I am expected to close, I presume, with a remark about the "population explosion." I oblige. I am against it! I do not wish, however, to draw direct parallels between insects and men. But despite this reluctance, several facts have emerged from the study of beetles in their flour which seem to have general currency. One of these is that overexploitation and intense "interference" are perilous and that the peril increases as the population increases.

And there is another fact, one illustrated earlier: The largest population, if exposed to stress, does not necessarily enjoy the best prospect of survival. Man, as we all know and pontificate, has the intellectual talent and the technical skill to avoid such coleopterous hazards. In short, he has the capacity to manage his own population and (of equal importance) to conserve those myriad other populations on which he depends. But one thing is certain. If man does not manage *his* biology *it* will manage him. (*15*, *16*).

References and Notes

1. There are other common ecological relations between species in addition to competition. These are the interaction between plant and herbivore, between predator and prey, and between parasite and host. The three differ from competition, however, in that they all share a built-in behavior such that one population is the attacked and the other is the attacker, with obvious consequences for both. Thus, horses "attack" grass; lynxes attack rabbits; tapeworms attack swine. Still other ecological relations are mutually beneficial, while at the pinnacle of specialization are those end products of convergent evolutions, populations which are socially structured.
2. Many of the points that I have raised here, and elsewhere, are of course not original with me. Several general references which pertain to various aspects of the problem of competition are as follows: G. F. Gause, *The Struggle for Existence* (Williams and Wilkins, Baltimore, 1934); A. C. Crombie, *J. Animal Ecol.* **16**, 44 (1947); E. Mayr, *Proc. Am. Phil. Soc.* **93**, 514 (1949); A. J. Nicholson, *Australian J. Zool.* **2**, 9 (1954); L. C. Birch, *Am. Naturalist* **91**, 5 (1957); C. Elton, *The Ecology of Invasions by Animals and Plants* (Methuen, London, 1958); M. S. Bartlett, *Stochastic Population Models* (Methuen, London, 1960); L. B. Slobodkin, *Growth and Regulation of Animal Populations* (Holt, Rinehart and Winston, New York, 1961).
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9. T. Park, *Physiol. Zool.* **27**, 177 (1954); J. Neyman, T. Park, E. L. Scott, *Third Berkeley Symposium on Mathematical Statistics and Probability* (Univ. of California Press, Berkeley, 1956), vol. 4, p. 41.
10. The actual temperature and humidity values, in degrees centigrade and percentage of relative humidity, are as follows: 34°, 70 percent; 34°, 30 percent; 29°, 70 percent; 29°, 30 percent; 24°, 70 percent; and 24°, 30 percent.
11. All cultures were started with eight young adult beetles per vial; sex ratio, unity. Control cultures received four males and four females of species *X* or four males and four females of species *Y*. Experimental cultures received two males and two females each of species *X* and *Y*.
12. There is one exception to this statement. Single-species populations of *Y* eventually became extinct in the cool-arid climate (temperature, 24°C; humidity, 30 percent). However, they persisted for a longer time than they did when in competition with *X* in the same climate.
13. P. H. Leslie, *Biometrika* **49**, 1 (1962).
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16. I am deeply grateful to the following friends who read the manuscript and gave me the benefit of their advice: P. P. H. DeBruyn, P. H. Leslie, D. B. Mertz, and Philip Wylie. I am also greatly indebted to the late Sydney Hadfield for a color slide used in connection with the lecture.

Science for the Citizen: An Educational Problem

Academic scientists have a responsibility for educating the nonscientist in the nature of science.

James H. Mathewson

The importance of technical education has been the subject of much discussion in this country since the sputniks forced world-wide recognition of Russian scientific prowess. The Russians are attempting to fashion a social order founded on the methods and achievements of technology and to extend the power of this technocracy beyond their borders in order to compete with us politically, militarily, and economically. They possess a large and effective system of education which nourishes this effort.

We are naturally concerned about the state of our own educational system in the face of this challenge, but there has been a tendency to underrate what we have done and what we are trying to do and to suggest measures for improvement that are not suitable for a democratic, pluralistic nation. I think this is due to a failure to keep in mind our fundamental goals. We must state what we are trying to do in education before we start talking about how we are to do it.

In this article I point out some deficiencies in our methods for teaching science to nonscientists in colleges and universities, and some alternatives. But first I will attempt to outline the philosophy behind the criticism and the suggestions.

The Purpose of Education

The purpose of our schools is the development of free, capable, and responsible individuals aware of something beyond their desks or benches—within themselves, within their homes, within their society, and ultimately within the nature of the universe. In this we are not challenged, for although the Russians may produce men who are capable technicians, they are coerced and apathetic citizens.

