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The Saga of American Universities: The Role of Science

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23 June 1972 is an important date in the history of higher education in the United States, for it was on that date that the finding of Congress that "the nation's institutions of higher education constitute a national resource which significantly contributes to the security, general welfare, and economy of the United States" was signed into law (*1*). In the preceding fiscal year, federal obligations for the support of higher education had amounted to $3.5 billion, over 12 percent of the total expenditure for higher education from all sources (*2*); but all these federal funds had been appropriated for purposes other than higher education itself, purposes such as the enhancement of the nation's health, or the improvement of agriculture, or the expansion of educational opportunity. The Education Amendments of 1972 (*1*), however, express concern about the "financial crisis confronting the nation's postsecondary institutions" and establish a National Commission on the Financing of Postsecondary Education to study the nature and causes of the serious financial distress facing institutions of higher education. It is of particular concern to scientists that, in spite of the substantial sums that flowed to the colleges and universities in fiscal 1971, changing national priorities affecting the support of academic science actually resulted in lower support in 1971 than in 1969 and produced critical problems for our major universities.

Although the 92nd Congress had before it many recommendations for noncategorical, formula-based support of colleges and universities, it chose to limit the institutional support authorized this year for undergraduate education by making the amount a function of the number of students receiving federal assistance of various kinds. By this device, institutional support was tied to the national goal of expanded educational opportunity, and the need for evaluating the quality of the college or university was passed on to the student. At the graduate level, however, direct federal aid to the institutions was authorized, a recognition that graduate education is a national undertaking. Thus, as we enter 1973, support of graduate education and of research in all academic fields has been authorized through a combination of federal programs.

In the hope of contributing to a better understanding of the present financial crisis, I discuss here certain aspects of postwar categorical support of scientific research in the universities, aspects that I believe suggest some principles which should influence future policy. As Congress studies the needs of higher education, what kinds of programs should we in the scientific and educational communities encourage in order to ensure the health and effectiveness of our educational institutions and to preserve the strength of science? What have we learned in the past 25 years that can assist us in building stronger institutions in the years ahead? Should we favor reliance on categorical grants or on formula-based institutional grants? What role should be played by the federal government, what role by the states?

In discussing these questions, I am aware that the assistant commissioner for education has warned that we must expect "some difficult times ahead" for education (*3*); and I realize that only the strongest public demand can be expected to clothe the authorization act of 1972 with budgetary reality. It is my hope that, like Lockheed, the institutions of higher education of the nation will be deemed worth saving.

The Carnegie Commission on Higher Education, created in 1967 to examine and make recommendations concerning the many vital issues facing higher education in the United States, addressed itself in its first report to the major tasks faced by the educational establishment (*4*):

> What the American nation needs and expects from higher education in the critical years just ahead can be summed up in two phrases: quality of result and equality of access. Our colleges and universities must maintain and strengthen academic quality if our intellectual resources are to prove equal to the challenges of contemporary society. At the same time, the nation's campuses must act energetically and even aggressively to open new channels to equality of educational opportunity.

Since the publication of this report in 1968, the second of these objectives, the expansion of educational opportunity, has moved apace, largely with government encouragement and support. In the sciences, however, during those same years, there has set in a recession that has frustrated attempts to achieve higher quality. Government programs that were focused on increasing the number of "centers of excel-

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lence" (*5*) and the general quality of college and university work have fallen on evil days through lack of funding. Virtually all our colleges and universities are suffering from the abrupt termination of these programs or from the decrease in federal support of other programs to which they have committed themselves.

Leading all the rest in the pervasiveness of the distress it has caused the country's research universities is the change of policy with respect to federal support of basic research in the sciences. After a decade during which dollar support of academic science grew at a rate of 15 percent or more annually, the rate of growth decreased until, within the last few years, the support received by many universities did not keep pace with inflation (*6*). As Ivan Bennett has said (*7*):

> When budgets began to contract, it became painfully evident in many universities that federal funds had indeed permeated the financial structure of the entire institution and that the reductions would result not only in a shrinkage in support of research of interest to the federal government but also in general financial stringencies for the entire educational process . . . we are now seeing that a system designed fundamentally to meet the needs of federal agencies for science and technology is not an adequate means of meeting the emerging responsibilities of the federal government for the support of higher education. It is now quite evident that forging a new and more logical relationship between federal support for academic science and the emerging federal role in support of higher education totally is a major task for the next decade.

This is the task we now face. It is a difficult one, and it deserves wide discussion among scientists, among the people on campus who are responsible for the welfare of colleges and universities, and among elected representatives in Washington and the state capitals. What emerges from these discussions will be, at best, appropriate for a limited period, for one must expect the political realities of public policy formation to be responsive to new values and new priorities as these emerge with changing social, political, and economic developments. The crisis faced by our colleges and universities has been brought about by a variety of forces that are clearly not the same for all institutions. Public universities are suffering, along with the elementary and secondary schools, from the inadequacy of state and local taxes to meet the costs of the vast expansion in public education. Private institutions are confronted with inadequate income from tuition and from endowments and gifts to cover their inflated costs, their expanded commitments, their obligation to make good on the claim that one of America's greatest educational assets is the diversity of its educational system, and their special obligation to provide for experimentation, innovation, and change.

