Scientific Literacy: Whose Responsibility?

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During and immediately following World War II, a great cry went out because America, with all her wealth and natural resources, was not producing scientists and technologists in quantities necessary for the day. The American people were not scientifically literate, even though most public schools and institutions of higher learning provided instruction in science.

The cry became a shriek with the advent of Sputnik. Science teaching came under attack from every quarter. Scientists, technologists, educators, politicians, and parents became *actively* concerned and began to review and criticize science teaching. Arising out of this concern was increased federal support for the teaching of science and of mathematics: "new curricula" in these fields were either given impetus or initiated. Federal money was provided for the further education of science and mathematics teachers in the form of academic-year and summer institutes. Large sums of federal money became available to local schools for science and mathematics equipment and facilities. Federal loans to prospective science and mathematics teachers became available, and guidance services were initiated for the identification of able students in science and mathematics.

Now that support for science and mathematics teaching has been in progress for a number of years, it is becoming increasingly clear that the American people are still not scientifically literate—not even the young people who have just finished one of the new programs or have been taught by teachers who have had additional science training. America is still lacking an adequate supply of scientists and technologists.

The purpose of this article is not merely to criticize the new efforts that have been directed toward the improvement of science teaching. Certainly, improvement was and is needed. The purpose is to describe some characteristics of a scientifically literate person, to identify factors that are inhibiting scientific literacy, and to offer suggestions for the attainment of a scientifically literate citizenry.

Scientific Literacy

In recent research at the University of Wisconsin (Pella, 1966), six referents to scientific literacy were identified by examining 100 articles on the subject. It appeared that a scientifically literate person could be charactrized as one who had an understanding of the "(1) interrelationships of science and society, (2) ethics that control the scientist in his work, (3) nature of science, (4) basic concepts in science, (5) differences between science and technology, and (6) interrelationships of science and the humanities" (Pella's summary). These referents form the nucleus of the present description of a scientifically literate person. However, the order is changed; some referents are combined; and several referents, not identified in the original list, are added.

A scientifically literate person perceives science as a product, a process, and a human enterprise. He recognizes that the product of science is a body of knowledge about the natural world, ranging from individual observations to conceptual schemes. This product is recorded in men's minds and on the printed page. The person who is scientifically literate does not confuse the product of science with space vehicles, miracle drugs, and nuclear reactors. These are the results of technology; *i.e.*, of the application of science.

The scientifically literate person is aware that the products of science are both static and dynamic. The static portion has remained unchanged, but it may become dynamic at any time. The product is dynamic because of the process of science. For example, a scientist makes observations, and he uses these observations to formulate a model of some aspect of the natural world. The model is tested *vis à vis* nature by making predictions and gathering additional observations. When the new observations are contrary to the model, additional observations are made and a new model is created, utilizing empiricism, reason, and imagination (Bronowski, 1968). Thus, the process of science causes the product to be dynamic, or ever-changing.

Three additional points concerning the process of science warrant attention and are requisite for scientific literacy. First, many names have been given to the process of science. These include scientific method, pursuit of science, spirit of science, and a way of knowing. Regardless of the name given, the process does not run counter to the laws of nature. The scientist is neither witch doctor nor magician. He endeavors to discover and use the laws of nature rather than try to bend them. Second, the scientist is guided by a morality. He has the responsibility to make his work public, and he is constantly aware that his product will be examined by other scientists. Third, there is not *a* process or method of science; there are *many* processes.

Studies by Mead and Métraux (1967), Beardslee and O'Dowd (1961), Allen (1959), and Korth (1969) reveal that many persons are unaware that science is a human enterprise: they do not view science as being conducted by men of varying ability, personality, and moral character. As a result, myths about science and scientists have arisen in the minds of persons not scientifically literate. Among these myths are the following: (1) science is exact; (2) all scientists have superior intellectual ability; (3) scientists are amoral monsters; (4) science and religion are antithetical; and (5) science can cure all of man's problems. The scientifically literate person realizes that science is conducted by men, and he understands that "scientific investigators are statistically distributed over the whole spectrum of human folly and wisdom much as other men" (Conant, 1956).