Our system of education is predicated on the existence of freedom. There must be no pressures of arbitrary authority or special interest on teachers or students. The opportunity for education must be open to all, and each individual must be allowed to go as far as he is capable of going in a program of his own choosing. We cannot allocate individuals to various trades or

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professions, or keep them out. We must meet the needs of technology for trained personnel without abandoning our culture by neglecting education in the humanities. The complexity of the modern world has forced us to place a great deal of authority in the hands of trained specialists. Under these conditions only an educated people will be able to retain the ultimate political power.

At the heart of our system of higher education is the liberal arts college. It is here that we expect our future leaders to acquire the perspective, the insight, and the ability to communicate that will enable them to become the catalyzers and the binders of an open society. The teacher of undergraduates must therefore be more than a specialized scholar; he must himself possess the general skills and exemplify the values he is responsible for transmitting. There will always be those who will not acquire a wider view and sense of responsibility commensurate with their achievements in specialized tasks, and there will be those who do not have the ability or the will to achieve mastery in some endeavor, but an increasingly high proportion of the educated must possess both depth and breadth if we are to avoid being ruled by technicians and demagogues.

Need for Rapport between Scientist and Nonscientist

Responsible participation in the functioning of a free society requires that each of us understand the meaning for us of the endeavors of our fellow citizens, and that in turn the purposes of our own work be understood. This is particularly important for the scientist and the engineer.

Experimental science in its 400-year history has grown to dominate our society. Man has discovered that he can rarely think or act independently of the influence of science. On the contrary he must work to preserve social values that are being eroded by technology and to reinterpret and extend these values in order to cope with social conditions created by technological changes. Illustration of our attempts to control what we have unleashed can be found in any newspaper—control of drugs and pesticides, control of population, control of armaments, control of space.

The layman thinks of the social effects of science most often in terms of the "conquest of Nature"—the spectacular achievements of engineering and medicine, such as atomic power and polio vaccines—but science is also a framework of concepts which has had an important impact on our thinking and beliefs. Man has achieved insights through the great tool of experiment that were not possible for the great thinkers of ancient civilizations. But these successes, like man's technological triumphs, have brought difficulties. Science has liberated man from superstition but cannot release him from the finiteness of his nature. The hope that science could help reveal the absolutes of good and evil, truth and beauty, life and existence has faded, but the rifts between men of science and men of religion and the arts that arose over this question of man's true powers have remained. Communication between the scientist and the humanist has broken down at a time when our society requires wisdom and consensus within the intellectual world.

In his daily existence the nonscientist can never escape his need to understand the purposes and methods of science. He is often faced with technical problems and decisions beyond his competence to understand. He could never be familiar with the whole colossal array of scientific fact and theory, a constantly changing edifice that even a scientist cannot comprehend in its entirety. The layman must seek the advice of the expert who is willing to advise, and must know enough about the powers and limitations of science and the methods and values of scientists to choose his advisers wisely and to work with them effectively.

The massive involvement of science in our lives has forced upon the scientist a new responsibility both as an expert and as a citizen. The scientist can no longer feel that the essential amorality of science absolves him from responsibility for the uses of technological power. He has become a new keeper of mysteries. Rather than act merely as an oracle he must learn to communicate to the nonscientist the essential implications of his methods and findings; at the same time he must not assume that his technical competence makes him infallible on questions beyond the realm of science.

We are past the time when words or technical manipulations can solve our problems, and we cannot legislate our science and technology out of existence. The scientist and the nonscientist must learn to understand each other and to act on the basis of common goals and values. This is a task for education.

Deficiencies in Our Present Educational System

How, then, is science taught to students who do not intend to be scientists, engineers, or doctors? The standard method has been to require each student to take a minimum number of courses in areas outside his "area of concentration" or major subject. For example, the history major can elect to take a course in chemistry. The science course requirement usually specifies that laboratory work be included.

It is assumed that the student will establish his own perspectives by relating his experiences in his major courses with those in his non-major courses. Some mature and well-prepared college students can do this. But the majority today do not realize that becoming educated requires more than getting grades, together with some information and social facility. Most students need an explicit presentation of basic ideas and values, and practice in using them in speaking, writing, and solving problems.

In spite of this need, elementary science courses are not taught with a broadening function in mind. They are designed to train the science major in specialized fact, theory, and technique from the start. They generally cover only one field in science, with little instruction in how the subject relates to other fields inside or outside of science. Under these circumstances the nonscience major finds his encounter with science a torment of meaningless detail, providing little that he may profitably use for a wider purpose than satisfying an academic regulation. He does not need to become a specialist in a science; he does need to understand the essential nature of science as a whole and his relation to it.

