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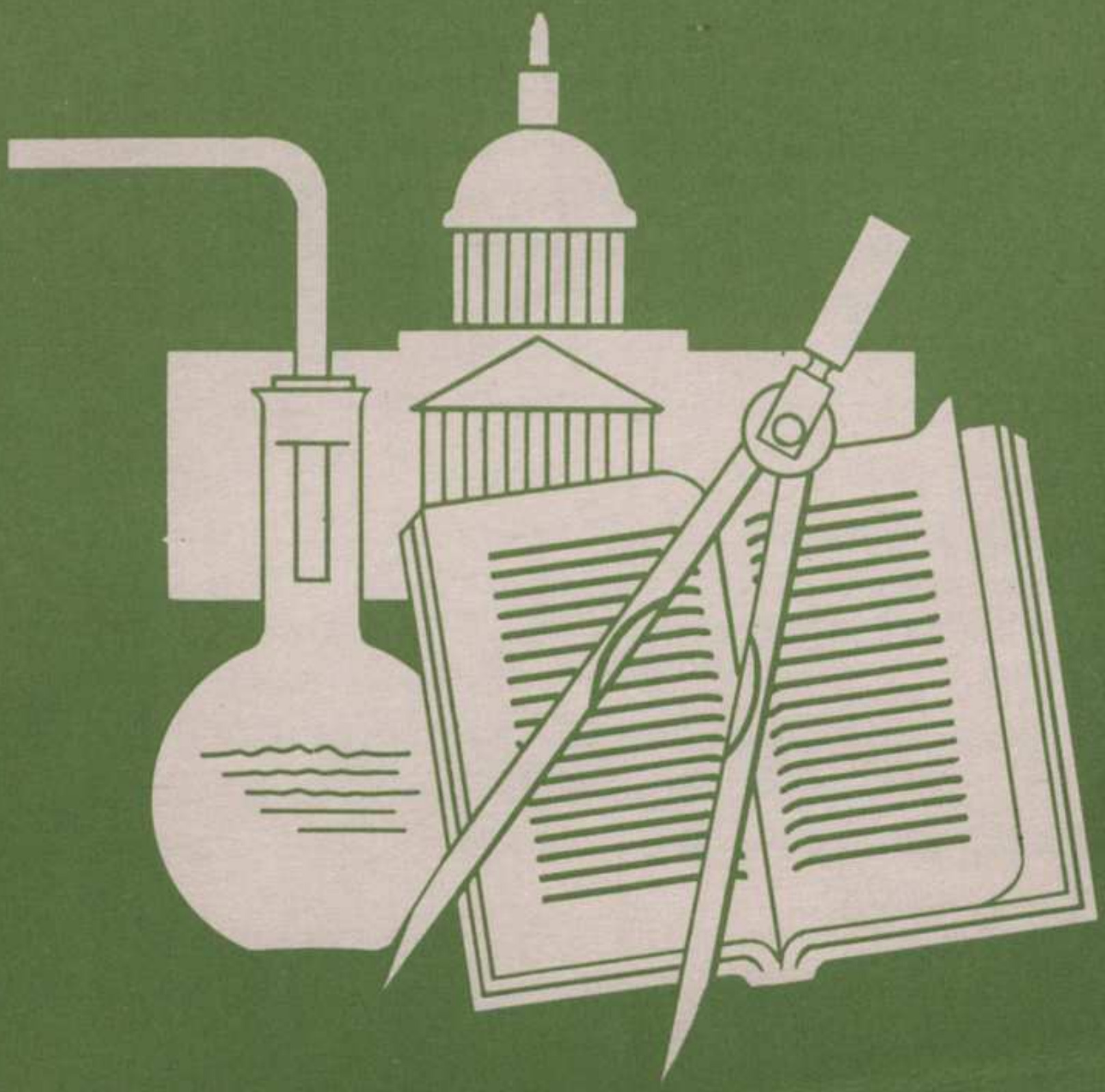
SHOULD THE GOVERNMENT SUPPORT SCIENCE?

BY WALDEMAR KAEMPFFERT



SHOULD THE GOVERNMENT SUPPORT SCIENCE?

By WALDEMAR KAEMPFFERT

WAR presents the scientist with a supreme opportunity. Resistance to innovation weakens. Years are telescoped into months, months into weeks. In a long global war, civil and military technology move ahead at a pace that cannot be matched in twenty years of peace. Electronic devices control factory processes with a new precision. Television is brought to a new pitch of perfection. Radar makes it possible not only to detect far-off bombers but to fight naval battles in the blackest night; also to reflect signals from the moon, to prevent collisions at sea, and

This pamphlet is based chiefly on *Science, the Endless Frontier,* the report by Dr. Vannevar Bush to the President on a program for postwar scientific research, and on the Senatorial *Hearings on Science Legislation (S. 1297 and Related Bills).*

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to make flying safer. Synthetic rubber is produced from alcohol and petroleum gases to take the place of the natural rubber normally supplied by the plantations of the Far East. Plastics are developed as substitutes for metal and wood. Jet propulsion and the gas-turbine increase the speed of airplanes—with still faster rocket-planes in the offing. The tropical diseases are subjected to better control. Penicillin is extracted from molds on an industrial scale. Derivatives of blood not only take the place of plasma but make it possible to deal with some infections in a new way and to perform operations from which the surgeon once shrank. DDT powder strips typhus of its old terror and controls insect pests with ease. Fabrics are devised which are wrinkle-proof, mothproof, mildew-proof, and moisture-proof. Atomic energy, suddenly released by two bombs, blasts away two Japanese cities and promises to compete industrially with coal and oil.

Research Need in Peace and War

A pamphlet larger than this would be required to list all the advances, for there are at least ten thousand items. Yet such a list would be deceptive. It would not bring out the fact that the thousands of scientists and engineers whom we card-catalogued and then assigned to specific research tasks were propelled by the momentum of the past. DDT, penicillin, plasma derivatives, synthetic rubber, radar, even atomic energy—all were known at least in principle before the war. What will happen if we are plunged into another war two or three decades hence—a war waged with atomic bombs hurled at us across oceans, a war which may spell victory in a few weeks for a ruthless, well-prepared aggressor? There will be no time to organize our scientific and industrial resources, no time to raise, equip, and drill a huge army. And what of peace? Peace, as well as war, imposes scientific and technological obligations. To meet these, research is as necessary as it is in time of total war.

A NATIONAL FOUNDATION OF SCIENCE IS PROPOSED

CONVINCED that we should not again be "too little and too late" in meeting emergencies and that we must prepare ourselves for a new social order, the late President Franklin D. Roosevelt sent a letter on November 17, 1944, to Dr. Vannevar Bush, head of the Office of Scientific Research and Development—an organization which had directed research in science, engineering, and medicine, but which was doomed to expire when peace came. Dr. Bush was asked what could be done to insure the continuance of the war against disease, the support of research in private and public institutions, and the educational development of talent in American youth. President Truman in his message of September 6, 1945, struck the same note and called for the creation of a National Science Foundation, which Dr. Bush and others had proposed. Legislation was introduced for creating such a foundation but Congress has as yet taken no action.