The scientifically literate person is aware of the differences between science and technology, but he also perceives their interrelationships. He knows that the primary goal of science is understanding nature, while the goals of technology are utilitarian and practical. Technologists endeavor to make things for the benefit of man and society. The scientifically literate person knows that it is theoretically possible for science to exist without technology, and that technology generally involves the application of scientific information. However, he knows that there are exceptions to this rule. Some technology has advanced independently of science, and technology has helped to advance science by inspiring scientific questions and by providing instruments for accurate observation and measurement of scientific phenomena.

Literacy in science should not be considered synonymous with scientific literacy. Literacy in science is that component of scientific literacy that involves an understanding of scientific facts, concepts, and conceptual schemes. Obviously, the required level of literacy in science is not the same for all persons. It is quite different for the scientist, politician, business executive, housewife, and science teacher. In fact, the literacy in science of an individual scientist differs from one area of science to another. Yet it is possible for all of these persons to be scientifically literate. It follows that there is a minimal list of basic concepts and conceptual schemes that any scientifically literate person must understand. Unfortunately, there is little agreement as to what should be included; but any such list must include those facts, concepts, and conceptual schemes that are necessary for a person "to read and to discuss scientific information found in common literature and to interpret common scientific phenomena with facility and confidence" (Carleton, 1963).

Scientific literacy requires an understanding of the relationship between science and the humanities. Science as well as the humanities—art, music, drama, literature, philosophy—have contributed together to Western culture. Science has influenced man politically, socially, and economically. Any study of history would be incomplete without including the history of science. Philosophy and science are both concerned with seeking truth, although their methods are not identical. In part, science has drawn its point of view from empiricism, rationalism, and pragmatism. The application of science has contributed new tools and methods for studying the humanities. It has provided leisure, resulting in the creation and enjoyment of drama, literature, and art. The scientifically literate person understands that science is not in opposition to the humanities; science is *one* of the humanities.

The scientifically literate person is aware of the relationship of science and technology to society. He realizes that science and society have a reciprocal impact on one another, and that this impact may be beneficial or harmful. For example, society determines the rate, direction, and application of scientific discoveries. Science flourishes when society offers a favorable environment; but society may be an obstacle to science. Science and technology have provided men with longer lives, more leisure, increased food, and freedom from ignorance. But they have also contributed to man's insecurity by challenging traditional ways, increasing interdependence, weakening psychological moorings, and providing the possibility of mass annihilation. Understanding the relationship of science and technology to society is an essential characteristic of the scientifically literate person.

Since the impact of science on society may be harmful or beneficial or a mixed blessing, the scientifically literate person has certain responsibilities. He should support basic research by providing a favorable environment in which the scientist can go about his work. However, the scientist too has responsibilities. He has an obligation to help educate mankind for living in the scientific habitat which he is helping to create. The scientist must interpret science in terms the layman can understand and remind the layman of the possible dangers of science and technology. The scientifically literate person is aware of these responsibilities and demands that they be fulfilled.

Science and technology have been successfully applied to many of man's problems; in fact, their application has been so successful as to give rise to a blind faith in science and technology. But the scientifically literate person knows that science and technology have limitations; *i.e.*, problems exist that can have no scientific or technological solution without an accompanying change in human values (Hardin, 1968). Examples are increasing population, increasing military power, and decreasing national security. And the scientifically literate person recognizes the fact that the application of science and technology (or their partial application) to one problem often results in problems of greater magnitude: longer life and increased natality have contributed to over-population, pollution, loss of individual freedoms, depletion of the soil, and exhaustion of raw materials.

In addition, then, to the characteristics identified in Pellas' study, the scientifically literate person (1) possesses objectivity, (2) has faith in and values logical reasoning, (3) rejects myths and superstitions, (4) accepts conclusions when supported by data, (5) is critical and skeptical, (6) displays the habit of weighing evidence, and (7) uses the methods of science to solve problems when the methods are appropriate.

Inhibiting Factors

Scientific literacy is generally accepted by science educators as a major goal of science teaching. Unfortunately, little effort has been given to defining the term properly. It has been falsely assumed that scientific literacy was some mystical set of characteristics concomitant with memorization of content: the more content memorized, the higher the level of scientific literacy. Herein lies the greatest obstacle to a scientifically literate citizenry. If its meaning is not clear, scientific literacy can only be attained by chance.