The science major remains correspondingly undereducated. He is frequently permitted to avoid all but the briefest exposure to nonscience courses and activities. He is given little encouragement or opportunity to learn the history, philosophy, or social implications of science—the profession he is going to enter. "Scientific information is accumulating with explosive rapidity," he is told, and therefore he must spend every available minute of his college years in specialized courses in one field of science if he is to be adequately prepared for a career.

In graduate school the science major is given a thorough exercise in original experimentation and the opportunity for some creative thinking, but he comes no closer to relating what he does to the tasks and values of other men. Some of these scientists become professors and are given the responsibility for instructing a new generation in the nature of science. Almost invariably, technical specialists are replicated.

So, in the end, neither the science major nor the nonscience major gains a true understanding of the nature of science, of the dynamism of scientific methods, or of the view that science affords of the universe, of man, and of his society.

The deficiencies in the system have been recognized for years by many educators. The distribution requirement was instituted originally to combat excessive specialization in a freely elective system. A few colleges and universities designed special courses and programs in general education in the 1920's and 1930's. Fifteen years ago Harvard University, our most prestigious institution, published a notable re-examination of our system of liberal education (*1*). This study proposed a major revision in the curriculum to re-establish the conditions that provide a reasonable balance between the extremes that produce the dilettante or the technician. Harvard's undergraduate college now requires each student to take courses in the humanities, social sciences, and natural sciences which are designed to provide a broad base of general knowledge and skill in communication upon which to build a more specialized course of study.

A number of colleges now offer courses in science specially designed to provide the nonscience major with a genuine understanding of the world of science. The approaches tried have varied with the background and preparation of the teacher and students (*2*). Some general-education science courses are very similar to standard science courses and others differ considerably. A course in the history of science is a common vehicle for presenting the characteristics of science, frequently in the form of original literature and classic works in science.

Whatever the style or content of a general-education science course may be, the basic objectives are in every case the same: to teach how facts in science are discovered and how they are used in the development of concepts; to describe the effect of scientific ideas in intellectual history; and to train the student to think analytically and critically. The student is expected to learn the limitations as well as the strengths of science. To achieve these objectives, a general-education course must involve a study of science in depth. A mastery of fundamentals is essential for acquiring broad as well as specialized knowledge. To be understood, the characteristics of a complex human endeavor such as science must first be made explicit and then placed in a context of particulars that is built up piece by piece until the student grasps the central theme and can fit other facts or events into this framework by himself. The technical information presented in a general-education course is intended primarily to serve as a context for general ideas. Gaps in factual knowledge can be filled by the student in later life if he possesses the intellectual skills and basic knowledge that make new information meaningful.

The case-history method (*2*) is an example of an effective approach in a general-education science course. In each "case history" the development of an important concept in science, such as the idea of the atom, is followed from its inception. The experiments and ideas which played a part in shaping, in supporting or failing to support, and finally in establishing the concept within science are examined in detail. Survey courses have been the least desirable; in these a brief coverage of a wide area in science is attempted, with no one significant episode or idea being examined in sufficient detail to provide a true picture of scientific endeavor. The survey course fails because it replaces the narrow technical content of the specialist course with watered-down technical information of the same sort.

Laboratory Work for the Nonscience Major

The question of whether laboratory work should be required of the nonscience major has not been satisfactorily answered. The laboratory work in specialist courses has been a target for complaints by science and nonscience majors alike. The standard laboratory exercises for students are designed to teach technical information and technique, not to demonstrate the creative processes of science. In theory, some of the experiments teach the student to think analytically by having him follow a prescribed procedure to "discover" a result of which he is not told in advance but which is, nevertheless, pre-established. But in repeating what another has done, he misses the complex interaction of perception, experience, and imagination of the original experimenter. The teacher rarely has any objective means of determining whether the student has comprehended the logic of the experiment or can transfer this logic to his thinking about other problems. These "experiments" also give the impression that there is one "scientific method" when in fact there is a wide variety.

In most general-education science courses, laboratory work has been replaced by demonstrations and paper exercises. But laboratory work for the nonscience major is not easily abandoned. The essence of science is experiment, observation, and calculation. The nonscientist should have some idea of the way in which a real laboratory is run. He should be exposed to the beauty and excitement of a brilliantly conceived and executed experiment, just as a student of music should listen to great music even though he may not become a composer or performer. It is in the laboratory that the student can best be trained in the important difference between an empirical and a subjective judgment.

