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SEARCHERS AND RESEARCHERS

*SELMAN A. WAKSMAN**

> *Science cannot be based on dogma or authority of any kind, nor on any intuition or revelation, unless indeed it be of the Book of Nature that lies open before our eyes. We need not dwell on the processes of acquiring knowledge by observation, experiment, and inductive and deductive reasoning. The study of scientific method both in theory and practice is of great importance. It is inherent in the philosophy that the record may be imperfect and the conceptions erroneous; the potential fallibility of our science is not only acknowledged but also insisted upon.*—R. ROBINSON [1].

I. *Random Notes on Scientists and Their Fellow Men*

In any attempt to analyze the attitudes, philosophy, or scientific contributions of a particular investigator, it is usually desirable to present first one's own point of view or philosophy, for in making such an analysis, one cannot escape his own prejudices. Even the definition of a "scientist" could be expressed in different ways, depending on the point of view of the definer. To some, it is a Newton, a Faraday, a Pasteur, an Einstein, or one who has reached the pinnacle of scientific attainment; a scientist is thus conceived as one who tries to solve basic or fundamental problems underlying matter and energy, by means of whatever tools he is best qualified to use. Others conceive of scientists as people who develop new tools, ranging to those of a technician or even a gadgeteer. Even the compilers of data—or the "literature scientist" and "information specialist"—are considered scientists, the mere concept being reduced to that of "researchers."

II. *Science and Society*

It has become customary in recent years to generalize about science and its place in society. It is rather difficult, however, perhaps even unjustifi-

* Professor Emeritus, Institute of Microbiology, Rutgers University, New Brunswick, New Jersey. The Upjohn Company's kind generosity in covering publication costs of this article is acknowledged with thanks.—ED.

able, to speak in a similar vein of the scientists themselves, unless one considers them in a purely abstract sense or as a special social group rather than as an assemblage of various individuals with quite different philosophies of life and different attitudes toward society. The various branches of science can be classified, but not so the scientists themselves. It is possible to analyze or even idealize the nature of the individuals who are engaged in scientific endeavors or the types of people who occupy themselves with science as a means of livelihood or as a natural calling. But one cannot attempt to describe scientists as a group. In the early days, when the field of science embraced only a few devotees, one could pick a Davy, a Dumas, or an Ehrlich and describe his emotions, his personal life, and even generalize, as some historians have done, about the kinds of wives they had or should have had, whether they should or should not have had any children, and whether or not they were generally normal human beings.

Various branches of science, notably physics, chemistry, and biology, have recently made such rapid advances that the result has been a complete revolution in our daily lives. The impact of this revolution upon society is only slowly being recognized, although "atomic" explosions and "sputniks" have tended to hasten this process. We have been hearing a great deal about the social responsibilities of science and of scientists recently; unfortunately, we have only little appreciation of what is really involved. The general impression still prevails that science is something abstract and that those engaged in it form, at best, a kind of a guild or, at worst, a group of medieval magicians.

In reality, science has become in recent years a definite profession and is often closely affiliated with what one might call "big business." Scientific research is now no longer limited to universities and special institutes. It is carried out quite extensively and quite competently in industrial laboratories and government institutions as well as in laboratories supported by private funds. It is true that important scientific contributions are still being made by individual scientists—that great ideas and leading experiments are still hatched in individual brains, like those of a Curie, an Einstein, a Fermi, or a Pavlov. These individuals are still considered the great pathfinders in science, who have opened new fields for others to explore and exploit. But with the growing need of expensive equipment for certain types of experimentation, with the growing importance of collaboration and teamwork in research, hastened and encouraged by the tremendous sums

contributed annually by philanthropic, industrial, and governmental agencies, the individual investigator often ceases to play the leading role. At best, he is a leader of a project; at worst, he is a mere cog in a machine. It becomes more and more difficult even to determine who has contributed a particular idea or is responsible for the development of a particular method in an important scientific investigation.

It is neither the magnificence of the scientific laboratories nor the wealth of the laboratory equipment that results in the creation of great scientific discoveries. It is hard work, perseverance, and innate ability that are the three greatest essentials in scientific endeavor. Claude Bernard and Louis Pasteur, two of the greatest scientific minds of the nineteenth century, had relatively little equipment to work with. The first two important antibiotics, penicillin and streptomycin, were discovered in a small hospital and in an agricultural experiment station, respectively—both rather poorly equipped and hardly to be compared with the great modern temples of science devoted to this field of research.

