GENERAL SCIENCE

Training the Creative Scientist

The success with which the United States meets the challenge of the future depends upon the extent to which exceptional talent is discovered and developed today.

By DR. GLENN T. SEABORG

Remarks of the Chairman of the U.S. Atomic Energy Commission at the 14th National Science Fair-International, Albuquerque, N. Mex., May 7.

➤ IT WAS ONLY A CENTURY or two ago that modern science became an organized study of natural phenomena deduced from experimental evidence.

Since that time applied science and invention have influenced the life of the individual, the development of industry, the evolution of political societies and the course of history. In the past few decades we have seen a great increase in the impact of science on our society owing to a new factor which was not previously present. This new factor is the systematic and intensive accumulation of new scientific knowledge—the result of basic or fundamental scientific research.

Unrestricted Research

We now know that the search for new knowledge, if not restricted to subjects of foreseeable and immediate practical importance, results in an unexpected increase in our understanding of physical or biological phenomena. These increases, in turn, give rise to far-reaching practical applications which could not have been anticipated from the original basic research.

Our scientific knowledge and technology are advancing at an explosive rate. The time lag between the discovery of a fundamentally new scientific principle and its application in engineering or medicine is now very short, and these rapid developments are changing the lives of all of us in many ways which we only dimly perceive.

Because of our inescapable dependence on modern science and technology we must regard trained brainpower as a precious natural resource.

The extent to which we discover exceptional intellectual talent, encourage and develop it, and provide conditions for its effective flowering will be a measure of our success in meeting the truly challenging problems which technology and population growth are posing for us in the remainder of this troubled twentieth century. I refer broadly to two types of trained brainpower. One is represented by the professional scientist or engineer, the other by the educated person in other fields who has mastered enough of the meaning and content of modern science to make valid judgments on the many questions raised by the influence of science on his field, whether it be law, medicine, politics, military affairs, industrial management or some other.

It is fitting, therefore, that considerable attention be paid to the early identification of intellectual talent.

Tonight we are gathered to participate in one attempt at the identification of boys and girls who have exceptional aptitude for a creative and productive career in science. We are here to honor young men and women who have demonstrated by their conception and execution of some science project that they have a strong motivation and exceptional promise for a scientific education.

I think it is quite proper that we pause on regular occasions to acknowledge the intellectual, esthetic and idealistic aspirations of our young people and encourage them by recognizing their academic excellence. Not unnaturally, a young person is influenced to seek goals which are recognized and respected. If praise is reserved only for athletic prowess or monetary success, who can blame him if he seeks these even if it means sacrificing a great potential in some other field. Perhaps some of you may have seen the Lichty cartoon of a month ago in which a father admonished his son, "The future is wide open for a science graduate, Otis! —But he can do still better if he can hit over .300 and catch fly balls!"

So, I am most happy to extend my personal congratulations to these young men and women. It would be extraordinary indeed if all of you should develop into brilliant scientists of international reputation. I would be the last to lay the heavy burden of such an expectation on your shoulders. It would also be extraordinary if any of you failed to contribute in some way and in some pursuit, which none of us can predict here tonight, much more than an average share of intellectual achievement.

I would like now to mention briefly a few important steps in the education of a scientist, and a few attractive features of the life of a research scientist.

Work of Research Scientist

The work of a research scientist is of great interest and importance. Often it is difficult to relate his work to matters of dollars and cents but in the value system of the scientist the subject he has under study—whether this be the origin of the solar system, the biochemical basis of heredity, or the nature of a meson—is of great significance.

I believe that most people have a deep psychological need to feel that what they are doing is of some importance. The scientist feels the satisfaction of this need, and this gives drive and zest to his efforts. This is particularly true if, from time to time, his efforts are rewarded by the thrill of discovery. In his search he knows that in the final analysis his success as a scientist is measured against the criteria of nature

Boeing

STRESS PATTERN—Polarized light reflecting from special coating on test part indicates stress pattern caused by drilling a hole in a metal disc. The plastic test parts covered with the special coating were used by the Boeing Company, Seattle, in designing landing gear for their 727 jet plane.

rather than the judgments of persons.

