GENERAL SCIENCE

The Third Scientific Revolution

In the complex world of today where science and society are so closely interrelated, education in the arts as well as the sciences is essential to meet problems with competence.

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➤ AS I LOOK at this group of outstanding young people I am encouraged about the future of the nation. There are always those who, forgetting their own past, view the younger generation with despair. But I must say that in my 21 years in education I have never before witnessed such a wave of eager, well-qualified, and dedicated students as that which is now emerging from our secondary schools and flowing into our colleges and universities.

As a group, today's students have an amount of intelligence, curiosity, and breadth far exceeding that of their predecessors a few decades ago. This may result in part from the reported "genius explosion" which is based on the fact that there are being born five to ten times the normally expected numbers of children with IQ's of 150. And the significant improvement in many secondary school programs certainly has been responsible to some degree. But these are not the whole explanation, for intelligence and education do not mean much unless there is a motivation, an involvement, a devotion. I think much of the answer is found in a statement by Thomas Paine, a revolutionary in an earlier age. He said: "Every generation is, and must be, competent to all the purposes which its occasions require." In other words, every age somehow develops the competent people to deal with its critical problems—whether they are political problems as in the 18th century, or the intricate, vastly complex social and economic problems of today.

Proof of Paine's Theory

We can find convincing proof of Paine's theory by turning the clock back nearly 350 years. Then, a 74-year-old Italian astronomer, under house arrest at the order of the Inquisition for having espoused radical ideas, lived in seclusion outside of Florence. He was secretly writing a book that would alter the course of history. A scientist in a world of shadows, he had lived an exciting, stormy, and immeasurably significant life. Fifty-six years earlier, when he was no older than some of the students here today, he had timed the oscillations of a swinging lamp by means of his pulse beat and discovered the isochronism of the pendulum. Later, he built one of the first complete astronomical telescopes and, by studying the movement of sunspots, with it proved at least to his own satisfaction that the sun turns on its axis. His investigations led him to publish a thesis supporting the Copernican theory which placed the sun rather than the earth at the center of the solar system. In 1638, then, very ill and nearly blind, with only four more years to live, Galileo published his greatest treatise, "The Two New Sciences," deriving the law of the free fall and sharpening his concept of inertia. In so doing, he changed man's view of nature and accelerated the scientific revolution which has shaped the modern world. . . .

Knowledge Explosion

The scientific revolution continues today with an incredible flow of new knowledge and new ideas. Though we stand at the center of the knowledge explosion, even we can hardly comprehend the scope and the impact of the scientific and technological information that pours from the world's universities and research laboratories.

In the last year for which international statistics are available, it was reported that 1,250,000 technical papers were published in the fields of the life and physical sciences. And the production of knowledge is increasing exponentially. The number of technical journals has doubled from 50,000 to 100,000 in only the past 13 years. By 1980 it is estimated there will be a million such journals. In one field—the biological sciences—research findings have increased by 60% in the past five years. And the average biologist can now review only about five percent of the material published each year. The proliferation of articles, journals, and abstracts is so tremendous that we are now publishing abstracts of abstracts.

The continuing scientific revolution has clearly affected every area of society. An especially pertinent example is the teaching of science in our schools. Since 1957 there has been a scrupulous appraisal of American science curricula. And for good reason. Until a few years ago the majority of American schools, including many colleges and universities, were failing to adjust to the rapidly changing nature of science. So rapidly was new knowledge being generated that the substance and methods of science were often becoming obsolete even as students were learning them in the classroom and laboratory. The many gaps disclosed in the past seven years have been meager compared to the chasm that separated scientific knowledge and science education. . . .

Today we are making substantial progress in adapting science education to scientific progress. In our secondary schools, there are some 20 programs designed to improve the teaching of mathematics alone, and the "new math" has reached three-fifths of all the schools in the country. Altogether there are more than 60 programs being offered to upgrade high school curricula in science, mathematics, and languages. The new curricula do not attempt the impossible task of including all new knowledge as it is discovered. They seek rather to provide a comprehensive foundation which anticipates advanced material and readily admits new concepts. . . .

