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The Future of Science

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HAVING SPENT MOST OF MY LIFE in scientific research, invention, and engineering, it is quite natural for me to suggest a long-range look at the operations of our great Association.

One of the functions of research is to study the future, its possibilities, and its problems.

In modern times the search for new knowledge in every field is a continuous process. Only when we have an important emergency, as that occasioned by war, is the normal course of scientific investigation interrupted and its great importance brought to public attention. During such emergencies our efforts must be diverted from the long-range fundamental problems to the short-term immediate problems of supplying the men at the front with the best weapons that the Armed Forces, science, and industry can devise.

World War II in Retrospect

Science played a major part in World War II—a war of science and production, fought for five years in the research laboratories just as it was fought in the factories and at the front. Only you who worked behind the curtain of secrecy realize how important the work of the scientist and engineer was in combating the forces which were sent against us.

This was a war of military and scientific measures and countermeasures. At times these became counter-countermeasures up to the fourth and fifth degree. Frequently our superiority over the enemy was measured only by the speed with which our scientific advancement could be capitalized upon and put into production. The scientist in this war was often called to the front lines to confer with military men, to obtain their reactions firsthand, and even to evaluate or obtain information on the enemy's technical activities. This advancement was possible largely because of our peacetime studies. Discoveries made in some college or industrial research laboratory months or years before the war became very important.

We have lost our continuity in many fundamental fields of scientific investigation. We are now faced with the problem of scientific reconversion—in fact, most of you have gone a long way in returning to peacetime problems. It is natural that, at the end of this break in continuity caused by the war, we review the progress of this organization of scientists during the emergency and then give some thought to our future plans. We have not had such an opportunity for many years. We have been forced out of the ruts of past generations, and we now have an opportunity to make the future anything we wish. I like the name of our organization—The American Association for the Advancement of Science. The word *advancement* implies motion and progress. Our opportunities are so vast that we must make a careful analysis of our past to determine where the need for advancement is greatest. I think we should pick up only what has proven good.

What have we learned out of the war accomplishments of the scientists, teachers, and engineers represented by the membership of the AAAS?

The Mobilization of Science, Education, and Industry

One thing we learned was how to cooperate. To tap our resources of scientifically trained men and their huge storehouse of accumulated scientific knowledge, science was mobilized for war. The technical societies, OSRD, National Inventors' Council, educational institutions, private and industrial laboratories, and the Armed Forces were asked to perform the immediate task of winning the war. Scientists dropped lifetime investigations when it appeared that these would not solve our immediate problems. Large groups were brought together on new projects. The Manhattan District, Radiation Laboratories, and a score of other activities were quickly organized. Everything was done to cash in scientific know-how

Address of the retiring president of the American Association for the Advancement of Science delivered at Boston, Massachusetts, on 27 December 1946.

without thought of cost and little more than a passing thought for the larger, long-range problems of the future.

You, as representatives of the science groups, produced results in every necessary field. To many outsiders these were miracles. New things seemed to spring up overnight. But we know that each miracle was made possible only because of the accumulation of knowledge in the field which comes as a result of our normal, unregimented, peacetime investigations. We must not let the public or the politicians forget this.

With men and organizations that had the training and experience, a whole new family of weapons was developed and soon appeared on the battlefronts. Radar, VT fuses, rockets, gas turbines, synthetic rubber, DDT, high-octane fuels, and a host of others came into tactical use. New equipment was not useful in helping to win the war until it was brought to the front. Here was the problem that our educational system solved. Education was necessary from the factory to the front line. When the equipment was finally turned over to the Armed Services, installers, maintenance men, and operators had to be trained to use new things, some of them entirely foreign to their past experience. Generals and admirals were eager to study the tactical use of new weapons in our fight against a regimented, scientific-minded enemy.

World War II can be looked upon as a dramatic test of the products of our educational and industrial systems over the past 25 years. The huge training programs of the Armed Forces could have been possible only through the fruits of our day-to-day educational and industrial system. Teachers of science, and teachers of science teachers, were as important in carrying out the broad programs as the scientists and engineers themselves. The accumulated experience in methods and techniques developed in our American educational system was called upon. Twelve million men were trained in highly technical fields. Several million were trained for the Army and Navy Air Forces alone, and tens of thousands were trained in the specialized radar and other electronic fields. Thousands of ships were sent out to sea with crews who only a few months previously were cutting hay on the farms, working in our factories, or doing any known peacetime job. These men were quickly trained to use the new scientific equipment developed and manufactured for this war, and the job was well done all along the line.