Science is self-correcting in that spurious results will sooner or later be unmasked by new experiments or the attempted verification of previous conclusions. Hence it can more readily establish truth and confound error than other more abstract fields of study. A scientist who is correct can prove he is correct, and by a proper marshaling of experimental evidence can convince his colleagues regardless of their superior reputation, seniority, or rank.

Scientific research is a stimulating activity requiring constant assimilation of new facts, theories and techniques. This feature appeals to many gifted persons who would be stifled by the repetitive, dulling routine of many other occupations. A career in scientific research has many deep intellectual satisfactions which appeal strongly to the person of superior natural abilities.

Let us turn now to a consideration of how an interested young person may make a career in this exciting field.

Science is an organized body of knowledge and a method of extending or revising that body of knowledge by observation, hypothesis formation, and experiment. The training of a scientist is a two-step process—the mastery of a body of knowledge developed by previous workers and the mastery of a technique for extending that knowledge.

Role of Scientist

I sometimes liken the role of the scientist to that of a mountain climber who with great care and exertion achieves some great prominence from which he is able to perceive immediately and clearly new vistas which are hidden from the sight of those down in the valley below even though many of those in the valley may have better eyesight. New science builds on the work of the past. The scientist of today stands on the shoulders of the giants of yesterday. Therefore, the first task of any serious aspirant toward a career in science is to master the recorded history of the past.

The task of the effective teacher is to organize and present that history concisely and effectively. Our libraries are so filled with an enormous accumulation of facts, hypotheses and theories that the complete mastery of any science or even one major branch of a single science is a quite impossible task. Hence there must be a judicious selection of material—a judgment concerning the relative importance of various fields of study at various stages of the educational ladder, and a continuing judgment concerning the relative importance of facts, laws and correlations.

We are greatly helped in this effort by the great unity of much of science because of the fundamental laws or generalizations underlying all natural phenomena. In physics and chemistry, for example, we are enormously aided by the laws of thermodynamics, the laws of conservation of momentum and energy.

We are also aided by the circumstance that many decades of past work in science may become logical and clear once some satisfactory organizing law or theory is evolved. By intensive study of the organizing law the new scientist may understand immediately many hundreds of individual facts which were quite mysterious to the past generation of scientists. New mathematical techniques may also make it possible to explain or quickly derive numerous experimental facts which could only be understood at the expense of great labor by previous students. Therefore, it is the purpose of high school and undergraduate education in science to teach with the utmost economy of effort the organizing principles which may unlock for the student the important heritage of the past.

Because the relative importance of facts is subject to rapid obsolescence, the goal is not to teach facts alone, but a system of understanding facts so that the new knowledge can later be absorbed.

No Ideal Teaching Method

There is no ideal way to teach high school or college science courses and we may expect a variety of approaches without a clear choice among them as to effectiveness. Nevertheless, whatever approach is tried must be subject to change in content to accommodate the material to new advances in science, particularly advances occasioned by important discoveries.

Unfortunately, our high school courses have not changed much over the years and such changes as have been made are mostly in the way of accretion of new material without significant deletion of the old. Another problem in science education is the need for more able and dedicated teachers. Poor salaries, the inadequate community status accorded to teachers, and misguided accreditation requirements have repelled many qualified professional scientists from a career in high school teaching.

Adequate preparation in his subject matter is essential to a good teacher, and normally a high school course in chemistry should, where at all possible, be taught by a teacher with a college degree in chemistry, and a high school course in biology by a teacher with a degree in zoology or biology. Such a person can usually better evaluate new developments in the field and effectively interpret them to young people. Yet it is a rare high school indeed that has such a professionally trained science teacher. New attitudes toward teacher salaries and recruitment would assist in improving this critical situation.