The benefits to society as a whole from the accomplishments of scientific laboratories and from the contributions of individuals or groups of scientists can be divided roughly into two categories: (*a*) the practical benefits obtained from many of the scientific discoveries; and (*b*) the broadening or educational influence exerted upon society through the increased understanding of nature and natural processes resulting from scientific investigations.

In speaking of science and the scientist, Professor Charles Richet said: "The future and the happiness of humanity depend on science." Then he added: "So much the worse for society if it fails to apprehend the outstanding truth."

III. *The Individual Scientist and the Team*

With the great support given in recent years by government agencies, especially to chemical and biological sciences, a new problem has arisen—namely, "planned research" versus the "individual investigator." Much pro and con have resulted. It is sufficient to quote from Cannan [2]:

> There is a place for planned research. It can take a defined body of knowledge and lay out a set of experiments which will exploit this knowledge to its foreseeable limits. It can take a set of postulates and drive these home to their logical conclusions. It can do this with exhaustive thoroughness, economy, and speed. Within its limitations, it is efficient, expeditious, and authoritative. . . . But there is a place also and a much more important

place for the random investigator. The role of project research is to consolidate ground already won: the role of the random investigator is to seek out new worlds to conquer.

In speaking of "free research versus design research," Richter [3] emphasized the limited relation between a man's ability to devise experimental designs and his ability to do research. Good scientists use research plans merely as outlines to begin their investigations and are ready to give them up once they are not justified by actual findings. Experimental designs tend to give rise to "team research," which "serves a purpose in developing and applying ideas; it rarely produces new ideas." Kroll [4] also took issue with those who assert that the days of "sealing wax–baling wire" science are over. Though teamwork cannot be avoided in development work, its justification in research can be challenged, except in cases of great national emergencies. When teams are put to work to make important discoveries or inventions, they often fail dismally or produce results that are far too costly, again excepting national emergencies. Ordinarily, many laboratories are over-fond of gadgets and complicated equipment that remove the investigator from his experiment; automatic research tools tend to be a great handicap to invention and progress. In the early stages of any new development, the lone-wolf research worker acts like a scout, prospecting new territory before it is exploited by the crowd.

I can best illustrate this by citing certain developments in a branch of science with which I have personally been concerned, namely, antibiotics. As in any other field, one can recognize two distinct approaches that have been utilized and have often led to rapid progress. One of these has depended on chance observation and the other was a result of systematic planning and investigation.

In the first approach, the "prepared mind" takes advantage of an accidental observation passed over by others without its arousing undue curiosity. Thus Fleming's observation of the production of an antibacterial agent which he designated "penicillin" later led to the discovery of a great life-saving drug.

In the other approach, a preconceived idea is put to test in practice. Systematic investigations are planned and conducted to prove or disprove this idea. The screening program on the production of antibiotics by fungi and actinomycetes may be cited as an illustration. It led to the discovery of streptomycin, and later of chloramphenicol, the tetracyclines, and numerous other life-saving drugs. Teams of workers were required to carry

out these investigations. They included microbiologists and chemists, pharmacologists and clinicians. It is often difficult to determine what individual in a particular team has made the greatest contribution to a given discovery. Was it the one who isolated the antibiotic-producing cultures from the soil or from the dust? Was it the one who isolated the active substance, or antibiotic, from the broth? Was it the one who solved the chemical composition of the particular substance? Or, finally, was it the one who established the activity or clinical effectiveness of the substance in the living animal body? Even the accidental discovery of penicillin might have remained buried in one of the dust-collecting journals for many years. Perhaps it is, after all, the team of workers headed by Florey and Chain—who developed penicillin and determined both its theoretical significance and its practical potentialities—who are entitled to the major share of the credit.

IV. *Scholars and Philosophers*

There are many who suppose that scientists form a class of special human beings. Two widespread extreme concepts of what scientists are can be clearly recognized. On the one hand, they are thought to be simpletons who do not understand the potential practical meaning of their own discoveries in the lives of men and who frequently become encumbered in a "scientific cobweb." On the other hand, they are considered as high priests who sacrifice their lives at "the altar of science" for the benefit of the human race. These concepts may be heightened by the fact that one frequently finds mountebanks who, either for personal aggrandizement or because of mental aberrations, greatly enjoy giving the impression that they represent a special class of society and are even prepared to set up a "scientific hierarchy" modeled after a sort of Plato's Republic. The great majority of scientists, however, are just ordinary human beings, average members of society, who happen to be engaged in scientific pursuits. Theirs is a profession which embraces searching for the unknown and uncovering facts and principles that govern natural processes—by observing, experimenting, generalizing, or "philosophizing" on the facts thus discovered.

