirable goal, (2) for all Americans, (3) measurable and assessable, (4) useful for everyday life, and (5) inextricably connected with its social context. Each of these principles is important, widely held, and strongly defended, even (somewhat paradoxically) in the United States where citizens are as much as 90 percent scientifically illiterate by some counts (Shamos 1995, 99). Yet, each also obscures significant complexities that can keep us from moving effectively forward.

Scientific Literacy Is a Desirable Goal

Two primary types of argument have been offered about precisely why scientific literacy is thought to be desirable. First is the idealistic, concerning what is thought to be of value: scientific literacy, like literacy generally, is an intrinsic good—good on moral, aesthetic, and other principled grounds. The emphasis here is on the attitude produced, on the process of doing science, and on scientific ways of knowing and critical thinking about the natural world: it is good to have critical thinkers rather than uncritical ones. Without such critical scientific thinking, as Carl Sagan (1995) argues, people will be swayed by superstition or pseudoscience and can be easily fooled. Being scientifically literate allows people to live "better" lives—in the philosophers' sense of the "good life," which is more reflective, fulfilling, and worth living, and also produces better citizens who will vote more intelligently and be more productive members of society. Science is beautiful, exciting, valuable, and fun, according to this view. It is, at the same time, valuable in many long-term practical ways, so this is not simply about abstract aesthetic values. This is really an issue of promoting *scientific literacy* as the best way of understanding the natural world.

Second comes the more directly practical value. It often has been argued that *science literacy* is practically or pragmatically even better, particularly with a mind to short-term results. It is, in this view, an instrumental good. And there are economic advantages when people have better training with more scientific, mathematical, and technical skills. This argument emphasizes acquiring facts and basic technical skills rather than ways of knowing and acquiring more abstract critical-thinking "habits of mind" such as those involved in the creative problem-solving of scientific literacy. Science literacy stresses gaining units of scientific knowledge itself rather than the process of always learning more.

Most of the literature embraces both arguments, often muddled together. Political leaders tend to be more influenced by the practical goals of science literacy, which relate to creating a productive workforce and enhancing quality of life for all. Academics—at least scientifically literate academics— tend to like the more abstract and idealistic approach of scientific literacy. We think that both goals are important for the long-term good of society but that it is scientific literacy that will actually produce practical as well as intrinsic value. People are really just interpreting the needs of society differently and focusing on relatively longer- or shorter-term goals.

The two interpretations and goals are often in tension, with different implications for science education, for testing, and for public funding of science. Scientific literacy requires teaching in a different way, a way that only a few teachers are currently prepared to do. It stresses longer-term process over shorter-term product and questions over answers, so that in the short run the student may know fewer things but goes forth in the world with skills for learning more things on his or her own. This scientifically literate person knows how to learn so that he or she presumably can better adapt to the challenges of a rapidly changing world. All three Washington-based groups (AAAS, NAS, and NSF) have worked hard to embrace both emphases (on scientific and on science literacy), without officially acknowledging the differences and possible contradictions. They probably did this initially for political reasons, since science and technical skills are easier to sell than longer-term skeptical and creative, scientific habits of mind. But we think it would be better to acknowledge the tension and work hard to convince the public and its government to embrace the goals of both the idealistic longer-term process and the more immediate pragmatic products. We need a society of critical and creative thinkers who will take us beyond what we know, but who also can function productively now.

Note also that in the instrumental pragmatic argument for science literacy, technology is frequently lumped together with science, in part because technology is often a result of scientific exploration. However, science and technology are importantly different things. Recognizing this distinction also points to the danger of overemphasizing technology's role in achieving literacy, since mere access to the Internet or computer skills, for example, will not promote an appropriately critical and creative hands-on engagement with the natural world.

Scientific Literacy Is for All Americans

On the surface, the argument that scientific literacy should be for all Americans seems noncontroversial, given that we have accepted democracy as a good thing and that we are supposed to be an egalitarian nation. But then we need to acknowledge that substantial numbers of the scientifically illiterate are adults, already out of school, so that we need new ways to reach them. If society accepts that some of us do not need to be scientifically literate, while we nonetheless accept the argument that such literacy is a good thing and that it offers an economic advantage, there is great danger that some people will be treated as inferior because they are not in the elite of the scientific "knowers." Indeed, as Robin Dunbar (1995) suggests, "we may well be heading for the creation of a high [scientific] priesthood that is beholden only to itself. Some would argue that we have already reached this point in certain areas of science" (p. 178). This raises problems for science, since a disenfranchised illiterate majority is unlikely to remain sympathetic to providing the public support on which basic science has come to depend. It also raises problems for our democratic society that depends on informed decision making by wise citizens.