Scientists have argued that only by "getting one's hands dirty in the lab" can one learn the real nature of science. In a lifetime of bench work and literature searching, the scientist acquires an intuitive understanding of most aspects of the scientific enterprise. But a nonscience student cannot possibly be given an equivalent experience. Specially designed exercises and problems are needed to recreate for the student selected episodes that are typical of the laboratory experience of all scientists. If, because of the size of the class, no laboratory work is required, a special effort must be made to present meaningful demonstrations that are carefully tied in with the lecture material. Tours, moving pictures, or other devices that can bring the student closer to the real world of science should be used. It might be possible to have a guest lecturer report the progress of a current investigation from time to time during the course.

Scientists in this country have been greatly concerned about the present state of science education for the specialist. Various committees and task groups are now engaged in redesigning lectures, laboratory work, and demonstrations for high school and college courses in an attempt to capture in student exercises more of the dynamic elements of real scientific work. Through these studies, successful techniques may be developed for teaching sound thinking as well as sound practice in the laboratory. Such techniques would be valuable for training nonscientists, as well as scientists and engineers, in the methods of scientific research.

The Scientist rather than Science

General-education science courses which present the nature of science through the history of science and the concentrated study of selected concepts can give the nonscientist some understanding of the characteristics of scientific investigation. However, I think these courses are deficient in an important respect. They are studies of science rather than of scientists. As I stated earlier, it is the scientist—the man seeking to know the nature of things through the manipulation of things—whom the nonscientist must understand. If the layman is to learn to work with scientists, to judge statements made by scientists, to communicate his own values and purposes to scientists, he must gain as true a picture as possible of what a scientist really is.

The natural way to teach the nature of science is through a study of scientists, because science is a human endeavor. It is a dynamic process, not a static collection of facts and theories. The work of the scientist and the effect of his work in society have resulted in the evolution of institutions which are as much a part of science as its instruments, data, and ideas.

The scientist has tended to present science to the outsider as a finished product — a flawless logical structure — and to de-emphasize the part that his own creative imagination has played in building this structure. We know today a great deal about the functioning of the mind of man, alone and in groups. We know that the creativity of a scientist involves not only cognitive logical processes but subjective, irrational elements as well. Faith and emotion are very much a part of his nature—faith in the unity and order of the universe, for example, and a nagging curiosity about the expressions of this order.

There is a wide literature that covers the nature of scientists. This includes their own introspective accounts of the events surrounding discoveries, their biographies, and analyses of the nature of the scientific mind by philosophers, historians, psychologists, and sociologists. Scientific professional journals frequently carry articles on such subjects as the communication of scientific information, the organization and management of research, and the involvement of the government and the military in science and technology. These are matters with which the educated layman will have to deal in real situations, and therefore they should be presented in a science course for the nonscience major.

Something of this approach is already evident in certain general-education science courses; it needs only to be strengthened and made explicit. Case histories of developments in pure and applied science would provide an excellent start for a course concerned with the nature of the scientist. Next, the life and work of a scientist could be examined in detail, and finally, toward the close of the course, a third type of case history could be presented—exploration of the role a particular development has played in society. In the first part of the course, demonstrations and paper problems (or in some cases laboratory exercises) should be included. Guest lectures, field trips, and group projects would be appropriate during the latter part of the course.

A general-education science course based on the nature of the scientist could serve to guide the science major as well as the nonscience major to an understanding of the role of the scientist in society. The science major would be exposed to the history, the philosophy, and the social effects of science with a minimum sacrifice of time. The course could provide an introduction to a program for training those scientists and engineers who would later be responsible for the communication and administration of technical matters in government and industry. Science and nonscience majors could take the same course, since its content could be selected from several fields without duplicating the specialized coverage of technical courses or courses in history, philosophy, sociology, or government. There is a more important reason than convenience for including the science and nonscience majors in one course—the possibility of engendering mutual respect and understanding in classroom discussions and group projects. If individuals are to work together in our nation they must be given the opportunity to do so in college.

Obviously no one course or program will ever completely satisfy all the students or all the faculty. The curriculum adopted must inevitably be tailored to the caliber and the type and extent of preparation of the students, the type of institution, and the attitudes of the faculty. In general there should be as much flexibility in the requirements as possible, so that the student may choose rather than merely react in the academic environment. He will make the best choices when the alternatives have been carefully pointed out to him, but wise counsel in the selection of courses or even in the choice of a career is in remarkably short supply on campuses today. The problem of science education for the layman must be handled with full awareness of other educational problems, such as that of guidance. This should be obvious if we view our educational tasks in the light of our ultimate goals.

