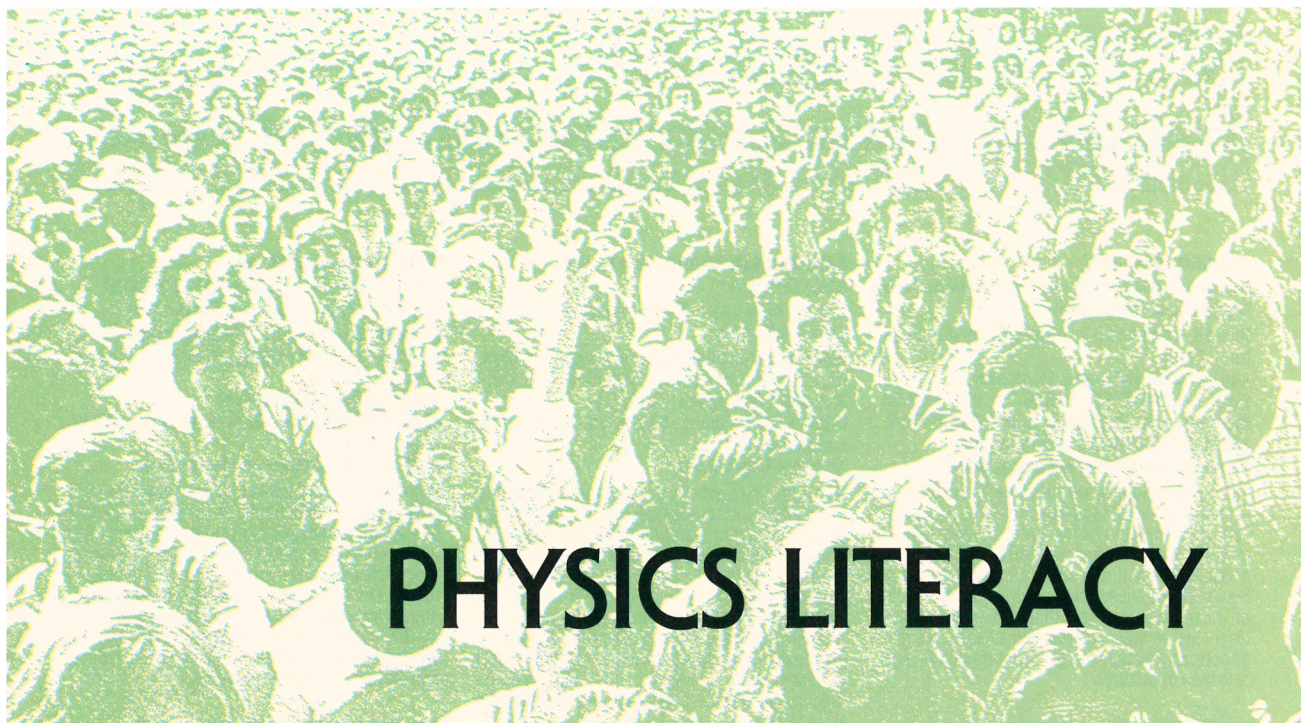




PHYSICS LITERACY

Everyone these days seems to agree that the general public is lacking in scientific literacy, but the agreement often ends there. Some see science literacy primarily in terms of industrial competitiveness, as something necessary to meet the needs of employers who are crying out for technically trained people. The primary concern of others is for the public to enjoy what they see as one of the greatest intellectual adventures of our day. Yet others seek a more self-confident citizenry, a public that feels competent to assess the credibility of technical experts and to take a position on which scientific and military projects should go ahead.

These differing priorities lead to differing definitions of science literacy itself. Is it knowledge of a set of facts or principles? Does it mean adopting, to some extent, a scientific worldview? Does it require an understanding of the historical and social contexts of science?

Whatever the definition, does the average person really need to be scientifically literate to enjoy life and perform well on the job? And if so, is science literacy for all—like the three R's—a reasonable goal?

What can be done to create a scientifically literate public? Can renovations in the educational system do it, or are basic changes in our culture necessary? What about the media? Television may be a way to reach the requisite numbers of people, but can viewers learn science when they are basically passive?

Such issues led PHYSICS TODAY to put seven questions to seven observers, inviting them to address the questions of their choice.

Our contributors are D. Allan Bromley, the President's science adviser; Robert N. Proctor, an associate professor of history at Pennsylvania State University; F. James Rutherford, chief education officer of the AAAS; C. Kumar N. Patel, an executive director at AT&T Bell Labs; James D. Watkins, Secretary of Energy; Sheila Tobias, a writer and lecturer; and Gerald Holton, a professor of physics and of the history of science at Harvard.