From this huge wartime training job we learned many things. It is possible to train men faster than had been supposed. New methods and training aids were developed. Paths of improvement in our prewar educational system were demonstrated. The value of close cooperation of the school with the laboratory, factory, repair shop, and the user was proven. Education contributed fully and, in so doing, gained new practical experience. We must not confuse all this training with basic education. Quick, special training can be the result only of long, basic education. We must also recognize that the production of special weapons can be possible only in a country where peacetime production and engineering are fully developed.

It is a common error to assume that such accomplishments as radar, penicillin, high-octane fuels, and atomic bombs are products of our recent conflict—that their development was attributable to the war and took place during that period. Nothing is further from the truth. For instance, penicillin was uncovered by Dr. Fleming in 1929, and one method of production was known before this war. However, the war did accelerate the demand, and new production methods were developed that increased the yield from a given quantity of mold a hundredfold, or 10,000 per cent.

Radar is another example of an idea that was born in the last century and was definitely demonstrated in the early 1920's, when scientists of the Naval Research Laboratories discovered that an object in a radio beam reflected part of the energy back to the transmitter. Long before this war, Admiral Bowen requested that Congress appropriate $100,000 for radar research. The first practical unit was installed in the *USS New York*. Of course, we all know that the Battle of Britain proved the value of British-developed radar as a defense measure, and during the war tremendous strides were made both here and abroad in its development and applications.

What has been true of penicillin and radar also holds good in the cases of other alleged wartime developments, such as synthetic rubber, high-octane fuels, and nuclear power. Of all of these, the last, the atomic bomb, has received the most publicity. Most of us here, I am sure, are familiar with the Smyth report on atomic energy. In this report Smyth mentions the work of Becquerel, the Curies, and Rutherford, extending back into the last century. Dr. Laurence developed the Cyclotron in 1931, Dempster detected U-235 in 1935, and in 1939 Otto Hahn, Strassman, Meitner, and Frisch uncovered the violent type of nuclear disintegration resulting from neutron bombardment of the nucleus of the atom. In the same year, small-scale chain-reaction experiments were performed in American laboratories substantiating the theories. The subsequent wartime developments have been so well publicized as to need no further mention.

I am sure that these few typical examples refute the popular belief that we were an ignorant and ill-prepared nation at the time of Pearl Harbor. Although we were not equipped at that time with a large standing Army, a tremendous Navy, and thousands of combat aircraft, we did have a few things that in the long run proved of tremendous value in winning the war.

Our Backlog of Scientific Knowledge

As I have just implied, we had an excellent backlog of scientific knowledge. Our research organizations were well acquainted with fundamental developments in many fields—developments that would prove invaluable in conducting a war. Furthermore, many industrial concerns had carried these developments beyond the research stage and had actually produced such things as synthetic tires, high-octane fuels, the sulfa drugs, and penicillin. In addition to these, our Armed Forces had developed prototypes of combat aircraft, various types of ordnance, and naval vessels that were ready for the greatly expanded requirements of our Services.

Our System of Mass Production

We had the ability to turn out huge quantities of new things in a relatively short time—a factor that has often been referred to as our "secret weapon," because it was greatly underestimated by our enemies. Over a period of nearly a century and a half America had developed a system of mass production that supplied not only this country, but the world as well, with millions of automobiles, telephones, radios, refrigerators, watches, and hundreds of other things. And, because of the oft-changing demands of the American public, our industries had accustomed themselves to yearly model changes and the incidental annual factory change-over. Through this process American factories developed a production flexibility and "know-how" unequalled by any other country. No other nation could have converted its factories from peacetime production to making airplanes, guns, and tanks as we did in 1942. The mass-production system is to the scientist and inventor what the printing press is to the writer.

The Role of Our Technical Societies

The part played by our technical societies was an important one. Here were organized groups made up of thousands and thousands of the best technical brains in our country. Through these well-established channels the best of our technical knowledge could be mobilized upon short notice. The experience of these thousands from every branch of science—physicists, chemists, metallurgists, and mechanical engineers—could be reached through these societies and focused on the problems of war.