Growing Need of Science

Government-supported science is nothing new in this country. Jefferson and Franklin realized its possibilities. Franklin founded and Jefferson encouraged the still active American Philosophical Society, which held meetings at Philadelphia for the promotion of useful knowledge. The American Constitution specifically calls for the cultivation of science and invention. Scores of uncoordinated federal and state bureaus have conducted research for a century or more. By the time of the Civil War, the relation of science to war was so clear that, at Abraham Lincoln's request, Congress in 1863 founded the National Academy of Sciences to advise and assist the government in organizing and utilizing research in the public interest. But the Academy's tasks are limited by its charter. Presi-

dent Wilson added a National Research Council to meet the needs of World War I. Both the Academy and the Council are useful bodies, but neither can fully meet a call for action. By Executive Order, President Roosevelt therefore created first the National Defense Research Committee and later (June, 1941) the Office of Scientific Research and Development and a Committee on Medical Research to cope with scientific problems in the defense and war periods. It is clear that the proposal to create a National Science Foundation marked no sudden awakening to the importance of research. It merely extended a view of the tasks of science which was familiar in colonial times both in Europe and America.

In response to President Roosevelt's letter, Dr. Bush appointed and consulted several committees of scientists to explore the need and the character of a National Science Foundation. On the basis of their recommendations he prepared a report, entitled *Science: The Endless Frontier,* which lays down these guides to legislation:

1. The pursuit of science is of national concern;

2. The scientist must be free to pursue his inquiries in his own way;

3. The wide dissemination of findings is essential (provided that military secrecy is not violated when discoveries of importance to the armed forces are made);

4. The internationalism which has always been part and parcel of the scientific tradition is not only to be fostered but heightened;

5. The control of the Foundation is to be left to a board of scientists who are accepted as authorities in their fields;

6. Research is to be conducted in the "fundamental" rather than in the "applied" sciences;

7. Social sciences are not to be included in the program of the National Science Foundation;

8. A system of free scholarships and fellowships is to insure the steady flow of trained young men to the research laboratories.

These principles will be followed in the main, but there will be some departures. It is likely that the National Science Foundation will be directed not by scientists who are responsible neither to the President nor to Congress, but by a single Administrator guided by an advisory board of scientists whose criticism he can hardly ignore; and the program will include the social sciences. There is no doubt about the scope and nature of the kind of research that will be conducted.

WHAT KIND OF RESEARCH?

MOST people lump together science and technology, so that astronomy and medicine, relativity and synthetic chemicals, locomotives and radioactivity, electric toasters and aviation are all "science." But scientists separate science from technology. Newton's laws, Einstein's relativity, the constitution of matter, the electro-magnetic theory of light and heat, most of astrophysics—these belong to "fundamental" or "theoretical" science. Paints, electron tubes, plastics, synthetic chemicals, electric lights, all the instruments and machines that we now use in industry or the home—even the atomic bomb—belong to "applied" science or technology. In the direction of a National Science Foundation, it will be necessary to decide how much research is to be conducted in "fundamental" and how much in "applied" science.

"Pure" vs. "Applied" Science

When they testified in Washington before a Senatorial subcommittee in favor of a National Science Foundation, scientists made much of the traditional distinction between "basic," "theoretical," or "pure" science and "applied"

science or "technology." The distinction was carried over into science from Greek philosophy. To the Greeks, the intellect counted for more than the senses, and since the senses are always coupled with material things, thought was placed higher than experience.



Back of this separation of "theory" from "practice" is something of the contempt in which the Greek philosopher held the craftsman and the manual laborer. Experimenting is often dirty, manual work. This is one reason why the Greeks did not develop experimental science. The "theoretical" scientist no longer despises the handicraftsman, but he considers it easier to design a television system than to discover the origin of the electron or neutron. It probably required more hard thinking and pertinacity for Edison to produce the first incandescent electric lamp than it did for Franklin to establish the basic fact that lightning and electricity are the same. An Edison is just as rare as a Franklin. Even if this were not so, no sharp line divides "theory" and "practice."

"Theory" and "practice" invariably merge in the long run. Franklin engaged in "fundamental" or "theoretical" research when he established the identity of lightning and electricity, but he hardly lowered himself by inventing the lightning-rod. Lister conducted his fundamental study of antisepsis for the practical purpose of reducing the risk of infection in surgery. Many illustrations can be given showing that the great "practical" discoveries have sprung from research that deals with fundamentals rather than with applications. Before we could have electron tubes and hence radio broadcasting and television, industrial laboratories had to conduct searching investigations

(which deserve the name "fundamental") of the flow of currents through tenuous gases or in a vacuum, of the emission of electrons from heated filaments, and of a hundred other problems. To develop the photographic film of today it was necessary to delve deep into photochemistry. An enormous amount of "fundamental" research was conducted in aerodynamics primarily to make airplanes faster and safer. The "theoretical" scientist would probably dismiss all this aerodynamic research as technological in character because it had a practical end in view, but if it had been conducted in a university laboratory to discover how bodies of different shapes part the air at different speeds, it would be accepted as "theoretical" or "fundamental" provided that the results were not at the same time applied to building a streamlined plane.

Science and Philosophy

What is time, and what is its relation to motion, matter, and space? Are tables, chairs, trees, clouds "out there" exactly as we see them, or are they inferences, indications of something we cannot comprehend? These are fundamental questions, and when he attempts to answer them, the scientist expresses himself philosophically. Relativity belongs to philosophy as much as it does to science. When physicists reduce atoms to electrons, protons, and neutrons, they know that they have not come to grips with reality. So we find them—Eddington and Jeans are examples—looking at equations and wondering what reality is.

It is not likely that a National Science Foundation will spend any money for the study of such real "fundamentals" as the nature of time and space. Nor will it devote money to improve such trifles as fountain pens or push-button conveniences. Yet it will not ignore important machines or industrial processes. The last word on heat-engines or radio has not been written. There is no doubt that a National Foundation will see to it that these and

other important inventions will be studied "fundamentally," so that engineers may be given theories that point the way to improvements. What Franklin, in establishing the American Philosophical Society, called "useful knowledge"—that is, socially useful knowledge—will be the chief concern. Piling up facts which are not socially useful is as futile as transferring bricks from one heap to another over and over again.