Persons responsible for organized instruction in science have not acquired a mature scientific literacy of their own. Usually they have a number of science courses to their credit; but these courses were generally designed for the neophyte scientist. Such courses are steeped in factual materials unrelated to the rest of life. Little attention is given to the social implications of the subject, and technology is seldom mentioned. Often the accompanying laboratory activities and the methods of grading laboratory reports cause the student to develop a false perception of a scientist at work. Unlike a research scientist, the student cannot afford to be incorrect: he has one chance to complete the experiment, and his grade depends on the correct response.

It should not be assumed that science courses have nothing to contribute to scientific literacy or that science courses, as presently taught, are totally responsible for the lack of scientific literacy. Other factors are involved. There is seldom time for a prospective science teacher (or, for that matter, any student) to assimilate what he is being subjected to: the training period is too short, too crowded with required courses. In addition, courses outside of science are failing to make contributions. What history course includes the history of science? What psychology or sociology course deals with the psychological and sociological problems that result from the impact of science and technology on society?

Federal support of science and mathematics in elementary and secondary schools has resulted in a number of improvements. Nevertheless, courses in science and mathematics are still only partly contributing to scientific literacy. In their concern for up-to-date content, basic science, and processes of science, these courses overlook several aspects of scientific literacy. They exclude such topics as science as a human enterprise; technology; and the impact of science and technology on society.

Political, military, and economic interests inhibit scientific literacy. Generally the interested agent simply fails to inform the public. For example, citizens are always informed of the advantages of a power plant or a factory, but they are not given notice of an accompanying extinction of certain species due to environmental changes. Another example is the failure of the military to make public its findings in the deaths of sheep at Skull Valley, Utah.

Many people rely on television, newspapers, radio, and motion pictures for their current information on science. Unfortunately, entertainment is the primary goal of these mass media. They capitalize on fictional stories of bizarre scientists who believe that ends justify means, and, they often picture science and technology as being synonymous. The media thus contribute to the erroneous view that the general public has of science and scientists.

The preceding factors, coupled with a tremendous growth of scientific information and continued specialization, have contributed to the average citizen's knowledge of, and attitude toward, science. As a result, the average citizen has dissociated himself intellectually from science. He is ignorant of science —and quick to admit his ignorance. Such an attitude is certainly a major deterrent to scientific literacy.

Suggestions for Action

Suggestions for attaining scientific literacy are easy to formulate, but their acceptance and implementation are another matter. They must run a gauntlet and do battle with the inhibiting factors just mentioned. Nevertheless, if we are to have a scientifically literate citizenry, the battle must begin; it must be won.

The first suggestion, and possibly the most important, is federal support of an all-out effort to come to grips with the characteristics of scientifically literate persons and with the means of achieving these characteristics once they are identified. The efforts of the National Science Teachers Association Conferences on Scientific Literacy and the previously mentioned research at Wisconsin are laudatory, but greater effort is needed. A greater effort requires money to free individuals and groups to consider the problems in depth. Funds for an intensive investigation of scientific literacy seem impossible to obtain except at the federal level.

The establishment of experimental programs for the preparation of elementary, secondary, and college teachers is the second suggestion. These programs should center on what is currently known about scientific literacy and should change as new information is gained. Such programs cannot be developed as they have been in the past; *i.e.*, by creating a plan on paper and trying to fit it into existing college or university courses. Failure of typical college courses to contribute to scientific literacy has been discussed earlier. New courses of study must be developed and initiated, to provide all prospective and in-service teachers the opportunity to see what science and scientists are really like. These persons must have the opportunity to identify and discuss the limitations of science and technology. They must examine the relationships among science, technology, and society at large. Unless teachers become scientifically literate, little hope exists for creating a scientifically literate citizenry.

The third suggestion involves science instruction at all levels. Emphasis on memorizing factual material should give way to the application of given facts and to the understanding of a small number of selected concepts and principles. Memorizing large bodies of scientific information is futile: science is constantly changing, and memorized facts are quickly forgotten. A person who knows how to apply given facts and who understands basic concepts and principles has a good foundation for understanding science and technology and for interpreting newer developments as they come along.

In the elementary school, science is often left up to the individual teacher, who may or may not devote time and energy to the subject. As a result, many students are denied early experiences in science that would contribute to their scientific literacy. Therefore, the fourth suggestion is for scientific literacy to become a real concern of the elementary school. It is imperative that organized and carefully planned science experiences be initiated early and articulated throughout the elementary school curriculum.