The Role of Our Educators

A factor that has never been accurately evaluated is the tremendous service rendered by our educators during the emergency. Through our principle of "an education for everyone" we evolved in this country the most widespread educational system in the world. Our educators developed a time-tried procedure which has been a decisive factor in our Nation's progress. At the time of Pearl Harbor the entire facilities and experience of this system were mobilized for the Nation's defense, and the problem presented to the educators was a tremendous one, involving as it did the rapid training of technicians in every branch of the Services. Time was not available for the usual four-year courses—the emergency called for months instead of years. The fate of a nation was at stake. But our educators had two things to fall back upon: first, the excellent basic education received by our American youth, and second, a knowledge of the procedure required to solve the problem—education experience.

Today we all know how successfully this program was carried out—our victories attest that. We know the training miracles that were accomplished—how LCT's were navigated across the Pacific by crews of bank clerks and automobile salesmen, how farm boys became bomber pilots, and how others learned to operate and maintain the intricate radar. We have not acquainted the public too well on the point: *it was the educators who brought about this miracle.*

We often hear people express their gratitude for America's natural endowments—its resources of coal, oil, minerals, land, and timber. The backlog of scientific knowledge, our mass-production facilities, our technical societies, and our educational system are rarely considered as resources, yet we know that without them we could never have reached the position we occupy today among the nations of the world.

THE STATUS OF SCIENTIFIC DEVELOPMENT

Where are we now on the great road of scientific development? Opinions, of course, will vary all the way from too far to not far enough. Prejudice and facts confuse the thinking of many people. Very many intelligent people, in fact, think science has gone so far that the entire human race is in danger of race suicide. Others think that science, unmindful of the effects of its work on society, should be curbed or limited by some form of legislative regulation. Have we reached a point where we cannot go further because we cannot trust ourselves?

In the enlightenment of modern times it has been accepted as a matter of course that the pursuit of science by independent research was a worthy endeavor. In our free and independent countries, scientists were encouraged to spend their lives searching for new knowledge. As representatives of this large group of scientists we should resist every attempt to curb the efforts of scientists to find new information. Science must be free. Wherever it has been controlled, it has been only partially productive. In an unsympathetic atmosphere science withers and dies, and all mankind is the loser.

I do not think we are behind because there is so long a time between the discovery of a principle and its utilization in a product. We are just beginning to learn to use science for the benefit of mankind. It was only 125 years ago that Liebig established the first chemical laboratory for the systematic study of that industry. It was in 1800 that Count Rumford started the Royal Institution of London, the first of the organized science laboratories. Industrial research, the application end of science, was not carried out in an organized way until almost the beginning of this century. Even up to World War I there were only a small number of industries which supported industrial research. So, planned scientific research is only 150 years old and industrial research less than 50 years old.

Science has so accelerated human progress in all fields in this short time that it should point the way to increased benefits to more people in the future by the advancement of science.

Nature as a Laboratory

Only 25 per cent of the 2,000,000,000 people of the earth are properly nourished. Only 500,000,000 ever get enough of the proper food. This is not because of natural limitations. We have the scientific knowledge to provide an adequate diet for everyone if the information were properly applied. The false barriers erected by man himself are responsible. The antiquated social systems, ignorance, stupidity, and fear prevent a large percentage of the peoples of the world from enjoying even the most fundamental of the benefits of science.

I believe we know enough to feed the population of the world. But if we do not, we can learn from the green leaf the principles of how to store the energy of the sun and hold it as food. The green leaf is Nature's organic chemical laboratory which takes water from the ground and carbon dioxide from the air to make sugars, starches, and oils. We know little of the process now, but someday we may be able to reproduce it in the laboratory. Radiation chemistry fixes billions of tons of carbon in millions of different compounds without a test tube, Bunsen burner, or burette, while from the photosynthetic storehouse we take 620,000,000 tons of coal and 1,600,000,000 barrels of petroleum in a year. Industrially, we use radiation chemistry to a very small extent. Photography represents most of the man-made radiation chemistry. All of Nature's reactions are made at ambient temperatures and pressures. How did this originate? I would like to see some brilliant young student write a thesis on what was chemically available in prebiological time. We do not yet know the elementary principles.

We know little in this field of photosynthesis. We know that the chlorophyll molecule is not very different from the hemin of the blood. Where there is a magnesium atom in the chlorophyll, there is iron chloride in the hemin. The important difference between a plant and an animal is that the plants are reducers and animals are oxidizers.