Not many of those now engaged in scientific pursuits do so because they feel a "call" for it and, therefore, become "dedicated" to it; nor are there many who are prepared to sacrifice their daily comforts to be permitted to continue with their selected field of endeavor. Because of the

tremendous practical developments recently made in the various fields of science, many individuals have entered this field and have taken up science as a profession. Frequently they are able to adjust their interests and abilities to one particular branch of science or another. To them it does not matter whether their work is concerned with the study of the stars—certainly an abstract or purely theoretical branch of science; with the study of nuclear reactions—a field that has recently gained great prominence as a potential for war and peace; or with the search for antibiotics and their role in the control of disease—which involves a group of problems that range from purely theoretical to manifold practical applications.

If one examines more closely the present concept of intellectualism as it has developed historically in various European centers, especially the concept of "savants" in the best tradition of European philosophy, one can hardly fit into that category many of the investigators who are now engaged in scientific pursuits. The scientist—and I have in mind the naturalist and the observer as well as the experimenter—is more concerned with the results of his particular observation or experiment than he is with any bearing that the results of such investigations may have upon human health and human economy. Whether he is trying to unravel properties and reactions in the domain of physics or chemistry or whether he is interested in genetics and is trying to untangle certain rates of mutation in the fruit fly or in a mold; whether he deals with the complex metabolism of a bacterium or with the role of a particular virus in the causation of a certain disease—in the end, he is not primarily concerned about the results of his investigations turning out to be "good" or "bad" for society. His efforts are directed, at the moment, toward unraveling certain links in a chain of an unknown process or processes. He is happy when he succeeds in making even the smallest contribution to a better understanding of such an unknown process. His major compensation is not always the remuneration received for his work; more often it is seeing the results of his investigations published in a reputable scientific journal. It is up to society to make use of these newly discovered facts, for its benefit or for its destruction.

Cannon, in his excellent treatise *The Way of an Investigator*, summarizes the qualifications of an investigator: curiosity, imaginative insight, critical judgment, thorough honesty, a retentive memory, patience, good health, and generosity. The real devotee of research is driven by an impelling de-

sire to learn, to satisfy his burning curiosity, to know whether his surmise is true or not. Look into an active, well-financed laboratory where a group of experimenters is at work and you will find that enthusiasm for advancing knowledge is mutually stimulating. Over the decades conditions for basic and applied research have become more and more favorable for those engaged in it. Concomitant with that change, there has been no indication that seekers for new facts have become remiss and slothful; rather, the advancement of science has been marvelously accelerated as the conditions have improved.

The concept of the true scientist is that of a man of learning and knowledge; he is guided by the passion to know, to find out, to create anew. In some languages he is referred to as the "savant." Unfortunately, this word which is so expressive in the French language has no equivalent in English, unless the word "scholar" can be made to serve. Some persons, however, find a certain degree of difference between the scientist and the savant, the latter often being considered a teacher or professor rather than an investigator or searcher. A further difference between the savant and the scientist is that the former does not look for, and may not even be interested in, application of the knowledge gained by his work to practical problems; the scientist occasionally does. The concept of the savant approaches that of the philosopher, while that of the scientist often serves as the bridge to that of the engineer, the surgeon, and the agriculturist. It has been said [5] that the philosopher contemplates (intellectual curiosity) and the scientist operates (by experimenting for the proper understanding of natural processes).

Scientists work either with their hands or with their imaginations—they observe and they experiment, or they generalize. They have often been divided into two categories: those who can and do work alone and cannot tolerate others around them; and those who can do their work best by having many students and assistants who can help them in their work, provide them with ideas, and thus carry on to broader horizons the observed facts and the spun theories.

G. W. Robinson, the eminent soil scientist, stated in his introduction to a delightful volume on "Mother Earth" [6]: "I deprecate the use of the term 'science' at all and would prefer 'natural philosophy.' I am loth to describe myself as a 'scientist,' but, I should be proud of the description 'natural philosopher.' "

V. *The Theoretical and the Practical*

The true scientist is hardly interested in making sure that his discoveries —if one is prepared to crown with that title the majority of observations and results of experimentation—are interpreted or digested for the education of the layman or are utilized for practical purposes. Once the results of his investigations have been announced, once they are accepted by his fellow scientists, he may be but little interested in any further development of the fruits of his labors. He is primarily concerned that the results of his studies become a part of the scientific background that may lead to the further advance of our knowledge of the universe and its natural laws. He is not always pleased when the popular press pays too much attention to his work, since relatively few investigations lead to practical applications that can at once be recognized and utilized; and often these are the results of a long series of investigations made by scientists who are not even known to the people who benefit from their labors. Frequently it is others who derive the practical benefits from scientists' work.