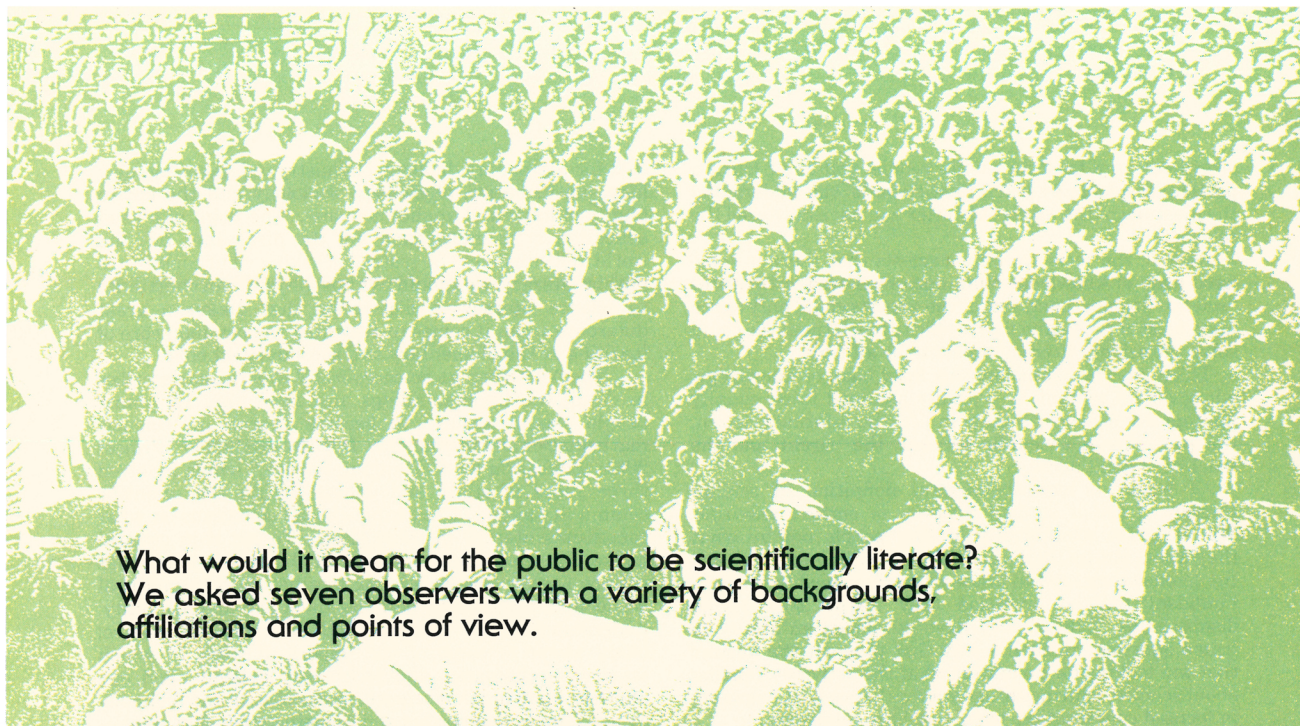
—JEFFREY SCHMIDT

What is the primary reason that you advocate public understanding of physics?

Bromley: The Bush Administration's emphasis on science and mathematics reflects a new and accelerating feature of modern societies: As the economies of the industrialized countries shift toward high-technology manufacturing and services, the jobs available to new entrants into the work force require higher levels of skill and education than ever before. Projections are that over half of the jobs available by the end of the decade in the United States will require some education beyond high school, compared with 42% of currently available jobs. There will be fewer jobs for the poorly educated high school graduate and fewer still for the 25–30% of students who drop out of high school without graduating.

These economic arguments for improved mathematics and science education are compelling, but I would add another rationale. It is difficult to make sense of the modern world without knowing something about science and mathematics. For the past several centuries, scientists have been engaged in one of humanity's most profound adventures—increasing our knowledge about ourselves and our world—and in the process have transformed the way we view ourselves and the world around us. To know nothing about the constituents of the atom, the theory of evolution or the genesis of the universe is to be intellectually handicapped in modern society.

Proctor: Francis Bacon more than 300 years ago recognized that “knowledge is power,” and this is certainly more true today than in Bacon's time. Science is a source of military and industrial might; science is a multibillion-dollar business. Why does the defense science budget dwarf the monies spent on interplanetary exploration or environmental research? What does it mean when Congress allocates funds to “harden” semiconductors against neutron flux or to explore hypervelocity physics



What would it mean for the public to be scientifically literate? We asked seven observers with a variety of backgrounds, affiliations and points of view.

and pulsed electromagnetic power? Social priorities often lie behind scientific problems—to be literate is to understand this larger field within which decisions are made. Much is at stake in the kinds of science governments fund: where we get our energy, the hazards to which we are exposed, whether we work for peace or for war. An informed citizenry has the capacity to understand and challenge technical expertise, and when the questions have to do with priorities, trade-offs, or risks and benefits, citizenship *requires* that one be informed.