Nature has devised a means in the plant of taking two low-energy compounds, carbon dioxide and water, with energy from the sun, to build our entire plant life in all its variations. She did this long before man was in existence. If I were talking to a group of students who had not yet specialized, I would say that life is dependent upon the ability of Nature to use sun energy to convert soda water through the medium of chlorophyll into the foods, fibers, and farm products we need. This is one of the fundamental problems we have yet to solve, and opportunities are as great as man's imagination in this field.

Much has been said about the depletion of our soil. This is a scientific problem of long standing. I believe that, if necessity demands, we can go to our inexhaustible supply of minerals in the sea for all the plant food we will ever need to keep our farm land productive, just as we have gone to the air for nitrogen. Only about $2\frac{1}{2}$ per cent, by weight, of a plant is mineral. We have learned how to obtain salts and bromine from the sea commercially. To obtain millions of pounds of bromine annually from sea water is an important chemical development of the past 25 years. There is one pound of bromine to about eight tons of sea water. What are the chemical reserves of the sea? Each cubic mile of sea water contains 90,000,000 tons of chlorine, 53,000,000 tons of sodium, 5,700,000 tons of magnesium, 4,300,000 tons of sulphur, 3,300,000 tons of potassium, 2,400,000 tons of calcium, 310,000 tons of bromine, and lesser quantities of many other elements, including the trace elements. There are 320,000,000 cubic miles of sea water. Here is a real challenge to future generations to become chemists and engineers of the sea.

Every place we look in Nature we find problems to be solved. Some can be solved in a short time, while others may take generations. There is nothing in research more important than the time factor. Research must be started years before the results come into general use. Many things, started as much as 100 years ago, have just recently come into use.

Work on synthetic rubber started back in 1826, when Faraday helped to establish that the chief constituent of natural rubber was a hydrocarbon. In 1860 the English chemist, Williams, isolated isoprene from rubber. It was not until World War I that synthetic rubber was produced in small quantity. Continued research produced the synthetic rubber necessary for our use in World War II. It has taken 120 years for the results of research, inventions, and discoveries in the field of synthetic rubber to be brought into general use.

Research is more a process of evolution than of revolution. Progress is slow and occurs in small increments, and long periods of time are involved in new discoveries. The time to lay the foundation for future developments is now.

The AAAS and the Future

With the present position of science in mind, what should be the future policy of the AAAS? What do we mean by advancement of science? What do the members of the Association want it to mean? I have outlined a very few of the things I think it could mean.

Should we be a clearinghouse of information for our members, and merely provide facilities for present activities and various meetings, including the presentation of scientific papers? Certainly these activities in which we exchange information are necessary and desirable—they are the fundamental of our society. This is advancement of science.

Should we have a long-range cooperative program, sponsored by the AAAS, to obtain the information needed to fill in the blank spaces in the many phases of the unknown? I am thinking of the key facts which open up entire new fields of activity. Some time ago I had lunch with a group of my medical friends, who said that, in any field in which many papers were given at a medical convention, it was extremely difficult and time consuming to sift through all the papers to find the important, usable information. One of the men present said that they searched the back publications and plotted number of papers versus time. The point on the curve which represented the present would sometimes be in the hundreds. The curve on the number of papers presented on any one subject would have many high and low points. Obviously, no person could become familiar with them all. As they went back over the curve they looked for the low points. There they found the original discovery that started a whole series of papers. This method of plotting can be applied to any subject. A whole new series of tests and investigations was started by these important pieces of information. It is these key facts which open up entirely new fields of investigation and are responsible for our greatest advances. To put in chart form what we do not know could be equally important in showing where we can have great advancement of science.

Complicated problems involve cooperation between all groups in our society. During the war pure scientists, engineers, chemists, biologists, industries, and educators learned how to work together. The scientist can often help the engineer to solve his problem and vice versa. The entire war effort was an example of the rapid advances in application that could be made only by cooperative effort. We should encourage the interchange of information and learn to use what the other fellow has to offer. This, too, is meant by the advancement of science. But convincing people of the value of a new idea is very difficult. Few people understand the difficulties of getting a new idea started. A friend asked me once what is the first requirement of an inventor. My reply was that he must not bruise easily.