Responsibility of the Science Educator

A great many colleges and universities do not offer general-education science courses but still require elementary specialist courses, or inadequate survey courses, to satisfy the distribution requirement. The basic difficulty in introducing and staffing adequate general-education science courses has been indifference or hostility toward the nonscientist on the part of science department professors and administrators. The present conservative trend in American education has encouraged these attitudes. This is unfortunate, since the critical factor in teaching science to nonscientists is the teacher. General-education science courses should be taught by men who are, or have been, active in scientific research, not by historians and philosophers. University science professors who have sufficient knowledge of the history and philosophy of science to teach special courses for nonscience majors are generally unwilling to sacrifice time and energy which they would otherwise devote to research and to the teaching of science majors and graduate students. The problem can be met by using a team of professors, but strong interdepartmental cooperation is necessary, and a qualified individual must still be found to take the responsibility for designing and organizing the course and for testing and grading.

A common argument against general education courses has been that a good science teacher can make a specialist course a worth-while experience for the nonscientist. But a specialist course, however well taught, still does not meet the needs of the nonscience major. The argument that there are badly designed and badly taught general-education science courses is no more valid.

Problems of course design, teacher preparation, and interdepartmental cooperation can surely be met if the scientist will fully accept his responsibility for the adequate education of the layman in science. When the scientist realizes that his freedom as a scientist and as a citizen is jeopardized when the community is ignorant of his real nature, then he may meet this educational responsibility which his power and his importance have given him.

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NEWS AND COMMENT

NIH Grants: Policies Revised, but Critics Not Likely To Turn Away

Under pressure from Congress, the Public Health Service has ordered some new procedures to govern the expenditures of its grants. The procedures, contained in a Grants Manual distributed to the business offices of all recipient institutions, take effect 1 January, and though they do not radically alter the ground rules for PHS grants, they do remove some of the freedom that has heretofore existed in the use of PHS funds.

The most far-reaching of these changes puts some teeth in an existing PHS regulation that provides that salaries drawn from grant funds should not be out of line with salaries paid with institutional funds. This has always been the rule, but with congressmen charging that some institutions are winking at it, the PHS has now decreed that the institutions must provide a quarterly accounting of the "time or effort" that investigators put into PHS-supported research. The rule provides that institutions may not set up a special pay scale for personnel who receive salaries from grants. And part-time researchers on PHS grants may not draw salaries from the grants in excess of what they would have received from their own institutions for the same time or effort.

The bookkeepers for these computations are to be the investigators themselves, and their findings are to be kept on file in the institution's administrative offices, for examination by PHS auditors. The National Institutes of Health, which is the principal channel for PHS grants, has offered Congress assurances that its auditors will make frequent rounds.

The new manual also directs that grant funds may not be used to buy equipment costing more than $1000 without PHS approval; nor may international travel be paid for with grant funds unless the PHS has specifically approved the trip. Domestic travel in connection with a research project may be covered by a lump sum.

In addition, investigators who do not have institutional affiliations (relatively few of these are receiving PHS support) must be bonded before they may receive PHS funds. The size of the bond is something that will be worked out between the two parties.

The regulations have been put together in response to increasing congressional dissatisfaction with NIH's administration of its extramural research program, but it does not appear likely that Congress is ready to say quits, for the dissatisfaction with NIH runs deep and has even spread to members on whom NIH could once rely for down-the-line support. The outcome of this sentiment is not the least bit likely to reverse the continuing growth of federal funds for medical research (NIH went from under $10 million a year at the end of World War II to an appropriation of $880 million in the last session of Congress), but it appears that the honeymoon between Congress and medical research is now over, and NIH will no longer receive the favored-child treatment.

Part of this change arises from nothing more than conservative concern over NIH's growing share of the federal budget, a concern that automatically locks onto any attempt to give an agency any large increase over its previous appropriation. Some of it arises from expressions of concern within the scientific community itself over whether NIH's rapid growth has sacrificed quality to achieve quantity. And some of it reflects nothing more than the know-nothing ramblings of scientific illiterates, who conclude that if the title of a research project is not readily comprehensible to them, some effort to swindle the government must be involved.

Congress Puzzled

But a great deal of the sentiment that now confronts NIH in Congress arises from the fact that many members are genuinely puzzled over the federal government's heavy involvement with medical research. They recognize that no alternative sources of funds are available for the massive research effort now under way in this country, and since they are as much against cancer and heart disease as anyone else, they want to make certain that wherever money can be usefully spent it will not be lacking. However,