So, we challenge whether those who promote scientific literacy really mean *all* Americans, and if so, we ask how much literacy and at what cost? Do they intend to offer access to scientific literacy for all disabled and disadvantaged students, despite the costs, and if so, who pays? We say, yes, they should mean all, but we must strive to lower the costs of access. We also accept that it may make sense to provide different levels of scientific literacy for different groups, since obviously not everybody will be a research scientist. But let us not settle for too little, for too few. What if we decide nationally that scientific literacy is good for all, but local and state groups decide either that it is less important than other goods or that it is simply too expensive? Who will then provide incentives for teachers and schools to promote critical scientific thinking? We think this is vitally important, and although citizens should have the freedom to choose not to use the critical and creative habits of mind that come with scientific literacy, they must all be offered the opportunity to acquire those habits, just as all citizens should have the opportunity to read and write. This will take a careful balancing of federal standards and local and state implementation.

Both for idealistic and pragmatic reasons, we believe that a nation—and a world—of the scientifically literate is better than one of the illiterate. But then why stop with Americans? Why not strive to make Americans more globally literate and help make everyone everywhere scientifically literate? After all, science shows that neither science nor the natural world it studies is constrained by artificial national boundaries. Why does winning the TIMSS (Third International Mathematics and Science Studies) contest (by scoring well on standardized tests) seem so important to so many? As the NAS's *Standards* acknowledges, individual investigators working alone sometimes make great discoveries, but the steady advancement of science depends on the enterprise as a whole. And, as the AAAS points out,

> The most serious problems that humans now face are global . . . the list is long, and it is alarming. What the future holds in store for individual human beings,

the nation, and the world depends largely on the wisdom with which humans use science and technology. (Rutherford and Ahlgren 1990, v-vi)

Even if frequent references to the United States' relatively poor performance on TIMSS is just strategic, an attempt to motivate concern for science and science education as Sputnik did four decades ago, the failure to recognize the interconnectedness of the global community—of scientists and citizens of the world—is real and dangerous (Schmidt, McKnight, and Raizen 1997). As the AAAS makes clear, isolationism conflicts both with the idealistic values for wider scientific literacy and with the search for pragmatic uses of science (Rutherford and Ahlgren 1990).

Scientific Literacy Is Measurable and Assessable

As the NAS points out, "teaching and testing are integral components of instruction, and cannot be separated" (National Research Council 1996, 11). Words such as *improve*, *sufficient*, *standards*, *expectations*, and *rewards* also abound, suggesting the value of testing to identify success. The basic premise of the AAAS's (1993) *Benchmarks for Scientific Literacy* and of the NAS's *Standards* is that we can set goals and then assess whether we have reached them. The NSF urges measurement and testing, and the current political climate emphasizes assessment and standards to ensure productivity—mostly at the state level since the country remains strongly opposed to national standards and national testing. This desire for assessment assumes, perhaps prematurely and presumptuously, that we know how to test and compare appropriately.

We do know how to test some things, but do we know how to assess whether someone has acquired a different conceptual approach or a better "habit of mind?" How do we assess whether someone has acquired the attitudes that will pay off in, say, ten years with more critical thinking and more creative approaches to the natural world? We may be able to develop effective measuring instruments, but it may take more than one single test given at regular intervals. This testing will not be easy. Nor will it be cheap. Any form of national benchmarks or testing must recognize the contradictory goals and must not generate any one simplistic test that then rewards teachers and students for teaching and learning for just that test.