Theory Is Father of Practice

All this does not mean that the distinction between "fundamental" and "applied" research is without significance. There is nothing so practical as a theory that works. Without such a theory, we should have no practical astronomy, no synthetic chemistry, no television, no nylon, no plastics, no electronic tubes, and very little of the vast paraphernalia of engineering and industry. Out of a sound theory, many inventions flow. No technologist today would think of following the example of Goodyear, who performed hundreds of experiments before he at last hit on the way to vulcanize rubber with sulphur. The chemists who showed us how to produce more rubber in huge factories in a few years than we ever imported from Far Eastern plantations were guided by sound theories. And so were the physicists who invented the atomic bomb. It is possible that a way of controlling cancer may be discovered by accident. But it is more likely to result from "theoretical" studies of normal and abnormal growth. Hence the scientists are right in insisting that the government spend its money on what they call "theoretical" research, rather than on inventions and processes that may be useful to industry.



PLANNED vs. UNPLANNED RESEARCH

THE question of method remains. How should a National Science Foundation proceed? The great philanthropic foundations follow the grant-in-aid system. That is, a university scientist submits a project and a board of experts decides whether or not money should be granted, and how much, to make the proposed study. Rarely does the board itself seek out a scientist and ask him to conduct research in a field. On the other hand, the seeking out of a scientist implies a plan. So we are confronted with the choice of waiting for a scientist to act on his own initiative or of deliberately planning research. As a class, scientists in this country are opposed to planning because it implies control—an implication which is not justified.

Planning in Industrial Laboratories

In industrial laboratories, research is organized, planned, and competently directed, and in a few great ones, even "fundamental" discoveries are made—so "fundamental" in fact that they have been honored with Nobel prizes. The atmosphere of such an industrial laboratory is that of the university. The ideas may be those of the director or of some member of his staff. Half a dozen men and a score of instrument-makers and mechanics attack a problem according to a well-conceived plan. No director in his senses would tell a scientist how to work, or what methods to follow. If he did his best men would resign and return to the universities from which they came. In other words, we have in these few industrial laboratories an example of what organization, planning, and able direction can accomplish without stifling freedom of inquiry.

"In normal industrial research there is very little 'direction' of effort of the kind we commonly associate with that term," says Dr. Frank Jewett, formerly director of the Bell Telephone Laboratories. "About all an industrial

research director does or can do is to see to it that his team is headed in the right general direction. . . . He more frequently than not approves support of ideas in which his men are interested but of which he himself is skeptical. He rarely withholds support." It is well to bear this in mind. Even though they have visited industrial laboratories, most university professors of science imagine that the staff is dragooned and that it has no mind or will of its own.

New Knowledge Needed

The reason for the growing industrial interest in "theoretical" science is to be found in the need for new knowledge. In much industrial research a point is reached where further progress is impossible because a theory is either wholly or partially wrong. It must be either thrown away or changed. Research must therefore be conducted to establish a new basis of investigation. It was largely because this was done that nylon and some of the remarkable vacuum tubes of radio were achieved. Will the same system work in "theoretical" science? It has worked in industry. The question remains how far it can be applied in carrying out the purposes of a National Foundation of Science.

Organizing "Discoveries"

Discoveries, unlike works of art, cannot be made to order. But it is possible to organize the conditions under which great discoveries can be made, as the industrial laboratories have demonstrated.

We have seen that organization, planning, and direction of research are the rule in the industrial laboratories. And in a few, "fundamental" problems are attacked with the same freedom of thought and action that we find in universities. "Pure" and "applied" science are welded together, so that there is no lapse of years before a "fundamental" discovery is carried into practice. Scientists and

technologists work in teams, with a consequent saving of much time, effort, and money.

Can teamwork give us "fundamental" discoveries without sacrificing scientific freedom? Despite the industrial evidence that it can, those who oppose teamwork in "pure" science argue that it hampers the isolated genius. The same argument was advanced when the industrial laboratories were established. It was maintained that the highly individualistic inventor must work alone. But industry has proved otherwise. If Einstein, Bohr, Schroedinger, and Heisenberg were asked to collaborate in unifying physics so that relativity would be reconciled with quantum mechanics, it is hard to believe that nothing of importance would follow. The reconciliation might not be achieved, but new ways of dealing with cosmology and the atom would surely emerge. If cancer were to be attacked by the industrial method—and cancer research involves a fundamental study of normal and abnormal growth—something of importance would surely result from the cooperation of physicists, pathologists, biochemists, geneticists, and mathematicians. Because teamwork has never been tried in "fundamental" research of this type, it is illogical to insist that it will not work.

PLANNING AND ORGANIZING FOR FREEDOM

THE chief reason for this emphasis on planning and organization is to be found in the limitations of unplanned research. Science has grown up in a haphazard way for lack of purpose and direction. Wide gaps yawn in our knowledge. The physical sciences have outstripped the biological sciences. This may be because profits and military advantage lie in physics and chemistry, but not in biology. Agriculture and medicine may seem to be exceptions among the biological sciences, but their relation to war and profits is evident. Also, it is true that the physical

sciences are simpler and inanimate matter is more adaptable to experiments and exact measurement. Soviet Russia has done more than any other country to correct the lopsided development of science. Under the Soviet Academy, all the sciences move forward together on a single front. Biology receives as much attention as the physical sciences.

If a National Science Foundation is to serve its purpose, its first task should be the mapping out of all science to reveal gaps in our knowledge that ought to be filled. The map would be kept constantly in mind when a grant of money or a contract for research is made. It would of necessity be flexible and all-embracing, so that a good project submitted by some university professor but not so mapped could easily be fitted into it. Ideas may originate either in the Foundation or in outside laboratories. If a distinguished biologist or chemist declines an invitation to fill a gap in our knowledge, there will be regrets but no compulsion. If he accepts, he will be as free as ever to think and to experiment as he pleases.

Great Tasks Call for Teamwork

Science and technology are so vast that no one man can grasp them entirely. Some problems in "fundamental" science clearly demand teamwork. Cancer is one. At present, we find specialists who concentrate on chemicals that start tumors, geneticists who study the heritability of tumors, physicists who limit themselves to the application of X rays and gamma rays to tumors, biochemists who have reason to believe that there is a relation between the hormones and cancer. No one man is ever likely to solve the problem of cancer. The geneticists, the pathologists, the physicists, the chemists, even the mathematicians, should work as teams on specific problems.

A good planning board would see to it that there is more such cooperation in research. As matters now stand, science is divided into many specialties, each one a closed compartment. The botanist knows nothing of

atomic physics, the geologist nothing of genetics, and the astronomer nothing of paleontology. It follows that the specialist is as much at sea when he reads a scientific treatise on the chain-reaction that occurs when an atomic bomb explodes as any mechanic. Yet each science has much to contribute to other sciences. Physics has invaded chemistry, and chemistry has invaded medicine. We have such sciences as geochemistry, biochemistry, psychosomatic medicine—a clear indication of a need brought about by limited voluntary cooperation.