But even as we have moved toward the unification of knowledge on the one hand, we have moved toward specialization on the other. As science fair entrants you have experienced a small amount of specialization even at this early stage in your careers. To complete your projects, you have undoubtedly taken time from other interests and activities, and focused a good portion of your energy on a specific area of research.

Let me make clear at once that I have no quarrel with specialization. If one is to comprehend anything in an age of a 100,000 scientific journals, specialization is essential. . . .

The specter of scientific overspecialization is more shadow than substance. The real danger is in knowing too little about a subject rather than in knowing too much.

It must be obvious to you young people that even with your remarkable early sophistication in science you have only begun to learn the basic substantive and methodological knowledge you will acquire in college. Even after four years of intensive college study, you will have only a foundation for the specialized training you will receive in graduate school. And even after earning a Ph.D., or an M.D., you may find it necessary to enter postdoctoral study to acquire the highly specialized knowledge you will need to be a creative leader in your discipline. And you will not be able to pause even at that point.

Lest you think that postdoctoral study is the ultimate reach of science education, let me say that within a decade after that, you will be confronted with a mountain of new knowledge that may make much of what you have learned obsolete. When you begin a career in science today, you commit yourself to a lifetime of study and self-development, for that is the only way you can keep abreast of the scientific revolution.

Second Scientific Revolution

To complicate matters, a second scientific revolution is under way. It is in the institutionalization of science. Even before the 20th century, the expanding techniques of science were beginning to join in technological matrimony with the advancing management techniques of industry. Government soon joined the partnership, and you have seen the offspring of this union. During World War II, enormous teams of scientists were assembled to work on the Manhattan Project, which, as you know, led to the development of the atomic bomb. Today, thousands of scientists have been

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gathered for work on massive projects, such as the Apollo program. As a result, the "professional" scientist on the payroll of government or industry has emerged as a 20th Century phenomenon. In fact, some 60% of America's scientists—280,000 of them—are working for the Federal Government, either directly or under grants and contracts. They have reduced—almost eliminated in some cases—the long-standing gap between science and technology, between the laboratory and the assembly line. And in so doing, they have brought science to the point where it bears directly on such social considerations as defense, unemployment, international trade, and economic expansion.

There are dangers in the second scientific revolution, some of them alarming ones. By directing the efforts of so many of our scientists toward limited goals, we may be restricting scientific freedom and stemming the wellspring of basic research. By marshaling armies of scientists into huge teams, we may be promoting conformity rather than nourishing creativity. I saw one particularly alarming study recently on the subject of management attitudes toward creative scientific employes. Those scientists who published the greatest number of research papers, and who were rated by their supervisors as being most productive and most resourceful, were named in a significant number of cases as being most expendable in case personnel cutbacks were necessary.

Despite its present faults, the institutionalization of science has succeeded in organizing and directing the single most potent resource of our society: scientific manpower. Moreover, the union of science with government and industry has tied the whole scientific venture, and therefore the scientists, to the social problems of our age.

Third Scientific Revolution

It is this tie that is leading us into the third scientific revolution: the use of science as a social force. I am convinced that scientists in growing numbers will devote an increasing share of their attention to the management and settlement of our social problems, and will bring to those problems the same energy which they have applied so fruitfully to pure research and technological innovation. Though some will disagree, I think the time has passed when any scientist can maintain that his task is solely the pursuit of pure knowledge without regard for the uses or abuses of that knowledge. I am not saying that scientists as scientists should not be free to follow where their curiosity leads them or to pursue the truth with complete freedom. I am saying that scientists as human beings must accept a responsibility to see that their knowledge and techniques serve the cause of humanity as well as the cause of science. There is ample evidence that the scientists themselves are becoming keenly aware of this. Their increased participation in the counseling and management of government and our other social institutions indicates their willingness to accept this awesome responsibility. . . .