Above all, we must not allow ourselves to be seduced into settling for only mastery of selected facts. As Joseph Levine (1990) put it in "Scientific Illiteracy: We Have Met the Enemy and He Is Us,"

> We have many major battles ahead of us. Not the least of these are direct confrontations with powerful national special-interest groups on both the political left and right and well-placed individuals in Washington whose "educational" statements barely veil their political and social agendas . . . these voices are attempting to replace curricula that teach students to think for themselves with rigid prescriptions for "what they should know." Lynne Cheney, [former] chair of the National Endowment for the Humanities, has railed at the "pernicious way . . . our elementary and secondary schools [emphasize] approaches to knowledge, on knowing how to learn as opposed to actually learning something." (P. 11)

"In that context," Levine (1990) urges, "it is our solemn responsibility as academics to act as perniciously as possible" (p. 11).

We agree. It is our responsibility to promote independent critical thinking, to develop skeptical and creative, scientific "habits of mind." We saw this discussion play out this past year in the Arizona Department of Education, which threatened to remove all references to "evolution" from the state's biology standards. Only active involvement by teachers and scientists with the support of prominent members of the board of education, including Superintendent Lisa Graham Keegan, arguing for the importance of science education to promote scientific literacy, won the inclusion of basic evolutionary ideas.

Scientific Literacy Is Useful in Everyday Life

Both the knowing of scientific facts and scientific ways of knowing are useful in practical, real-world settings. "Americans are confronted increasingly with questions in their lives that require scientific information and scientific ways of thinking for informed decision making." So, scientific literacy is useful for "informed decision making." Furthermore, "And the collective judgment of our people will determine how we manage shared resources—such as air, water, and national forests" (National Research Council 1996, 11).

We have identified numerous other areas where scientific literacy makes a difference in everyday life, including the increasingly important areas of medical and genetic decision making. It is not just (or even primarily) knowing particular facts that is important but being able to sort through the confusion to make decisions informed by the best available information at any given time. And this must be done by the public—a scientifically literate public—rather than by scientists who might seek to control the decisions themselves but should not. Informed use of science and banishing of pseudoscience should help to combat the racism, sexism, bigotry, and social injustice that often are grounded on false perceptions of biological differences that science shows are of no real significance.

Increased scientific literacy can help with basic actions like informed selection of a doctor and determining which treatments to accept and which to question. It produces both skeptical habits of mind to keep seeking to know more and a willingness to accept change and revision. What is "known" one day may be replaced the next day with something quite different and even apparently contradictory. Scientific literacy teaches us to expect such change and difference, and gives us approaches for sorting through and selecting among alternative accounts. So it teaches us why we need to take the entire course of antibiotic treatment and also why those antibiotics will someday be replaced with something different. It teaches us, for example, why simple genetic explanations of disease are not sufficient and can, in fact, lure people to false expectations and dangerous decisions.

But while science is necessary, it is not sufficient for making real-life decisions. It is useful for everyday life but cannot alone solve all our problems. Science is a social activity and inevitably is part of the social context in which it takes place. Therefore, science is useful in particular ways, as providing a basis for informed decision making.

Scientific Literacy Is Inextricably Connected with its Social Context

We realize that this is the most controversial point of all. We are told, "Science as an enterprise has individual, social, and institutional dimensions" (Rutherford and Ahlgren 1990, 9). And that despite its attempts at objectivity, "in matters of public interest, scientists, like other people, can be expected to be biased where their own personal, corporate, institutional, or community interests are at stake" (Rutherford and Ahlgren 1990, 13). Both the AAAS and the NAS readily agree that science is a human enterprise, carried out by real people who can be fallible and who can become biased in their pursuit of knowledge when diverted by personal or social interests. As physicist Morris Shamos (1995) points out, even scientists do not vote dispassionately. Yet, such writers seem not to recognize the profound challenge they are issuing. This is not a simple point, but it profoundly affects our view of science and of the way it should be taught.

If science can be biased, in the sense of less than perfectly objective, then how do we know which scientific claims to believe? True, the conventions of the scientific community contribute to a self-correcting process for science. Yet, selecting among competing claims by competing scientists in different communities is difficult and can lead to appearances of relativism and lack of reliable standards. We do not want to get caught in battles about postmodernism but feel that scientists must remain as skeptically open-minded about different scientific interpretations and approaches as they are supposed to be about the natural world in general. There is room for science to be a social activity, shaped by social forces that influence not only individual scientists but also the content and doing of science itself. There is room for that social side of science without giving in to the claim that science is just one of many equally useful or equally valuable ways of knowing, and perhaps not a particularly important one at that. We believe in the power of science, but we see it as inextricably part of society.