Unless a broad plan of research is adopted, involving all the sciences, the bias in favor of the physical sciences will continue. There are fashions in research as there are in automobiles and hats. An all-embracing plan carried out by an able director who is guided by an advisory board of scientists will ignore fashions yet follow good leads. It was thus that we mobilized, organized, planned, and directed technological research during the war. There is no reason why the same procedure should not give "theoretical" science a similar impulse in peace—and all without departing from the freedom on which science rightly insists. No university or industrial or other private laboratory need be drawn in against its will. The chances are that the projects will be so attractive that refusals will be rare.

Some Planning Inescapable

It is not likely that any National Foundation of Science in this country will see to it that research is conducted according to an all-embracing plan. But it cannot escape some planning. Even the preferred term "program" implies a plan. Surveys certainly must be made in particular fields if tax money is to be spent wisely, and out of surveys plans inevitably flow. Even if the advisory scientific board of a National Foundation follows the usual method of waiting for applicants to submit projects for its consideration, research is bound to be stimulated.

"Fundamental" Problems to be Solved

What are the tasks of research? Questions arise by the score, some of which can be answered only by "fundamental" research, others by technological research. Why do cells divide and thus produce noses, eyes, fingers, and toes of the right size and put them in the right places? How does one kind of egg develop into a chicken and another into a man? By what process does a plant absorb and utilize elements that it needs from the soil and the air? How does the body build up protein? Progress has been made in answering these questions, but if research is to continue to depend on individual whims, it may take decades before satisfactory information is obtained. A National Science Foundation with enough money at its command can marshal the best authorities, set them to work on a scale never before even approached, and save time. Medicine and agriculture would leap forward. The control of cancer and the diseases of old age would be more than a hope.

Untrod Fields in the Physical Sciences

In the physical sciences, we have a host of similar "fundamental" and "practical" problems. All the ninety-odd elements have variants which are called "isotopes." There are several forms of lead, for example, which are chemically alike but which differ in weight and sometimes in radioactivity. Millions of compounds can be made from these variants or isotopes, but as yet very few have been studied intensively. We need a better science of meteorology, so that our weather bureaus may be able to engage in long-range weather forecasting. Little or nothing is known about the exact structure of the earth beyond a depth of the few thousand feet reached by miners, yet until we know more about that structure there is little hope of predicting when an earthquake is likely to occur in an unstable region. We must conduct technological research to know much more about the stratosphere than we do if we are to soar between breakfast

and luncheon to communities in the antipodes. The new branch of physics called "quantum mechanics" promises to revolutionize chemistry—a promise which a National Foundation of Science could probably translate into a reality in ten years. We know that when two different metals are connected and heated, an electric current is generated. But thermoelectricity has not progressed much in fifty years, so that we must still cling to steam-turbines and generators to light our lamps and drive our factory wheels. Atomic energy can be developed for industrial use if we give corporation laboratories a free hand, but a National Foundation can arrive at the engineering principles more rapidly by coordinated research. Metallurgy needs far more "fundamental" research than it has ever received. Why should it not be possible to orient crystals —and all metals are crystalline—so that they will be stronger in the desired direction than in others? The result would be less expensive bridges, skyscrapers, and machinery. Only a beginning has been made in synthetic chemistry, for all the thousands of coal-tar dyes, perfumes, drugs, and plastics. A National Foundation could support "fundamental" research which would surely lead to new synthetic fibers and hence to textiles with entirely new properties.

PLANNED RESEARCH IN SOVIET RUSSIA

THE greatest development in organizing, planning, and directing science has been reached in the Soviet Union. Over every research institution, over every agricultural experiment station stands the Soviet Academy of Sciences, which is part of the government. The Academy maps out the whole field of science, organizes all research to carry out its plans, and weaves science and technology into agriculture, industry, and warfare. There is no question that astounding results have been achieved in less than

a generation, and this in a vast country which had accomplished little in research under the Czars and which, in consequence, was industrially retarded. Various British and American missions that visited the Soviet Union during and after the war returned with nothing but admiration for what they saw, despite obvious deficiencies in the quality of research and laboratory personnel.



But there is a catch in Soviet scientific methods which should be frankly faced. In accordance with Marx's teaching, Soviet citizens believe that under the system of free enterprise science is exploited by capital for profit. They believe that science should serve the state. Hence the individual scientist cannot engage in investigations without official approval. No distinction is made between "theoretical" and "practical" science. There is only science—science in the service of the state. Identical medals are pinned on scientists who have successfully conducted "fundamental" research and on mechanics who have made some improvement in a machine or a process. Yet "theoretical" science is pushed just as vigorously as technology.

Politics and Research Don't Mix

Imposing a state's views on the scientist has far-reaching implications. Conflicts cannot arise when research is concerned with the practical application of theories. But it does arise when theories are formulated. In 1939 the President and eighteen members of the Astronomical Division of the Soviet Academy of Sciences passed some impassioned resolutions which denounced believers in

relativity as counter-revolutionaries because they felt that the infinite universe of Newton alone is compatible with Marxist doctrine. Similar clashes have arisen in education, psychology, archeology, and other fields.

We have not much information on what has happened in Soviet science during the war. There appears to be more freedom of expression now than there was ten years ago. The distinguished physicist, Kapitsa, for example, has objected to the emphasis on practical technological achievement to the detriment of "theory." And we have the opinions of such men as A. E. Joffe, director of the Physico-Technical Institute of Leningrad—opinions which express complete satisfaction with freedom of research and the ease with which the authorities grant money for worthy projects in "theoretical" sciences and with which plans can be changed. Moreover, experimental stations are given a larger freedom of action within the prescribed framework than opponents of the Soviet system admit. On the whole, the Soviet Academy is well aware of the need of flexibility in "theoretical" research. The western technologist, who must now worry over the problem of disposing of a by-product which must not be wasted in a capitalistic country, might well consider Soviet Russia an engineer's paradise.

RESEARCH IN THE UNITED STATES

SUCH a system could hardly be imposed on this country, though science is by no means as free in the United States as it is supposed to be. In some areas, "freedom" has given place to planning. But "freedom" still rules in "theoretical" and "applied" science despite the laws against the teaching of evolution in a few states, despite the difficulty that inventors have in contending with monopolies, and despite the power of the philanthropic foundations, with their grants-in-aid, to direct research into what they deem to be

the right channels. The traditional freedom of science is more than worth preserving. It is essential to the advance of science in a democracy.

Failure to Carry Through

The main objection to an unplanned system of research lies in its failure to make the most of good clues. Some scientists seek grants merely to win an academic promotion. Having carried out the project and having made an important contribution in one field, they far too often fly off into an unrelated field and the clue that has been uncovered is neglected for years.