Although the bulk of the observation of routine laboratory studies might better be left undisturbed on the library shelf, in the numerous scientific journals where they are published, some of these results—and these are relatively few—find, sooner or later, important practical applications. Fewer still are the discoveries spectacular enough to attract the attention of the popularizer and thus be digested for the benefit of the public at large. It is of interest to take a look at those who do this digestion and interpretation.

H. O. J. Collier says in his excellent analysis of the "presentation of science to the public" [7]: "Scientists are aware that the general public sometimes fears or dislikes science, which makes some of them keener to explain how their work may ultimately be valuable to everybody. Some scientists believe that they owe society an account of their doings."

Few science writers have the necessary preparation or the capacity to analyze for popular consumption much of scientific work, especially what is largely theoretical. Some are able to penetrate into the mind of the investigator and intelligently present the story of his labors, sometimes even better than the scientist could himself, but the majority of interpreters, unfortunately, accomplish at best only a superficial recording of some of the obvious results. They often fail to understand the underlying philosophy of the particular scientific contribution and lack the technical knowledge

to recognize its significance. Often their accounts do not distinguish between a discovery with great potential practical applications that could affect society in numerous ways or an isolated though profound observation tending to form an essential link in a complex chain of natural events but possessing little practical potentiality.

The public feels that it is entitled to know what is going on in the numerous laboratories in the land, in private institutions, as well as in the universities and government laboratories. Since in the end the public pays the bill for the support of scientists, their assistants and technicians, and their equipment and supplies, it should know how these funds are being spent.

The question is: How should the results of fundamental investigations carried out by scientists be presented so that the public at large understands? Should the job be left to scientific popularizers, running the whole gamut from first-class interpreters to the pseudoscientific wonder-workers? Should it be done through special journals by specially trained writers? Such people would surely render yeoman service to the public. Should the collaboration of investigators working in various fields of science be solicited for such tasks? The trained interpreter could carefully analyze information from one or more scientific laboratories and interpret it in terms of the scientific significance—and, even more important, in terms of the social implications. He would thus work hand-in-hand with the scientific groups involved.

VI. *Scientists and Technicians*

Not so long ago scientists lived and worked in comparative isolation from the general public, and the expression "ivory tower" had more meaning. They depended for their support largely upon philanthropically minded individuals, notably kings and nobles, or Maecenases. They were not interested either in contact with the public at large or in making the results of their findings generally known. At best, they communicated only with those engaged in similar scientific or philosophical pursuits.

As they became more and more dependent upon public support and as the results of their observations, and later also of experimentation, began to find more and more practical applications, scientists learned to recognize a duty to society, which could be paid only by making the results of their findings known. The general public's distrust, if not fear, of scientists contributed in no small measure to the need for popularization of their

findings. Then the popularization itself began to obscure some essential distinctions and to confuse the public about science.

Often not understood or clearly distinguished were the following classifications of scientists: *observers*, for those whose work is based purely on observations, which may or may not be followed by experimentation; *experimenters*, to label those who are primarily involved in laboratory manipulations; *fact gatherers* or *fact collectors*, for those who are not primarily interested in correlating and coordinating the facts obtained by observation or experimentation and thus building them into a new theory or even philosophy; and, finally, *theoreticians*, for those who try to coordinate facts into scientific theories, laws, or hypotheses. The danger is always present that a theory or hypothesis not well substantiated by facts or by evidence obtained from observation or experimentation may lead to empty speculation or erroneous conclusions on the part of the public.

Further, modern science, especially experimental science, depends upon technicians to help the scientist carry out his experiments or manipulate the often complicated apparatus essential for his observations. Technicians vary greatly in their previous preparation and experience, their ability to follow instructions, and their personal interest in the work they contribute to. In some cases they are most anxious to carry out the spirit and the letter of instructions and are often even able to improve on the procedures involved, with the result that they themselves become scientists. In other cases technicians take little interest in the problems in which they are involved and may often record data without recognizing or appreciating their significance. There are even cases on record of a technician's knowing or guessing the results that the scientist would like to obtain and seeing to it that the experiments or observations produce such results.