Rutherford: Science, broadly construed, is essential to a good education. The case for science, so convincingly argued nearly 50 years ago in the Harvard report *General Education in a Free Society*¹ and more recently in the AAAS report *Science for All Americans*,² has to do with the needs of individuals and society, with economic and philosophical considerations, with issues of relevance and significance. The case does not rest on the fact that lots of people do not know—or care to know—what quarks are, cannot get mass and weight quite straight and think physicists are strange. Rather, it rests on the fact that we live in a world pervaded by science and technology. People cannot participate meaningfully in such a world unless they have a basic understanding of science and the scientific enterprise, and can think quantitatively.

Patel: We hear every day that society is becoming intertwined with science and technology. Indeed, to function effectively today, society needs science. However, it is now becoming clear that in a society that functions effectively, an understanding of science and scientific methods is not the privilege and responsibility of a few—it is a basic requirement for all. In a complex society, intuitive reasoning unsupported by knowledge and logical thought would lead to chaos. Physics is an important part of science. Without an understanding of physics and physical methods, the public will not be

equipped to make rational choices concerning the risks and benefits of new technologies.

Watkins: Public understanding of physics is important from at least two perspectives. From one point of view, physics is humanity's search for order underlying the apparent chaos of the physical universe. Everyone should have the opportunity to share in this exciting quest, not just the fortunate few who are trained to be physicists. Physics can be viewed as a spiritual and intellectual exploration through which the human mind becomes more aware of its rational nature. By providing a splendid picture of our universe, physics can foster aesthetic and philosophical values. Through the rigor of its study, it can promote intellectual discipline and integrity.

From another perspective, physics is part of the cultural fabric of our technological society. Understanding this fabric provides an operational framework within which we can work and make decisions. An understanding of physics therefore enables an informed electorate to make rational choices and decisions, logically assessing risks and uncertainties while recognizing inherent biases. To survive as a nation, we not only must remain technologically competitive but also must be able to provide the essentials for civilized life that physics-based technologies make available. Securing long-term support for the research necessary to develop these technologies is in the best interest of society. Therefore, society should encourage the study of physics necessary to guarantee a scientifically literate public that will provide such support.

How would you define science literacy?

Tobias: The term "science literacy" is misleading on a number of counts:

▷ First, "literacy" implies "fluency," and as scientists know better than anyone, it is not word fluency that constitutes understanding in science. As I have written

elsewhere, in a book for young people, you don't learn a particular science by learning the words; you understand the meaning of the words only after you have mastered the science.³

▷ Second, the term wrongly suggests that there is some fixed body of knowledge that, once mastered, constitutes "science literacy"; and that if the experts could only agree upon a list of topics and find people to teach them, we could solve the science literacy problem for all time.

▷ Third, and by extension, this fixed body of knowledge, whatever its content, is typically assumed to be equally appropriate for every station in life: the informed citizen, the professional or public servant, the parent and the teacher. I don't agree.

I prefer a more behavioral definition of science literacy. I call it *applied curiosity in matters scientific*. We recognize scientifically literate people not by what they know but by their capacity and willingness to learn the science they *need* to know when they need to know it. Confident that no question they might ask can be dismissed as "dumb," they have developed an ability to frame questions in such a way that they get the answer they are looking for no matter what the activity—reading about science, figuring things out for themselves, engaging in focused conversation, even watching television.

Theirs (and mine) is a "flypaper" view of learning. The more one knows, the more one wants to find out; the more one finds out, the more experienced one becomes in processing new information and the more one remembers. From this perspective, formal schooling should both increase the store of knowledge and enlarge the surface area and "stickiness" of the mind. If we are to cultivate applied curiosity in matters scientific, I believe we must focus on the flypaper, not the flies.

Holton: Consider the definition of the chief task of education given by the philosopher Friedrich Schleiermacher in the first decade of the 19th century: The aim of education is *the replacement of the child's internal intellectual chaos by a coherent world picture*. It is a daunting formulation, which seems to me to apply first and foremost to scientific literacy.

However, anyone who has the task of introducing a typically underprepared class of college students to, say, the rudiments of physics knows that it is much more difficult than removing a preexisting internal chaos of ideas or imprinting the right equations on a slate kept clean by previous ignorance. After the first few years, the child's chaos has been replaced by something much worse and more permanent than mere ignorance: by a robust counterpicture, a self-generated set of ideas about nature that is quietly called on to respond to the phenomena. Such a schema deserves the term "*science sauvage*" (*pace* Lévi-Strauss).