There is no reason why a scientist should not fly off at a tangent, just as Pasteur flew from chemistry to bacteriology and Helmholtz from physiology to physics; but there is every reason why the clue should be systematically followed. DDT was developed many years ago and its efficiency demonstrated in combating a pest that threatened to destroy the Swiss potato crop, yet it was not until the war that it was intensively studied and widely introduced. Sulfanilamide was discovered before the last war, but its antibiotic properties received no attention for twenty years. A decade had to elapse before penicillin's remarkable properties were established by Sir Howard Florey and his associates and its chemistry studied by Ernest Chain. It is because science has never, except in time of war, been given over-all purpose and direction that such irregular progress occurs. In the long run, some scientist may pick up a forgotten clue and rediscover it—which is what happened in the case of the Abbé Mendel's experiments with inheritance in peas. We may be dazzled by the accomplishments of science, but we ought to have made more of science than we have. We could not make more of it because the social responsibility of science was not admitted by scientists until recently and because it was nobody's business to plan "theoretical" research and carry it out systematically.

HOW OUR RESEARCH CAN BE IMPROVED

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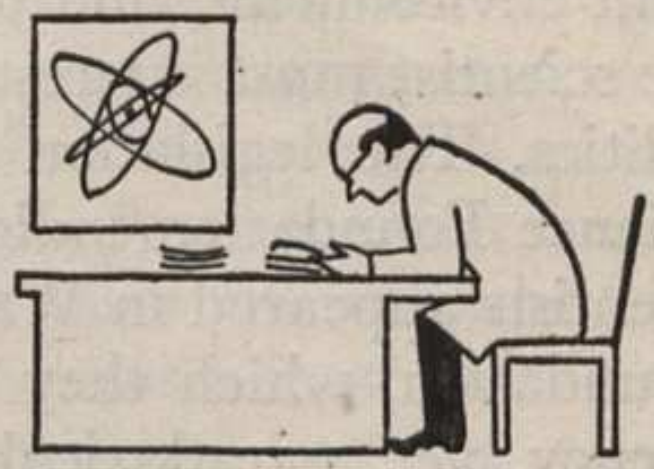
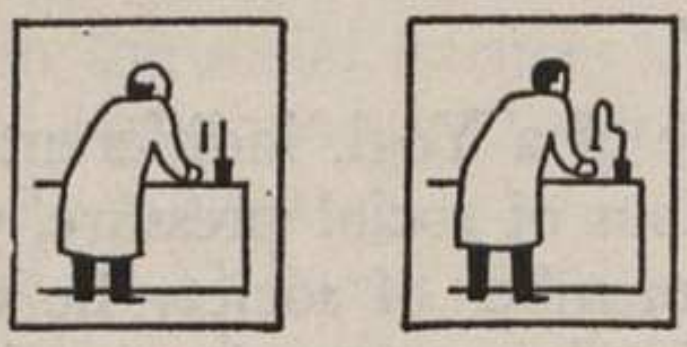
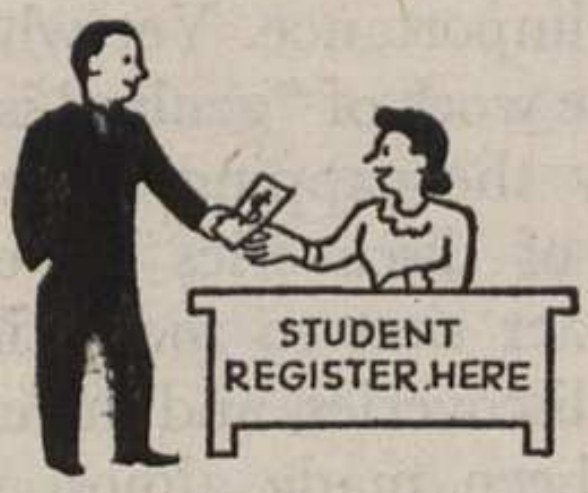
 RESEARCH CHIEFLY IN PROFITABLE APPLIED SCIENCE	 RESEARCH ALSO IN NON-PROFITABLE "FUNDAMENTALS"
 LACK OF CONTINUITY IN RESEARCH	 "SYSTEMATIZED" RESEARCH
 OPPORTUNITY TO THOSE WHO CAN AFFORD TRAINING	 OPPORTUNITY TO ALL WHO HAVE TALENT

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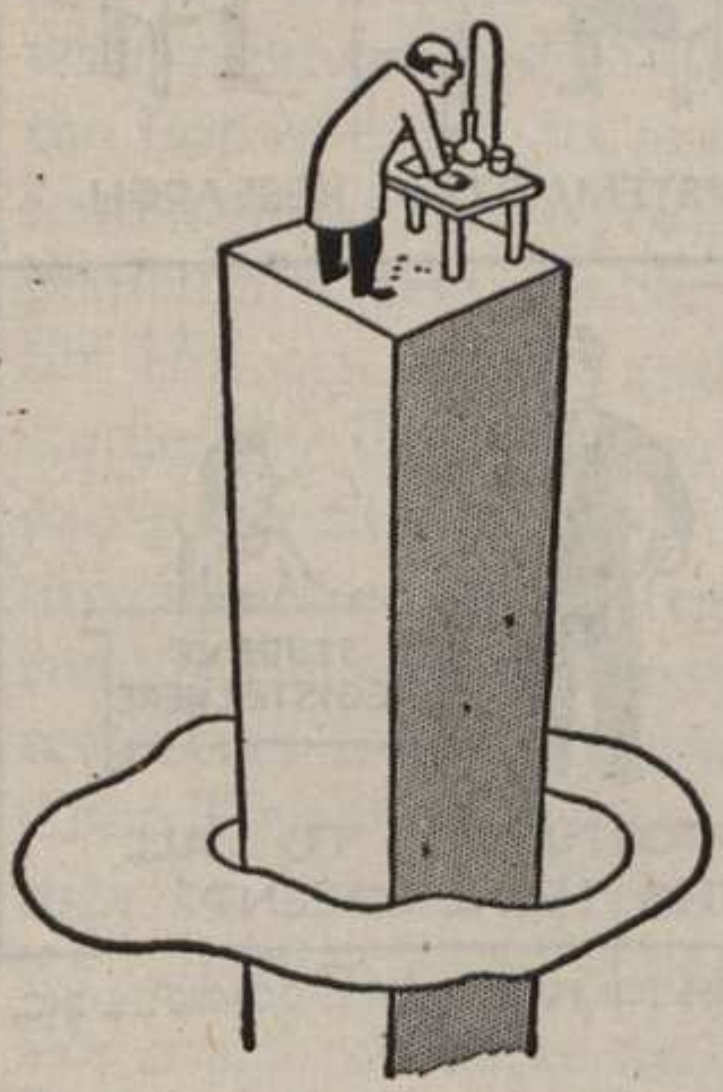
WHAT OF THE SOCIAL SCIENCES?

Scientists are the instruments of social progress. For this reason alone, they cannot remain indifferent to the consequences of their activities. Research flourishes in the right environment, and to achieve the right environment the scientist must interest himself in social issues, even in politics. The legislation which is to create a National Science Foundation indicates as much. Over a hundred scientists appeared in Washington to testify in favor of a Foundation, which they recognized as a powerful social agency, yet, paradoxically, many of them opposed the inclusion of the social sciences in the framework of the Foundation.