One encouraging development of the past few years is the renewed interest of the universities, the professional scientific societies, the private foundations and many governmental agencies—particularly the National Science Foundation—in the plight of the high schools. This interest has taken the form of summer institutes for the retraining of teachers, writing projects to revise outdated course outlines, textbooks and laboratory manuals, the preparation of films, TV programs and TV courses and the publication of a wealth of new explanatory and authoritative scientific material in paperback form. School board members, school administrators, and interested citizens who are acquainted with these programs find them a new and very effective means of developing adequate science teaching in their school systems.

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Creative Scientist

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One of the chief purposes of high school science and undergraduate college science is to present the huge output of previous scientists to the student in a compressed form. They must give the student a meaningful, accurate, unified body of knowledge so that the general features of the sciences may be correctly perceived, so that new information to be acquired in the future can be related to the old and so that important features requiring further study can be recognized.

Training in Scientific Methods

We turn now to the next step in the making of a scientist, namely, his training in the methods of carrying on scientific investigation.

The principal centers for this type of instruction are the graduate schools of our great universities. The graduate holding a bachelor's degree in science has a good knowledge of his field, is able to perform a variety of laboratory tasks and may, with on-the-job training, develop into a creative research scientist. But as a general rule we rely on the rigorous training of our graduate schools to convert the trained intelligence of the holder of a bachelor's degree into the creative intelligence of the resarch scientist. The Ph.D. degree is the symbol of this creative intelligence.

The chief instructional technique of the graduate school is to put the student in the laboratory under the supervision of a master scientist to do a piece of original scientific investigation on a problem of considerable importance and difficulty. Here he learns a variety of experimental techniques. He learns the importance of asking big questions. He learns how to set up a meaningful experiment and how to extract correct answers from the data he collects. He learns the importance of letting the unexpected result lead him to new conclusions or at least to new experiments.

Graduate research is a rigorous, demanding experience which makes an enormous change in the scientific effectiveness of the candidate. At the better institutions the research interests of the professor are very advanced and are likely to be in a frontier area far beyond the material currently appearing in undergraduate textbooks. The professor is also greatly stimulated by the student. The student is usually brilliant, comes to the problem with a rather different educational background from that of his professor, and is eager to work hard to find out what the experiments will reveal. With this fresh outlook it frequently happens that he contributes greatly to the success of the research and may transform it into an advance far greater than might reasonably have been expected at the initial stages of the work.

The American people can regard with great pride the graduate schools of our great universities. They meet all the qualifications of excellence. They train virtually all of our great creative scientists. The scientific research done under the student-professor symbolic working arrangement adds a major fraction to our truly important new knowledge.

I could cite many, many examples of this. The selection of any scientific problem involves a judgment concerning what is worth investigation. In the first-rank graduate schools it is the big problems which are attacked. It is free research. The fact that over 40 living Americans hold the Nobel Prize in chemistry, physics or medicine attests to the excellence of our graduate schools of science. Unfortunately, there is not a sufficient number of such schools.

A study made by the President's Science Advisory Committee in 1960 included recommendations that it be our national science policy to strengthen these schools, to increase their number and to work out ways to extend the mutual creative stimulation of graduate education and research into more of the laboratories in which our fundamental research is done.

It is important that the standard of excellence of our top-rate universities be maintained and extended to more institutions. In the extension of scientific knowledge excellence is crucial. There is an enormous difference between pretty good and the very best. A system of scientific training and research institutions which can produce and support a few Enrico Fermis or John Von Nelmanns or Ernest Lawrences will be profoundly more effective than one which fails to do so.

A potential young scientist listening to these words may be hesitant to embark on such a foreboding and rigorous course of training. A few words of comfort may therefore be in order.

Graduate Study

Your decision whether or not to consider graduate training in science can be deferred to the middle or later undergraduate college years. By then your decision will be based on a clearer knowledge of your abilities, interests and intellectual performance. Should you then decide that your talents and interests lie in other directions there is a strong likelihood that the science courses which you studied will nevertheless form a significant part of your total education.

While graduate training usually takes from three to five years, the extra expense attached to this period can be greatly lessened by the many teaching and research appointments and fellowships which are available. In many fields the student can expect to pay *all* his living and school expenses from such appointments.