Gaining scientific literacy is not merely a matter of evolving from primitive talk to a more complex language, but of replacing a whole, originally functional worldview, with all its concepts, hypotheses and metaphors—and then of amending the replacement constantly.⁴

Rutherford: Literacy in science implies understanding some physics. It does not follow, I believe, that we need to define physics literacy itself as though it were an independent goal of general education. The same can be

said for astronomy, biology, chemistry, engineering, geology, mathematics, physiology, sociology and the entire family of basic and applied sciences. The point of a good education is to understand not the disciplines but the world and ourselves. So instead of asking what constitutes physics literacy, we should ask how physics can contribute to science literacy—a distinction that makes a great difference when it comes to designing the common core of learning in the elementary and secondary schools.

The AAAS report *Science for All Americans* describes in detail the understandings and skills that all young people should acquire to become literate in science, mathematics and technology. It is the product of "Project 2061: Education for a Changing Future," which involved three years of study and debate within the scientific community aimed at reaching a broad consensus on what constitutes literacy in these areas. To put it in general terms, the consensus expressed in the report holds that science literacy includes being familiar with the natural world and recognizing both its diversity and its unity; understanding key concepts and principles of science; being aware of some of the important ways in which science, mathematics and technology depend upon one another; knowing that science, mathematics and technology are human enterprises and knowing what that implies about their strengths and limitations; having a capacity for a scientific way of thinking; and using scientific knowledge and habits of mind for individual and social purposes.

In all of this, physics has a major role to play. As a body of knowledge, it contributes central concepts. As a paradigm, it gives concrete, systematic expression to general notions about the nature of science. And because of its historical significance, it is the focus of several of the episodes in the history of science with which all well-educated people should be familiar.

Literacy should be the outcome of the core of learning common to all students. But some students will want to pursue physics as a discipline or to investigate advanced topics in physics, and the school curriculum surely ought to provide opportunities, through courses and independent study, for them to do so. Indeed, if, in the process of becoming literate in science, students encounter physics from the earliest grades in many interesting and personally meaningful contexts, it may happen that more of them will elect to study physics as such in high school—more than the one out of six that do so now.

Patel: Science literacy is not the knowledge that is printed in textbooks. It is the ability to analyze situations and problems logically and to use available or new technology in the most effective manner. Scientific literacy further includes the ability to reason out a proposed course of action, taking into account what is known, to arrive at possible outcomes.

Proctor: In very rough terms, physics literacy must include some sense of the structure and dynamics of the universe (cosmology), craft techniques (experimental methods), symbolic representation, probabilities and rates (algebra, statistics and calculus) and how priorities are formed in science (the social origins and social consequences of science).

The last point is important, and is an area in which

physicists themselves are often deficient. To be literate is to be able to read with comprehension, and to comprehend science one must understand its social and historical contexts. In a larger moral sense, science literacy also means understanding who loses, as well as who benefits from scientific knowledge or its applications.

How literate is a person who has read articles on quarks, black holes and the Big Bang but who has no feeling for the size of the atom, conservation of energy or the orbit of the Moon? That is, which is more important in your definition of science literacy, the fundamentals or the cutting edge?

Patel: Reading articles without making appropriate contact between the content of the articles and realistic day-to-day situations does not promote one's scientific literacy.

Holton: There is no royal road. Both are important—as is the phasing. Before a person is really ready for the “cutting edge,” we need to take serious measures to understand and modify his or her naive but “functional” scientific world picture.

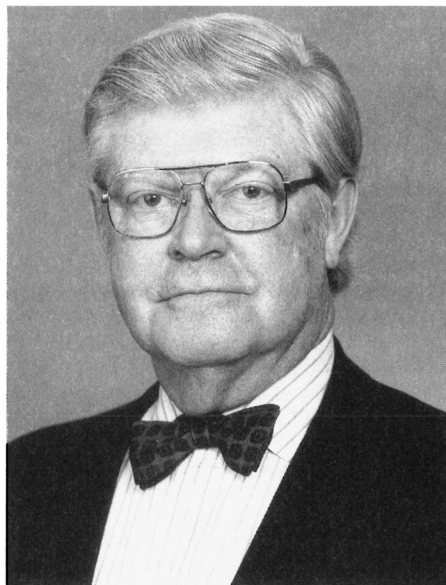
In this picture, material bodies come to a stop unless they continue to be propelled; electricity flows through wires as water does through pipes, only much faster; space is a big container in which matter appeared at the beginning of time; time is everywhere the same and marches on inexorably; science and engineering are hardly distinguishable; the pattern of cause and effect works most of the time, but incomprehensible and magical things do occasionally intervene; science provides truths, but now and then everything known previously turns out to have been entirely wrong, and a revolution is needed to establish the real truth. And so forth.

Proctor: Science literacy must include both the fundamentals and the cutting edge. University instruction tends to dwell excessively on the former, journalism on the latter. The media's fascination with quarks or strings is designed to titillate but rarely informs; university instruction often suffers from the opposite problem.