A revision of the secondary school science curriculum is the fifth suggestion. The "new curricula" in science and mathematics have brought about a number of improvements, but they are not educating students with regard to the realities and problems of modern society. Secondary-school science should be organized around the real problems of mankind, such as pollution, food production, and population. It should include technology, science as a human enterprise, and the social impact of science on society; and it must be articulated with the elementary-school science program.

The sixth suggestion is for science to be presented to the general public in terms it can understand. A good portion of the misunderstandings concerning science and technology stems from a breakdown in communication. This fact has been pointed out by Snow (1959), Barzun (1964), and Calder (1965). As science becomes more specialized, the cryptic and private jargons of scientists build barriers between science and the general public. However, the barriers can and should be removed. Ritchie Calder has suggested that there is practically no scientific or technological advance that cannot be made intelligible to the general public—but it requires considerable effort and close cooperation among scientists, technologists, and those persons and agencies responsible for mass communications.

The establishment of a national panel of scientific advisers to the general public is the seventh suggestion (Evans, 1962). Scientists and technologists often do not want to take time from their work or are not able to communicate effectively; this burden could be shifted to the scientific advisers, who would inform the general public on scientific and technological matters. The advisers might serve as consultants to, and reviewers of, television productions, radio broadcasts, motion pictures, books, and periodicals—not in the name of censorship but of greater accuracy in reporting. They could counteract political, military, and economic interests by presenting the dangers as well as the advantages of scientific and technologic advances.

The preceding suggestions will contribute to scientific literacy, but they will not provide the solutions by themselves. If there is to be a scientifically literate citizenry, each person must become aware of the need. He must make a conscientious effort toward becoming knowledgeable; that is, he must not continue to dissociate himself intellectually from science. Science and technology and their relationship to society must be understood and discussed publicly (Barzun, 1964). Thus, the final suggestion is for scientific literacy to become the active concern of each individual member of society. When it is realized that scientific literacy is everyone's responsibility, attainment of a scientifically literate citizenry may become a reality.

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FOREST FIRES AND NITROGEN LOSS

For years, forest scientists have wondered how much of the nitrogen that literally goes up in smoke from forest fires is in water-soluble form and later may be redeposited on the soil. In other words, does nitrogen thus released come back to earth to assist in plant growth?

C. W. Ralston, dean of the forestry school at Duke University, and Dean S. DeBell, a research forester with the Southeastern Forest Experiment Station at Charleston, S.C., knew an average acre of pine forest litter weighs from 5 to 10 tons. They knew also that green pine needles and other living plant tissues destroyed by fire each year over hundreds of thousands of acres in the U.S. give off nitrogen in the burning process. Thus, they reasoned, if a substantial portion of the fire-released nitrogen is in a form that could return to the soil through precipitation, all is not lost in those too-frequent disasters.

The scientists' laboratory tests showed that 62% of the nitrogen in pine needles and forest litter is released by combustion. Of that, only a small proportion (less than 0.5%) is in soluble compounds available to be returned to the soil in forms helpful to tree growth. The remainder of the nitrogen in the combustion gases, they concluded, is lost by becoming part of the free nitrogen in the atmosphere.

CAN'T SEE THE FOREST FOR THE SMOG

Foresters have raised their estimates of smog damage to forests in southern California mountains as a result of a survey conducted by the Forest Service in the San Bernardino National Forest. The survey, which included both aerial photography and groundwork, took place in the heart of an area where smog damage had been reported. Trees principally affected were ponderosa and Jeffrey pine.

Though foresters previously estimated 25,000 damaged acres throughout the region, research forester Steven L. Wert said smog-type injury showed up on trees everywhere in the 100,000 acres surveyed. He indicated that the actual extent of smog-damaged forest is really greater than 100,000 acres, for trees in the Angeles National Forest and on private land in the San Bernardino and San Gabriel Mountains are also affected.

An estimated 1.3 million trees in the San Bernardino National Forest are affected. Wert said that there are about 26 mature ponderosa or Jeffrey pine trees per acre in the area surveyed. About 50% of the trees showed some smog damage. Of those damaged, 82% were moderately damaged, 15% severely damaged, and 3% dead. Wert said the affected forest will be resurveyed in three years to determine the speed at which the forest is deteriorating.