Scientists Are a Part of Society

No scientist can lead the life of a Yogi, indifferent to society. He may not be conscious of social pressure, yet as a member of society he unconsciously responds to that pressure. This does not mean that creative thinking counts for nothing and that the "genius" is of no importance. Yet what we call the work of "genius" is often merely the capping stone of a series of discoveries by others. The fact that so many important discoveries and inventions have been made almost simultaneously by different scientists working independently proves as much. Always there is a relationship between what the scientist thinks and does and what society expects of him. The time has come for a closer union of the natural and social scientists.



Natural science's contribution in partially controlling our environment has been widely recognized by sociologists, economists, and political scientists. Civilization is a perpetual struggle to harness the forces of nature. Today that struggle is carried on with the deliberate aid of the scientist and the engineer. Science is woven into the pattern of this culture. The scientist who imagines that what he is doing is of no concern to the outer world is as out-of-date as the theologian who once spent his time in calculating how many angels could dance on the point of a needle. Science and society are so finely interwoven that the two must of necessity be considered together.

Lessons from Atomic Fission

The danger of any attempt to separate the natural from the social sciences should be evident from our recent experiences in developing atomic energy. Overnight, uranium became as important as coal and oil. Some form of control became necessary. It is generally conceded that uranium deposits cannot be left in private hands, that traffic in uranium from the mine to the laboratory and power plant must be regulated if a war waged with atomic bombs is to be avoided. But natural scientists know nothing about controls, and the social scientists were not even informed that atomic energy was being developed until the bomb was dropped on Hiroshima.

Many far-reaching, and largely unanticipated, social questions were raised by the release of atomic energy. They were economic as well as political. To take an example, Brazil has large deposits of thorium (from which energy can be released just as easily as from uranium), iron, and manganese, but no important deposits of coal. What if Brazil, through atomic energy, should become a competitor of Great Britain, France, Germany, and India in the steel-export trade? All the countries named would be affected. It would become necessary, perhaps through the United Nations, to cope

with world-wide unemployment, which in turn would mean some scrutiny of tariff and other policies. Scientific and technologic research always affects production and employment, as well as social security, race relations, public administration, agricultural policy, conservation of natural resources, the utilization of raw materials which are not uniformly distributed in the earth's crust.

Social and Natural Sciences Must Work Together

For all these reasons, no National Science Foundation can afford to ignore the social sciences or even assign them to some independent body. In this age of science and technology, we cannot leave legislation entirely to legislators. For regardless of their intentions, most legislators are untrained in gathering and grasping technical facts. A representative body, like Congress or Parliament, needs the guidance of men trained in the natural and social sciences. The social scientists cannot provide that guidance alone; neither can the natural scientists because of their ignorance of sociology, economics, and government. Clearly, the two groups must sit down and study together, and this can be done most efficiently by just the kind of organization which has been envisioned for a National Science Foundation.

Today's World Is One World

There are other compelling reasons why the social scientist should work with the natural scientist. When the steam engine, the telephone, the automobile, the radio, the motion pictures, and other great inventions were introduced, no one was deeply concerned with social effects. Hence the history of labor-saving machinery is a history of temporary economic distress and even of riots and sabotage. When the Germans after years of research at last achieved synthetic indigo, it mattered nothing to them that the indigo planters of the Far East were ruined. The perfection of rayon wrought havoc in the silk industry.

Haber's process of synthesizing ammonia brought Chile to the verge of economic collapse about twenty years ago, for the world was no longer dependent for fertilizer and explosives on the nitrate deposits along the Pacific coast. A hundred years ago it mattered little to an American if a famine devastated China or if a financial depression had thrown a million or so out of work in Europe. Today we cannot afford such indifference. Science and technology have woven the world into an economic whole. What happens in a country that lies halfway around the world affects life at home. The depression that began in 1929, for example, was world-wide.

Scientific Change Means Social Change

Change within science and technology always means social change. The greater the discovery, the more marked is the change in business and folkways. We clearly need foresight, a more orderly way of making the most of science and technology.

The late Herman Frasch, an oil chemist, provides an example of how this foresight might be applied. Ordinary mining methods had been tried at enormous expense to bring buried sulfur in Louisiana and Texas to the surface. They had failed because of the peculiar geological conditions. Frasch drove two concentric pipes down to the deposits. Through one he forced down superheated water and thus melted the sulfur deep in the ground; through the other he pumped up the molten sulfur. Thus he obtained blocks of pure sulfur as large as many an office building. He tried to make an arrangement with the Anglo-Sicilian Sulfur Company, which had a monopoly of Sicilian sulfur, only to be rebuffed. In five years the monopoly was crushed, and Sicilian sulfur burners were threatened with ruin. Frasch opened negotiations with Crispi, then Prime Minister of Italy, to avert riots and disaster. As a result, an arrangement was made whereby Sicily was able to adjust itself to the new situation.

Such a procedure demands some power of prediction. That prediction is possible was shown by the report on *Technologic Trends,* which was issued by the National Resources Committee in 1936—the first serious and systematic attempt to forecast the immediate future of a score of industries in the light of technological advance. The contributors to that report limited their forecasts to twenty years, and this because it takes at least that long to introduce a revolutionary innovation in normal times. Under the pressure of war which broke out only a few years later, industry achieved in a few years what were only hopes in 1936. Nevertheless, the report proved that prediction is possible. Only a wildly reckless government or manufacturer would fail to heed such a forecast.