Social frontiers must also be distinguished from science frontiers. Old physics can often provide the solutions to new problems; space platforms can as easily look for climate change as for rocket boosters.

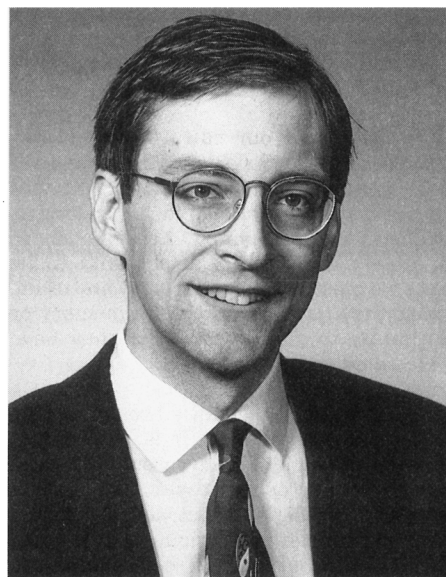
Does the typical physicist meet your definition of science literacy?

Proctor: College-level instruction rarely includes any adequate training in the history or philosophy of science. It is altogether possible, for example, to obtain a PhD in physics without ever looking at how the Manhattan Project shaped postwar physics, or why quantum mechanics was met by such strong philosophical resistance. Physicists are also too often unprepared to assess the political or ecological implications of their work. Why did it take so long for the hazards of low-level radiation to be exposed? How will the demilitarization of science affect research opportunities? Why have women been underrepresented in the profession? The perspective provided by



WHITE HOUSE

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Robert Proctor is an associate professor at Pennsylvania State University, where he teaches the history of science and technology. Proctor received his PhD in the history of science from Harvard University in 1984, and for three years was on the faculty of the New School for Social Research in New York City, where he organized the undergraduate curriculum on science, technology and power. Proctor's book *Value-Free Science? The Origins of an Ideal* will be published next fall by Harvard University Press.

historical understanding could be especially useful in helping to restore the forest lost for the trees.

Patel: Physicists are capable of meeting the definition of scientific literacy, although many choose not to because they often try to conform to the public's image of the "mad scientist" who is obsessed with a single problem to the exclusion of everything else.

Tobias: Decidedly yes. Physics, being the fundamental science (if not the central science, a position reserved for chemistry), it is not surprising that the study of physics brings with it a knowledge base and a framework for asking questions about all other sciences. Further, the study of physics, it seems to me, teaches a way of asking questions that is both provocative and illuminating, and that whets the appetite for ever widening circles of understanding—exactly what science literacy is all about.

What single change—in our culture, for example—would do the most to increase public science literacy?

Patel: A single change that would make scientific literacy a desired state of being would be to make science itself more fashionable. If "L. A. Law" can motivate young people to become lawyers, we need "Berkeley Biology" or "Philadelphia Physics" to make science an in thing to do. But beyond such cosmetic changes, the teaching of science must change. Science ought to be taught in such a way that students can use it to analyze and solve everyday problems. And it should be taught in a way that depicts its practitioners as "regular" people.

Tobias: No single change in our culture can reverse decades of neglect in science education. But more years of science in school—a recommendation of the National Science Teachers Association—would do much, so long as *curiosity* and *confidence* were cultivated as assiduously as *skills* and *facts*. If we want to teach students to be "literate" in science we must reward them early and often, not merely for what they have committed to memory or have learned obediently to do, but for what they have *thought and wondered about* on their own.

Bromley: What has most impressed me since joining the Bush Administration is how difficult it is to separate scientific literacy from the much broader issues of verbal and numeric literacy. I do not believe that it is possible to foster greater scientific literacy without addressing the overall quality of pre-college education, because the problems with both arise from the same root—the failure of our elementary and secondary schools to provide a top-notch education for more than a comparative handful of American students. It is shocking to find that high school graduates know no mathematics or science; it is even more shocking to find a great many who have never read a novel or who are unable to write a coherent paragraph because they have never been expected to do so.

The Administration has focused great effort on pre-college education, highlighted by the six national education goals developed jointly by the President and the nation's governors. Within this overall focus, science and mathematics have received special attention. Two of the

national goals deal directly with science, including the most ambitious of the six—making American students first in the world in science and mathematics achievement by the year 2000. And the goal calling on all adult Americans to be literate and have the skills needed to compete in a global economy by the year 2000 implicitly recognizes the technical skills and scientific knowledge necessary to achieve it.