A further comment that I should make is that there is plenty of room in scientific research for those who are not in the genius category. All Ph.D.'s are better than average in intelligence, but few of them indeed approach the manifestly superior intelligence of Enrico Fermi or John Von Neumann.

There is a large volume of work which needs to be done and which can be done very well by the trained scientist of more modest endowments. Furthermore, much of the potential of a Fermi or a Von Neumann would be lost were there not many other scientists to try out their suggestions or to turn up new phenomena and new data for them to study and consider.

American Telephone and Telegraph

TRANSISTORS IN VACUUM—Tiny transistors used extensively in satellites, such as Telstar, are placed in vacuum jar to prevent moisture or contamination from reaching them. Mrs. Mae Astl, Western Electric Company, Allentown, Pa., examines transistors prior to final assembly.

Creative research calls for a combination of qualities only one of which is superior intelligence. It is difficult to specify the combination of characteristics which may be of crucial importance for success in solving a specified scientific problem. Perhaps an intuition or a "feel" derived from lengthy experience with certain types of phenomena, perhaps special knowledge of a new instrumental technique, perhaps a natural manual dexterity in some important type of laboratory manipulation, perhaps an unreasonable stubbornness in seeking a better explanation of some phenomena which others have passed by as "explained" may be the key to a fruitful series of developments.

I should find it difficult to explain the secret of the effectiveness of the many able scientists I know or the relative ineffectiveness of others who seemed to hold out great promise. Maybe it's just plain hard work, because, without downright hard work, there can be no success in a scientific career. All the productive scientists have been "smart," it is true, but the ways in which they have been "smart" have differed greatly. And, as I have said, they are all dedicated hard workers.

In the near future we shall hope to see a great expansion in our colleges and universities including our graduate schools of science and engineering.

We should see an expansion of research activities adjacent to university campuses and in university-related institutes as the importance of our scientific education and research to our national growth is fully realized. We should also see a more vigorous and understanding support of uncommitted research in industrial and governmental as well as university laboratories, with the realization that such research over a period of years will result in faster discovery of radically new developments.

Today, new discoveries in the nature of matter, the structure and the electrical and magnetic properties of materials, etc., are rapidly reduced to engineering application. To carry out this reduction rapidly and surely the engineer must have a sound and sophisticated knowledge of science and an adaptability which in general will be achieved only under a thoroughly revised engineering curriculum including some graduate training.

In the education of the nonscientist there is a necessity of including a course or courses that will insure a better understanding of science as part of the general high school and college or university undergraduate curriculum.

We live in an age in which, for better or worse, the influence of science is pervasive and revolutionary. It is a part of our culture which is shaping nearly every aspect of our lives and our institutions. We can no more ignore it than the man of the middle ages could ignore the Christian church or the feudal system.

Properly nurtured and employed, science can provide us with marvelous tools for the solution of many of the weighty problems of our physical and social world. The promise of the future lies in the hands of the dedicated and the educated. A most significant part of that promise lies in the field of science. I would invite the earnest young men and women who are prepared to study and work hard to join in the exciting and rewarding profession of science and the scientist.

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SPACE

Russia and U.S. Plan Meeting on Space Probes

➤ RUSSIAN EXPERTS who worked on a rocket heading for Mars and the U.S. scientists who worked on the recent Venus probe are planning to meet together early next month to trade data and conclusions.

The exchange is being arranged in the interest of spreading basic scientific knowledge. Plans are to hold the meetings in Warsaw along with sessions of COSPAR, an international group to coordinate space research.

The Russian spacecraft, launched Nov. 1, is scheduled to reach Mars around June 19. The United States' Mariner II, launched last Aug. 27, passed within 22,000 miles of Venus on Dec. 14, sending back information about the "solar wind" and magnetic field there.

U.S. and Russian scientists also plan to join hands in a study of information about the earth's magnetic field as revealed in satellite readings. Those meetings will be in Geneva along with the technical subcommittee of the U.N. Committee on Peaceful Use of Outer Space.

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