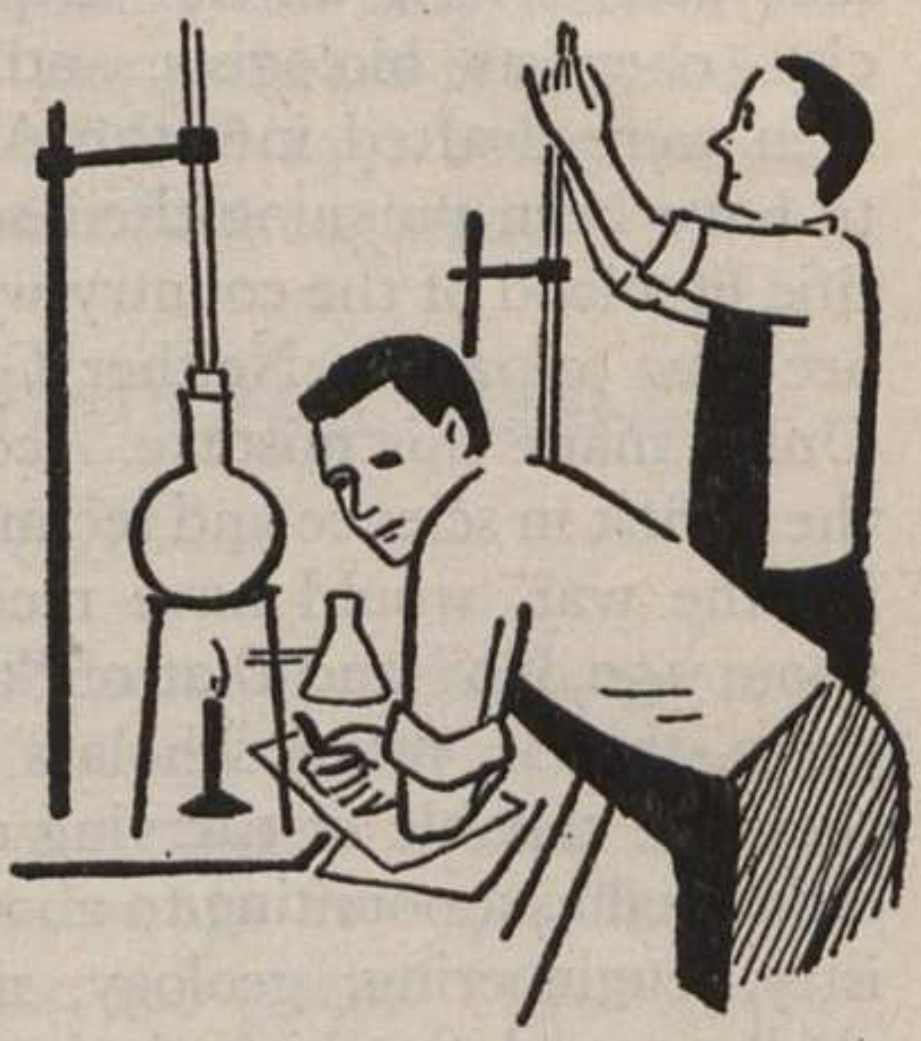
Teamwork between Social and Natural Scientists

During the war we saw the extension of scientific methods into many fields of social and economic life. Mixed research teams of mathematicians and economists, physicists and psychologists, were needed to cope with problems in their entirety in a framework constructed by social scientists, with the result that the statistician was given something that he could convert into figures which in turn inspired social action. Thus was "operational research" born. Psychologists, experts on population, economists, physicists, chemists, biologists, public health experts must be organized to use it effectively. To confine a National Science Foundation to research in the natural sciences and mathematics and to leave the social sciences to some independent body is to ignore the worth of operational research.

Operational Research

There was nothing revolutionary in this combined application of the physical and social sciences called "operational research." Both American and British industrial firms had used it in the study of markets. But in the war

it was highly developed. Economists, geographers, and weather experts cooperated with technicians familiar with airplanes and bombing in mapping the targets for strategic bombing. Similar cooperation was developed when it was discovered that general staffs were unable to use most effectively the weapons and explosives with which they had been supplied. Social scientists were called in to find out what was wrong. They discovered that what had been supplied was not always what commanders at the front thought they wanted. As a result of teamwork between the social scientists and the technical experts the army concluded that it would be best to supply, not weapons which approximated an ideal, but weapons that could be effectively used with other equipment on hand. Governments and industrial organizations would probably learn through operational research not only what is the best type of material or machine to achieve an end but whether the end itself is worth achieving.



Though we were not aware of it, we applied the social sciences and a crude form of operational research when legislation was necessary to control railways, radio, public utilities, and other industries that were built on great discoveries and inventions. A representative body like Congress needs the guidance of natural and social scientists who work together as a team. Combine the natural and social sciences in a single division in accordance with plans now looked upon with favor, and we even lay the foundation for a science of civilization.

EDUCATION FOR RESEARCH

WHEN the Office of Scientific Research and Development was established, the universities and many industrial laboratories were all but stripped of their trained physicists, chemists, biologists, and research clinicians. Young men were drafted into the Army and Navy who ought to have been pursuing their scientific studies. The scientific lifeblood of the country was tapped, with results that are now apparent. Neither Great Britain nor the Soviet Union made this mistake. According to the Bush report, the deficit in science and technology of "students who, but for the war, would have received bachelor's degrees is about 150,000" and that of "those holding advanced degrees—that is, young scholars trained to the point where they are capable of carrying on original work—has been estimated as amounting to about 17,000 by 1955 in chemistry, engineering, geology, mathematics, physics, psychology, and the biological sciences." Apart from this, young scientists can devote only a portion of their time to study under the prevailing system of fellowships and scholarships; the rest is needed to earn a living. Too many boys who are potential scientists cannot afford to attend a college or university; they enter the employ of commercial firms and are lost, so far as science is concerned. For every 1,000 students in the fifth grade, all but 72 have ceased formal education before completing a college course. It must also be remembered that no longer will it be possible even for young men of means to complete their scientific education under some distinguished European professor. European universities will be crippled for years, even if we assume that Germany will again restore its old academic freedom. The time has come for us to make the most of our own educational resources.

Because of research's needs, the Bush report recommends that 24,000 undergraduate scholarships and 900