Greater literacy—whether verbal or numeric—will not be achieved solely through the actions of teachers and school administrators. It will require changes in the way teachers are educated and hired, in the way schools are structured and, in general, in our attitudes toward education. We must reinvolve parents in the education of their children and stop treating our nation's schools as if they were a utility providing a service that can safely be ignored. We must give parents and children a choice of schools, both so that students can go to the schools best suited to them and so that the free market forces of competition will act as a spur to school improvement. We must return to objective standards of performance and learning so that our students know what is expected of them and what they are capable of. And we must reward excellent teachers and students to demonstrate the continued importance of achievement.

In science and mathematics, the professional societies have a special role. They must reach beyond parochial interests to recognize the broader impact on society of their members' activities. Society supports science and technology not only because of their impact on economic competitiveness or international affairs but also because society believes that scientific advances enrich its cultural and intellectual heritage. Scientists have an obligation to contribute to this heritage, not only through their work but through their involvement in this broader sphere of endeavor.

Watkins: The best strategies for improving science literacy involve both our formal and informal educational systems.

The first solution would address the perception that our math and science teachers are somehow outside the boundaries of the scientific community. It seems clear that teachers hold a critical position in ensuring literacy and "numeracy." Yet in our society the role of teachers is grossly undervalued, as evidenced by their low salaries and the often inadequate preparation they receive in our universities to do the increasingly important work required of them by society.

One can also argue that far too often, because teachers of science and mathematics are underprepared and poorly equipped to translate the discipline of science and math to their students, those students also miss the joy and excitement of those fields. There is a great need for new approaches to education, at both the pre-college and university levels, in terms of curriculum and materials development and teacher preparation.

DOE recently announced new efforts to better utilize its scientific resources to provide opportunities for teachers to do "hands on" work with cutting-edge science. Several new initiatives, based in our national laboratories, were developed at the May 1990 Math/Science Education Action Conference, which I co-chaired with Nobel laureate

Glenn T. Seaborg ten days after the Charlottesville education summit. Much can be accomplished by utilizing resources already in existence—for example, Federal laboratories and personnel.

Teacher preparation and enhancement is also a mission of the Committee on Education and Human Resources of the Federal Coordinating Council on Science, Engineering and Technology. This committee, which has representatives from 16 Federal agencies, will produce the first-ever coordinated Federal budget submission for math and science education.

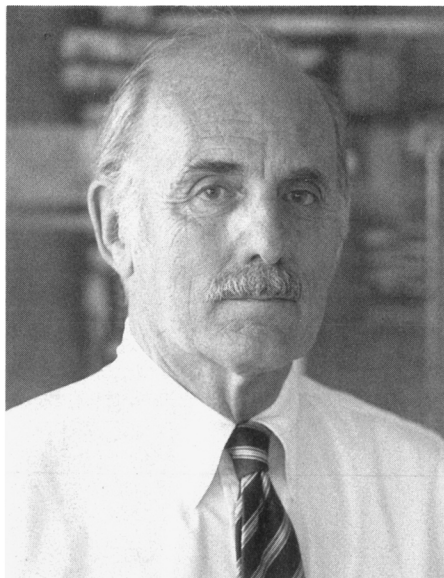
But it is not sufficient to foster public science literacy through formal educational channels alone. The media are a powerful influence on today's society and should be enlisted in the public literacy effort. In the same way that enjoyment of athletic participation is not limited to the professional athlete, the enjoyment of mathematics and science should not be limited to professionals in these fields. The benefits of science, and positive images of scientists, must be conveyed to our broader public through television, radio and our print media. In addition, scientists must be able to communicate with the public in a manner that will increase confidence in and admiration for science and technology and their role in bettering the world in which we live.

Holton: As individual physicists and teachers, we can surely do better than we have done lately to help solve the looming crisis in science literacy in our country. Here are a few examples:

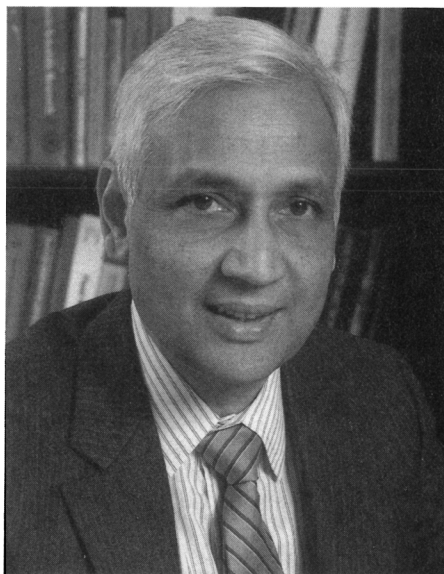
- ▷ We can start rethinking our own courses for nonscientists so as to deal better with the complex transition we demand from the "savage's world picture" to that of modern physical science. Refusing to pretend it can be done in one term in college would be a good start.
- ▷ We can rethink what inducements, help and pressures the pre-college educational system needs to provide. These should include at least one hour a day for science from kindergarten to 12th grade for each child.
- ▷ We can decide to be more eloquent with the top management at agencies such as NSF, where the support of improvements in science education has been sporadic and is still smaller than recommended even by its own commissioned studies over the past decade.
- ▷ Simplest of all, we can help to nourish the needed "revolution from below" in the science classroom by turning out more well-prepared physics students who will—even if only for a few years—undertake to teach in pre-college schools. Programs of this sort exist that might be useful models. (Information about the one at Harvard College, initiated recently in collaboration with the School of Education at the instigation of Sheldon Glashow and myself, will be gladly provided on request.)