The method of presenting a new idea is one of the important factors in all advancement. The AAAS publications—our permanent record of the progress of the members of the Association—are tools which we can use for the advancement of science. Not many people can hear the papers given; many can be reached by the printed report. There is no reason why our monthly magazine should not become the one authority on the whole field of science for the public at large. If, and this is a big if, we can or will write it so that the average man or student can understand, it would become an important way to advance science. Perhaps we might learn something from the National Geographic Society. Their publication prints more than 1,000,000 copies a month and is the standard authority on many subjects.

Science is not fully advanced when the discoveries are made. There must be a follow-through from the conception of the idea to the experiment, to the device, to the product. It is often just as important for the businessman, the lawmaker, and the general public to know of discoveries in the field of science as it is for other scientists to know of the technical details. We must make the results of science available to all peoples of the world in facts and not in prophecy. A little more scientific public relations would forestall criticism and regulation. Science will be advanced furthest when its results and problems are better known and understood. Our *Scientific Monthly* publishes less than 15,000 copies. That is one copy for a town of 10,000 people, which is not enough. We should aim at a circulation of several hundred thousand.

The advancement of science by its very nature implies education. The war proved the necessity of a population with a good scientific background, from the research scientist to the operator of scientific equipment in the field. We learned many new methods and developed many teaching aids which should be used in our peacetime education. Our continued interest in the field of education is basic to the advancement of science.

At one time many scientists looked to European schools for their postgraduate study. Postgraduate study for research workers, educators, and all scientists who work in creative fields is a necessity. Since many of the past foreign facilities are no longer open to us, I would like to point out a new approach. Let us look to the research laboratories of industries, privately endowed institutions, government, and schools for our future postgraduate work. The shops, the mines, the hospitals, and the hundreds of progressive organizations in our own country offer unlimited possibilities for advanced study. The exchange of men between the various activities of our economy will do much to advance science.

The Universe, including our earth and most of biology, was here and working long before man was here or conscious of the world around him. Science to me is the process by which we can, by cooperation, work to understand the process of Nature: The scientists should be open-minded students sitting in the great classrooms of Nature, listening to her lectures, and using this information to benefit their fellow men. We are still in the kindergarten and should not let our present accomplishments prevent us from seeing how little we really do know and what great opportunities there are for advancement. Here is a limitless field. How can we best use it?

A National Science Foundation?

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A CONTROVERSY DEVELOPED AROUND science legislative proposals in the last Congress—a controversy which remained unresolved in spite of compromise and which eventually blocked, for better or for worse, the passage of any of the rival proposals for the Federal support of science. Since then, decisions of a sort have been made on most of the issues originally at stake, and it seems time to take stock of those decisions, to give objective consideration to their wisdom, and to make necessary and appropriate recommendations to the new Congress.

The main issues at stake were:

(1) Shall we have Federal subsidy of basic research?

(2) Shall we have Federal scholarships and fellowships as a means of developing scientific talent?

(3) Granting the need for a National Science Foundation to do these things, shall it be administered by a part-time Board or a single administrator?

(4) Shall this proposed Foundation be asked to coordinate all federally-supported research?

(5) Shall private profit be allowed from patents on discoveries made with public funds?

(6) Shall support be given to basic research in the social as well as the natural sciences?

With the passage of time, these issues are being partially resolved in one way or another as follows:

(1) We now *have* Federal subsidy of basic research on a fairly large scale through the Office of Naval Research in the Navy Department, as well as several of the Bureaus, and through various organizations within the War Department.

(2) We *do not have* Federal scholarships and fellowships (except in a few isolated instances).

(3) The Federal support of basic research is being *administered* by Naval officers, by Army officers, and on a smaller scale by officials in other branches of the Government.

(4) The *coordination* of all research supported by the Army and Navy is to be achieved through a newly-established Joint Army and Navy Research and Development Board under the chairmanship of Vannevar Bush.

(5) There are *no restrictions on patents* of discoveries made while using naval funds except to reserve to the Government a free, nonexclusive license. The policy of the Army is not so clear, but tends to be more restrictive.

(6) Financial support *is being given* for basic research in social as well as natural science.

These issues have given rise to new issues which will again be resolved in one way or another. The important question is whether they will be resolved on the basis of considered opinions of scientists, educators, and others, or whether the whole matter will simply be

[1] The views expressed in this article are personal and not official.