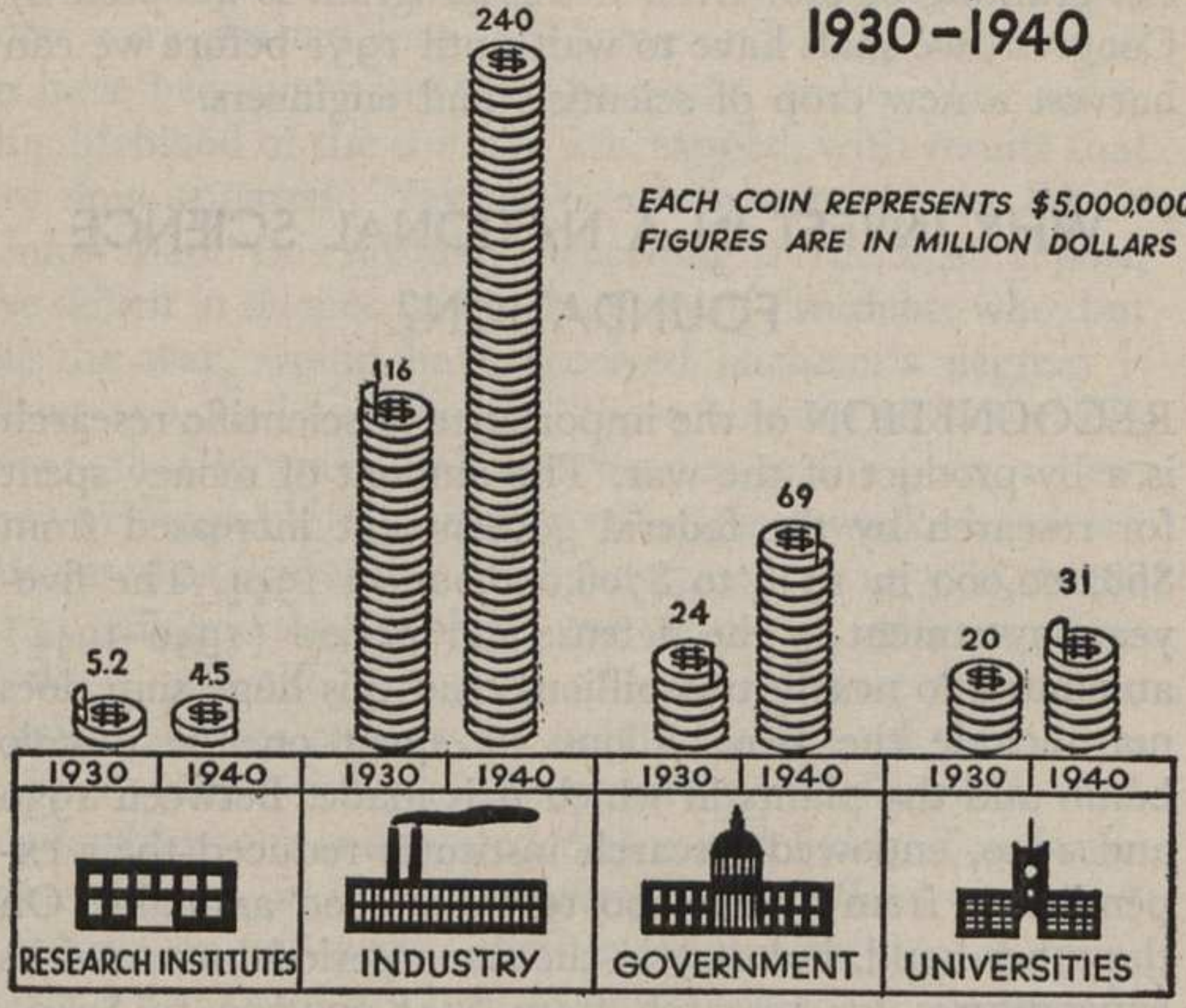
graduate fellowships be provided at an annual ultimate cost of $30,000,000. Thus, each year 6,000 scholarships would be made available to high school graduates and 300 fellowships to college graduates. A paid scientific education is to be open to all promising young men, with ability and scholastic achievement the only criteria for the granting of aid. Even if this program is adopted by Congress, we shall have to wait until 1951 before we can harvest a new crop of scientists and engineers.

WHY INVEST IN A NATIONAL SCIENCE FOUNDATION?

RECOGNITION of the importance of scientific research is a by-product of the war. The amount of money spent for research by the federal government increased from $68,000,000 in 1938 to $706,000,000 in 1944. The five-year investment in the defense-war period (1940–1944) amounted to nearly two billions, and this huge sum does not include the two billions we spent on the atomic bomb and the plants in which it is made. Between 1930 and 1940, endowed research institutes reduced their expenditures from $5,200,000 to $4,500,000 annually. On the other hand, industry in the same period increased its expenditures for research from $116,000,000 to $240,000,000, the government from $24,000,000 to $69,000,000, and the colleges and universities from $20,000,000 to only $31,000,000. In 1938, a year of peace, thirteen corporations employed one third of all the industrial scientists and engineers in the country. We cannot leave the development of science entirely to industry, even though the day of open-handed philanthropy is waning and the foundations are reducing their grants, for the simple reason that industry is too preoccupied with profits, and conducts "fundamental" research only when it is likely to pay dividends.

A National Science Foundation must take the long-range point of view. It must consider not profits, which must be earned by industry, but the public interest. It is as much concerned with medicine and the public health

HOW MUCH WE SPENT FOR RESEARCH 1930–1940



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as with geology and navigation, with agriculture and animal-breeding as with atomic energy. The whole of science must be covered and not a few fields.

What will such an enterprise cost? According to Dr. Bush, an adequate program of federally supported research will cost about $10,000,000 annually in the beginning and probably about $150,000,000 in five years. No such sums have ever been spent here on "fundamental" research or in applying it in the public interest. It

is a question if they are "adequate" even in peace. In 1939 the Bell Telephone Laboratories alone were spending more than $20,000,000 a year, and only 1 per cent of this on their small part of the government's defense program. A single important project such as that which has the conquest of cancer in view could easily absorb $5,000,000 a year if enough competent research biochemists, pathologists, physicists, geneticists, mathematicians, and other essential research scientists were available. Any good specialist could draw up a program in his own field which would require millions annually for its execution. Apart from the lack of scientists there would be no difficulty in spending $5,000,000 annually for a decade to explore the many ramifications of atomic energy when we consider the biological and medical uses of radioactive elements created when uranium atoms are split and the safety and engineering problems raised by the utilization of atomic energy in industry. Even a rich government like ours must place some limit on its support of science. Modest as Dr. Bush's sums seem in the light of our ignorance and our needs, they will set our feet on the right path. The Soviet Union, which spent more money before the war on research than any other government, may be our only formidable competitor in science.

THE OLD FRONTIER IS GONE

WHAT we have, then, in a National Science Foundation is a recognition of the part that science and technology play in molding our culture. The Foundation is bound to be created because of the sheer impact of science on society, but it has taken a world war to accelerate the process of birth. From Napoleon to Eisenhower, war has assumed an increasingly totalitarian character, so that in World Wars I and II it was necessary to weld industrial and fighting forces, medicine, and shipping into a unit,

with only the aged, the infirm, and the very young spared even an indirect participation. Today large-scale, mechanized, total war is a luxury that only highly industrialized, extensive, and populous countries can afford. Because of this total character of modern war, scientific research cannot be restricted to purely military and naval problems. If science is mobilized for war and the far-reaching influence of war on industry is kept in mind, the national peacetime economy is also bound to benefit; for there is no doubt that new discoveries will be applied in creating new industries that will help maintain employment.

Boundless Possibilities of New Frontier

A National Science Foundation does more than insure military security. In little more than a hundred and fifty years, a mere tick of the clock in any nation's evolution, the United States has become a leading economic power. The story of the transformation is familiar. It is a story of frontiersmen who pushed out from the Atlantic seaboard until at last they reached the Pacific Ocean, hewing farms out of forest, planting tobacco and cotton in the South and grain in the Middle West, launching steamboats on the Ohio and Mississippi and building transcontinental railways, mining about all the metals and fuel that an industrial nation requires and more to boot. Today the choice acres are settled, the best stands of timber cut, the richest mines and oil fields discovered. Physical expansion is no longer possible. Yet a new frontier beckons. Though invisible, it is there—in men's minds. Its possibilities are boundless. They lie in the progress of science and technology, in raising the standard of living to new heights, in more widely distributing the fruits of research. We see all this more clearly, now that the war lies behind us—a war in which we marshaled all our scientific and industrial resources. And because we see it more clearly a National Science Foundation is a national necessity.

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