Calculators, computers, digital tuning, computer-aided manufacturing, cash register buttons labeled with pictures—are such technologies actually "deskilling" people, distancing them from physical processes and making them less physics literate?

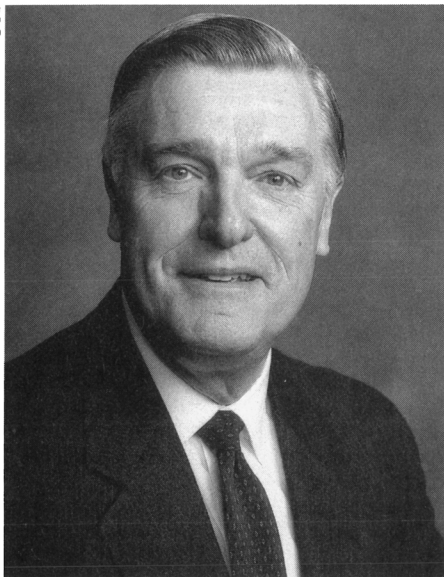
Proctor: Deskilling originates in the division of labor into small and repetitive tasks, and in this sense the technology itself is not to blame. It is probably true that many new as-



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Kumar Patel is the executive director of the research, materials science, engineering and academic affairs division at AT&T Bell Laboratories in Murray Hill, New Jersey. He is a member of the oversight boards of two industrial concerns and has been director of the electronics research laboratory and the physical research laboratory at Bell Labs.



James Watkins is Secretary of Energy. To help fulfill DOE's mission to develop human resources, he has increased DOE support for math and science education programs. In October 1989 Watkins convened the Math/Science Education Conference in Berkeley, California, which spawned several new education projects. He currently heads the education and human resources committee of the Federal Coordinating Council on Science, Engineering and Technology. Watkins is a retired admiral and was chief of Naval operations in the US Navy.

sists to calculation are contributing to the deskilling of society, but then again, complaints of this sort have been around for centuries. Plato in the *Phaedrus* has the Egyptian king Thamus express his fear that the invention of writing will soon "implant forgetfulness in the souls of men" by allowing them to write down that which in previous times would have been committed to memory.

Many technologies create dependencies. The question, though, is how one can work to ensure that freedoms outweigh dependencies—and that conveniences and burdens are shared equally. This requires a conscious effort on the part of the designer, and the funder of the designer. It requires that one pay attention to the distribution of costs and benefits, not just to abstract bottom lines.

Patel: Calculators, computers and other such devices, used blindly, would "deskill" people. They are tools; they are enablers for speeding up processes. Just as the development of machines (to help people do manual tasks more effectively and with less strain) has not resulted in disappearance of people's muscular functions, the use of tools to extend the range and effectiveness of people's thinking can make it easier for people to understand physical processes.

Why do physics and the scientific worldview sometimes elicit anxiety or hostility?

Holton: As one of my students—brought up with the inalienable right to choose in everything—put it, the worldview of modern science appears to be "not optional, and therefore in a sense totalitarian." By this he meant that in a humanistic area the college catalog gave him a wide choice of topics for what is acceptable; if one did not like to gain an understanding of literature through *The Iliad* or Shakespeare, there were many entirely different paths open. But to reach even an elementary understanding of physics, such topics as Newtonian gravity and the nuclear atom seemed inescapable.

The process of initiation into a modern scientific world picture, coming as it usually does long past the stage of high natural curiosity in early childhood, is fundamentally invasive, and is therefore painful. Long ago I gave from time to time one of those one-year courses in physical science during which the students, initially pure Aristote-

lians, were to be made over into Newtonians by Thanksgiving, Einsteinians by Easter and Heisenbergians by mid-May. Among the more honest and insightful ones, there occasionally was a student who would break into tears as the intuitions were being forcibly reshaped.