The present great vogue of science in general—and the physical, chemical, and biological sciences in particular—has attracted many men and women to scientific pursuits—as assistants and technicians as well as independent investigators—who are often designated "researchers." Research has suddenly become the popular activity to be engaged in, and researchers have found their place in the sun. The word itself is largely a misnomer. Originally used to designate those who check upon certain facts and gather information, usually in libraries, it came to replace the designations "scientist" and "investigator," who are engaged in research embracing careful and systematic investigations into a profound branch of human knowledge.

VII. *The Scientist and His Fellow Men*

Only a century or two ago the scientist worked by himself. He had little equipment and less assistance. He was usually a philosopher. His ideas and the results of his investigations seldom had an important effect upon people's daily lives. Advances in astronomy and in certain branches of mathematics resulted in important practical applications for navigators, bridge builders, and the members of other limited professions, but the larger social groups benefited little. Gradually, as theoretical speculation led to experimental observation, as the sciences of physics, chemistry, and biology grew and broadened our understanding of the inanimate and living universe, the results of the laboratory entered into our daily lives bringing new wealth to society and opening up possibilities never before visualized. Possibilities for our improvement as well as for our destruction were greatly increased, our average life-span was prolonged, and potential uses of our natural resources were vastly enhanced. The influence of scientific progress during the last few decades has been so great that we call our times "the space age," "the atomic age," or "the antibiotic age."

The scientists of today—theoretical, practical, basic, and applied—have come, therefore, to occupy a prominent place in our society. Great resources are placed at their disposal, and much is expected from them. Our communication network is to include the whole planetary system. Energy supplies are to become unlimited. All diseases are to be eliminated. Population changes are to be brought under control. World peace is to be established. All this may sound fantastic, but it is no more so than increasing the average life of man by twenty years in one generation, eliminating some dreadful diseases that have plagued the human race since the dawn of history, or achieving controlled release of nuclear energy.

Scientists have revolutionized our understanding of natural processes and have produced enormous changes in our daily lives—changes affecting our health, our food supplies, and our relationships to our fellow men everywhere on this planet and possibly beyond. These changes have been so sudden that society as a whole has tended to become suspicious of the scientist, and the old notion of the magician is being reincarnated in a new costume.

What sort of person is he, really? Is he a special type of individual? Does his work entitle him to a special place in our society?

The accompanying chart illustrates the many different characters he may assume. The natural scientist of yore, who often became a philosopher, or even a pseudoscientist or magician, has now become the experimental scientist, who is related to or may become either a theoretician or an applied scientist; he may also become a gadgeteer or an inventor. The scientist himself may become the interpreter or popularizer of his discoveries. Finally, he may also be or become a teacher who tries to transmit to a younger generation his own and others' ideas and findings.

The field of science thus engages the attention of many kinds of persons who represent a wide range of qualifications, activities, and accomplish-

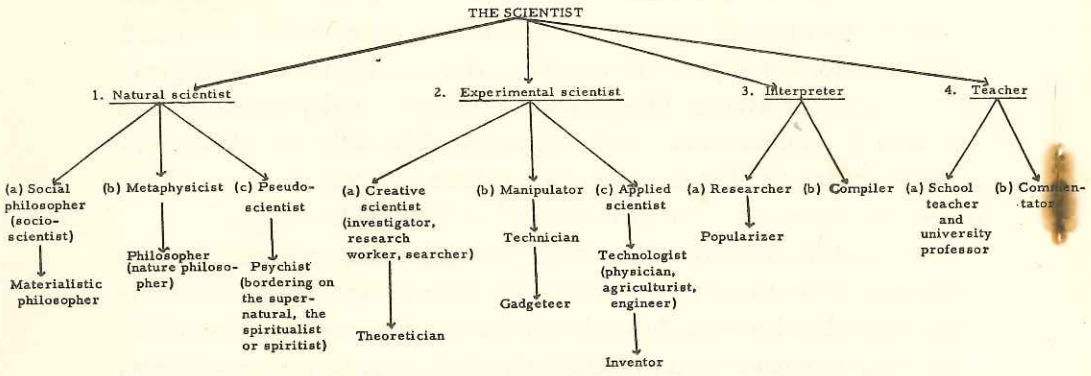

FIG. 1.—A chart illustrating the development and position of the scientist in society

ments. They comprise no particular guild, in spite of the many societies to which they belong, and they do not comprise any one profession. They must, therefore, be considered as members of society like any other conglomerate of individuals engaged in such pursuits as medicine, architecture, law, and various business enterprises. Their place and obligations to society are no more and no less.

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