In all our readings, discussions of science as a human and social activity seem tacked on rather than deeply or profoundly integrated with discussions of the "real science." The social considerations do not inform the rest of the arguments for scientific literacy. We think they should and that this will not hurt science at all. We do not need to see science as transcendent or carried out in a vacuum to preserve its importance and success. And when we accept science as shaped by society, it becomes more real and more interesting to students who are otherwise intimidated or alienated. It gives science a more central place in societal decision making. The implications of this principle need more attention, and we should not be afraid to deal with the consequences and teach science differently at all levels, as a social process. Science and scientific literacy are strong enough to handle what might seem like challenges and questions.

Conclusions

In summary, we see all the writings and discussions we have studied as a great start on an important subject: What is scientific literacy and how do we promote it for all? We were pleased that the first Ph.D. physicist in Congress, Congressman Vernon Ehlers, was appointed by the U. S. House of Representatives Science Committee Chairman James Sensenbrenner and House Speaker Newt Gingrich to study science education in the United States, alongside his development of a science policy statement, and that he recognizes some of the important questions about scientific literacy. Unfortunately, not much of that discussion found its way into the report *Unlocking*

Our Future (U.S. House Committee on Science 1998). Nonetheless, we are pleased to find some basic consensus in all the pile of written materials and verbal discussions by all the different "alphabet soup" of groups participating in the discussions.

But so what? What do we conclude from this study?

1. Scientific literacy is a desirable goal, but different definitions and arguments for it have markedly different consequences.
2. Scientific literacy is good for all, but it is not good enough to target only Americans in isolation without promoting a global perspective. In addition, we may need to settle for different levels of literacy to maximize the number of those who have any at all.
3. Measurement and assessment are desirable, but only if we know what we are measuring and why.
4. Scientific literacy is necessary, but not sufficient for making informed decisions in modern society.
5. Science is a process carried out by human beings who work in a social context—that perspective must be an inseparable part of our science education.

We must not pretend that science is a pure and absolutely objective pursuit, insulated from all social forces. We should expect controversy and disagreements, then develop the critical habits of mind to deal with them. Above all, we want to reinforce the point that the apparent consensus obscures significant complexities, and we need further work to continue moving successfully toward the goals of achieving fuller and wider scientific literacy. We need constant attention and refocusing to keep the objectives clearly in view. Even as we have worked on this article through many drafts for more than a year, presenting ideas at an AAAS meeting and in our invited editorial for *Science*, we have felt the ground slipping under us and have had to work at keeping the main points clearly in focus. As members of a society concerned with promoting what is good, we need to continue working at arguments advocating scientific literacy that draw on past successes while looking to future improvement. Rachel Levinson at the President's Office of Science and Technology Policy told us, in jest, that perhaps we need to clone Bill Nye "The Science Guy." Well maybe. But that is clearly not sufficient. We must engage all in promoting scientific literacy for all.

Note

1. The project began when Professor Jane Maienschein was asked by Arizona State University President Lattie Coor to serve as science adviser to our district Congressman Matt Salmon. Part of that agreement involved a special seminar on "Science, Literacy, and Washington, D.C."

We considered issues of scientific literacy and also asked about the relative roles of the federal government, nonprofit organizations, and educational institutions. Some of the students have graduated and will be pursuing studies or research in bioethics or careers in public health, creative writing, teaching, editing, medicine, and other graduate study, with a selection of Rhodes, Truman, Udall, and other national scholarships, a couple of *USA Today* All-USA team winners, and local service and academic awards. The project and follow-up results included presentation of a paper at the 1998 American Association for the Advancement of Science (AAAS) annual meeting and publication of an editorial in *Science* on 14 August 1998.

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JANE MAIENSCHEIN is Professor of Philosophy and Biology at Arizona State University and codirector of the Biology and Society program there. Her research centers on the history and philosophy of biology, especially developmental biology and genetics, asking about the changing assumptions concerning what counts as good science. She is author of Transforming Traditions in American Biology *and numerous other books and articles, and is coeditor with Garland E. Allen of the* Journal of the History of Biology.