The least interesting thing about the student's preexisting world picture is that it is wrong. The naive world picture is a legitimate form of knowledge in the sense that it is functional. It organizes and explains, up to a point, what is going on; it is a sturdy framework for interacting with the environment. Once a "baby talk" scientific world picture has been allowed to establish itself, the internal resistance against advancing to the more sophisticated one can be overwhelming. The modern world, in which evolution is central on many levels, from biology to cosmology; where absolutes in science have disappeared, and classical causality has been replaced by a probabilistic one; where concepts are often nonvisualizable and expressed in mathematical formulas—all this is counterintuitive to the point of being sometimes repellent. For the young person, the labor of getting from the Aristotelian to the post-Darwinian and post-Einsteinian world picture is herculean.

Proctor: There are several reasons physics and the scientific worldview more generally elicit hostility. One has to do with the perennial defense of science as necessary "to beat the Japanese." Economic competitiveness is a fine thing, but it is hardly the best ground on which to defend the pursuit of science. A related problem is the narrowness encouraged in most science education. Hermann von Helmholtz more than a century ago warned against the dangers of overspecialization. Science majors even today are rarely required to study the history or social context of their disciplines. Science can be a humanistic endeavor, but the effort must be made.

The largest source of hostility, though, is probably the intimate link between science and the military—a marriage formed during World War II and drawn even closer under Reagan. Today some 70% of all Federal funds for R&D goes to the Defense Department, and a significant fraction of all physics baccalaureates end up in military-related work. In a world where more than one-quarter of all scientists and engineers have some form of security clearance, it is hardly surprising that the very idea of

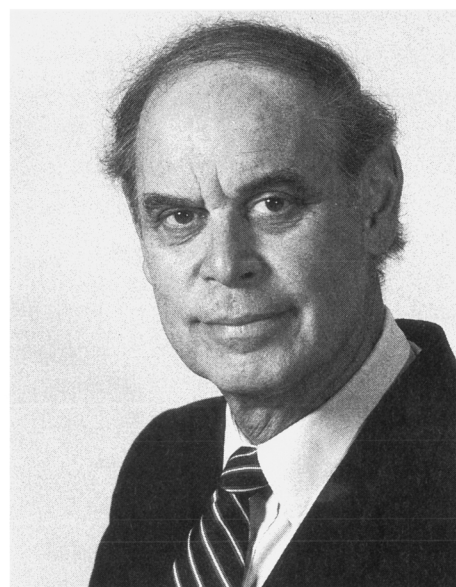
Sheila Tobias describes herself as a "self-taught demystifier of mathematics, technical information and national defense." She is the author of *Overcoming Math Anxiety* (Norton, New York, 1978; Houghton Mifflin, Boston, 1980) and *Succeed with Math* (College Board, New York, 1987), and is a coauthor of *The People's Guide to National Defense* (Morrow, New York, 1982). Tobias's latest book, *They're Not Dumb, They're Different: Stalking the Second Tier* (Research Corporation, Tucson, Ariz., 1990, available from Science News Books, 1719 N Street, Washington, D. C. 20036) explores the reasons why otherwise intelligent college students have difficulties with science.



MOLLY MOORE

Gerald Holton is the Mallinckrodt Professor of Physics and a professor in the history of science department at Harvard University.

His books include *The Advancement of Science, and Its Burdens: The Jefferson Lecture and Other Essays* (Cambridge U. P., 1986) and *Scientific Imagination: Case Studies* (Cambridge U. P., 1978). Holton was the founding editor of the quarterly journal *Daedalus* and founder of the journal *Science, Technology, and Human Values*.



science calls up images of "hostility." The demilitarization of science in the wake of Gorbachev's *perestroika* may well do much to ease this hostility. Efforts are also afoot to enlist science in "environmental defense initiatives"; the image of science may brighten as it proves itself able to assist in cleaning up the messes for which it is being blamed.

Watkins: One reason lies in our basic fear of the unknown and the view that what is not understood is sinister. This can be changed over time through our educational system, both formal and informal, and our media.

Another cause may lie with the scientific community itself, which traditionally has done too little to counter its perception as aloof, arrogant and demanding at a time when social problems in society are requiring a greater portion of increasingly limited available funding. Scientists themselves are the answer here. At the Department of Energy, we have a tradition of volunteerism, community service and educational outreach, a tradition that I have greatly expanded since becoming Secretary of Energy. We are putting our scientists in the classroom, working with students and parents, assisting entire school districts, cities and states, in order to reach out and help reform our system of education and bring science alive in our classrooms. We are also opening the doors of our facilities and bringing the community in to see scientific excellence in action. In this kind of interaction lies our greatest hope of improving communication between scientists and society and helping to dispel false images of scientific disciplines.

Patel: Physics and the scientific worldview often elicit hostility and anxiety because we have become a society where "bad" news sells papers. Problems with the proper functioning of a nuclear reactor, for example, get splashed all across the news without any mention of the fact that there are many more reactors that work safely. The TV shows exacerbate the anxiety by mixing up fact and fiction and by casting all science in a bad light.

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