You students here today will likely play a highly significant role in the future of our society. I would do little justice then to say that you are here because you won a first prize in a regional science fair. And it would miss the point entirely to say that you are here so that you can enter your projects in competition with one another. You are here because you have proven yourselves capable of taking part in the most exciting venture of our age—which is, of course, the venture of science. In other nations, in other ages, the spotlight of public attention focused on outstanding young athletes, poets, warriors, and statesmen. Today it is focused on you. And it is interesting to note that though you have supplanted the athlete, the poet, the warrior and the statesman in the public imagination, you have also assumed a large share of their roles. As future scientists you will be expected by your fellow citizens to provide them with glory, self-awareness, security, and direction. No matter if these are the proper or improper responsibilities of the scientist as scientist; they are what society demands.

Illusion of Golden Age

In our generation, scientific progress has given substance to the illusion of a Golden Age. It would seem that there is nothing beyond the power of man. There is promise of farming the ocean, harnessing the power of the sun, inhabiting the distant regions of space. More immediately, our scientific and technological prowess has conferred innumerable blessings upon us. . . .

But on closer scrutiny, much of the Golden Age is still illusion. With all the knowledge, techniques, and tools we have developed, we still fail to provide satisfactory answers to many of our most urgent problems: How, for example, can we build a lasting peace? What can we do about our burgeoning population? How can we create work for the millions of unemployed? How do we win a war against poverty?

The solution of these problems requires a new competence. And it is to its scientists that the nation has come to look for a large share of that competence. And, I suspect, that means it looks to you.

As scientists, you young people will have an awesome responsibility to live up to. You will be playing a greater role in the leadership of the government. You will be expected to provide a new competence to solve the great social problems of our time. Frankly, I would sympathize with you at this point if you began thinking of a career in journalism or business administration. But I rather think that the challenge will beckon you and provoke an eager response. And the question will then be: What must you do to equip yourselves to meet this challenge?

I have already stressed that you will have to be specialists in your scientific fields if you are to be part of the first scientific revolution. And I have indicated that you must maintain your integrity in the second revolution of the institutionalization of science. To be participants in the third revolution—to employ your knowledge and apply your techniques as a social force—you will have to be, in addition to scientists, good citizens, well informed men and women, compassionate and involved human beings. . . .

In short, you must be liberally educated if you are to perceive the relationship between science and society, between right and wrong, between man and his fellow man. It is not sufficient to know "what is"; you must also consider "what ought to be." It is not enough to measure; you must also feel. You will have to judge issues that admit no mathematical models, no complete set of evidence, and no possibility for experimental control.

Science and Human Values

I realize that there are many who claim that science can say nothing positive about human beliefs and values. They insist that when science speaks at all, it can only say "no" or, at best, "perhaps" to everything outside the boundary of statistical analysis and quantitative measure.

Nonetheless, I believe that science *can* speak in a positive way about human behavior and human values. An analysis of the history of science shows a group of men analyzing the behavior of matter and energy as other men analyze the workings of the legislature, others the workings of the economy, and still others the workings of the soul. All of them make perceptions which can contribute richly to our insights. The challenge facing us is to use science to add a new dimension to our thinking which will at least give us a greatly improved perspective and which may possibly guide us toward many yet-unrecognized solutions. . . .

I can only hope that Paine's theory holds true—that this nation will develop the competence to solve its problems and recognize its opportunities. The new generation of students—of which you are certainly the vanguard—is a promise that we will be competent to all the purposes which our complex occasions require.

If this promise is fulfilled, the third scientific revolution will be a reality and the cause of humanity will be served. Science will at last proceed beyond analyzing our motives to stating our purposes; beyond dissecting our problems to offering solutions for them; beyond delineating our fragments to comprehending our totality as human beings; and, finally, beyond saying "no" and "perhaps" to our aspirations to declaring "yes."

• Science News Letter, 85:322, May 23, 1964

Do You Know?

A nuclear *generator* the size of a trash can will generate electricity to power an unmanned lighthouse for 10 years without refueling.

The Great Salt Lake's 1,500 square miles are the remnant of *Lake Bonneville*, an inland sea that once covered most of western Utah and parts of Idaho and Nevada.

• Science News Letter, 85:332 May 23, 1964