All types of institutions have responded to federal and to state or local pressure by assuming obligations for programs that are peripheral to their main mission: for example, special undertakings in aid to developing countries, community development programs, and a host of efforts that reflect the confidence that the American people have had in the university's ability to serve a wide variety of publics. In particular, there is an increasing expectation that the university will provide further professional training for as long as the individual wishes to keep his knowledge and competence up to date, possibly by providing "modules" of learning, as the individual moves in and out of the university every decade or so.

Ironically enough, in spite of widespread dissatisfaction with the programs of the educational establishment, increasing percentages of young people, or at least of their parents, consider college attendance necessary. Society has endowed the university with so many certification functions that the customers are still crowding into the shop, even though they are uneasy. The need for manpower, in science at least, has been perhaps too well served by post–World War II support of science at the university—a program of support that has been largely responsible for giving this country its position of scientific leadership in the world and that has provided the nation with new power and wealth generated through the use of science and its related technology. This year's sweep of the Nobel awards emphasized again the quality that has characterized the best of our science in the past decades and underlined the requirement that any change in science policy must preserve a solid core of support for basic research. The problems that have accompanied the applications of many scientific results are the other side of the coin, and there is general agreement that these problems demand attention. Some would argue that, as a matter of public policy, we should address ourselves to the better coupling of programs and needs, both in manpower and in applications, by providing reviewing machinery for both. But the consideration of such a plan is beyond the scope of this article.

What I do want to do is review the early history of the government's program for the support of scientific research and see whether there are lessons that can be learned from it. Like Dean Acheson vis-à-vis the United Nations, I was there at the Creation. Before embarking on this brief history, I should add that it was during World War II that the federal government evolved the machinery for contracting with universities to provide the research and development needed to support the war effort and poured unprecedented amounts of money into universities to pay for these undertakings. In the light of the present attitude on most university campuses toward the military establishment, it is worth giving a description of the World War II atmosphere as related by Harvey Brooks (*8*, p. 942):

> In a certain sense World War II and the subsequent period of the Cold War might be characterized as a love affair between the intellectual community and the government, which affected not only the development of science but a much broader range of academic scholarship. The Nazi menace united the American intellectual community as nothing else had or could. Nazism was a specific attack on the values that the academic community held in highest priority, and the reality of its threat was brought home to American academics by a stream of refugees from Europe whose names [were] a byword among American scientists—Fermi, Wigner, Bethe, Teller, Ewald, Franck, and many lesser luminaries. Thus academic intellectuals were well prepared, emotionally and intellectually, to close ranks behind the American war effort. Natural scientists left their home universities and flocked to the war laboratories set up by OSRD [Office of Scientific Research and Development]. An informal and extremely effective system of recruiting for the war effort was established within the academic community.
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> At the same time humanists and social scientists flocked to the Office of Strategic Services and to the various agencies set up to manage the war economy.

It was within this environment that I was asked, in 1945, what I would think of the creation, within the Navy, of an office that would give universities money to pursue basic research in mathematics. I expressed grave doubts. I thought it unlikely that mathematicians would be enthusiastic about receiving money from the government to support their peace-time research and even more unlikely that money from one of the military services would be welcome. But when, in 1946, I was invited to go to Washington to establish such a program, I decided, after consultation with some of my wisest friends, to participate in what seemed to me to be a somewhat doubtful experiment. When I arrived in Washington, it was impossible to find a place to live. No apartments were available and most hotels permitted a guest to stay only 5 days. When I found one that extended its hospitality for 2 weeks at a time, I was enchanted. I made a virtue of necessity, and, every 2 weeks, I went on a trip to a leading mathematics department. These were the conditions under which I consulted most of the senior mathematicians in the United States. Together we evolved the mathematics program of the Office of Naval Research. Basically, our decision was to support applied and pure mathematics, statistics, and computer development, with its related numerical analysis, and to use the Navy's research support to buy time for able mathematicians to carry on their research, providing support in the guise of research assistantships for the education of promising young mathematicians, for whom there was an acute need in those days. Time and the education of able students are, of course, components that any research project undertakes to provide. In the experimental sciences, however, because the costs of equipment may be very large, substantial funds were needed.

In time, it became clear that the scientists and mathematicians were enthusiastic about accepting support from the Office of Naval Research; but most university presidents were cautious about building Navy support into their budgets, and some refused to do so. There were two issues. If scientific research were really deemed important for the nation, why finance it through the Navy? In most cases, the suspicion that gave rise to this question was overcome by the performance of the staff of the Office of Naval Research and, in 1950, by the establishment of the National Science Foundation (NSF). The second issue was the conviction that the interest in scientific research was a passing phase and that financial support would be short-lived. Actually, it continued and expanded for more than two decades. With the passage of years, increasing numbers of university presidents began to build this support into their budgets. In some cases, well over half of the university's budget came from government support of scientific research. And therein lies the dilemma of a number of institutions.

The program for the support of university research grew and flourished through the years, with the establishment of research offices in the other military services, the Atomic Energy Commission, and the National Aeronautics and Space Administration (NASA) and with the impressive growth of the National Institutes of Health. All this greatly magnified the support available to universities. Most important of all, in principle, although not in level of support, was the NSF. With its establishment, science itself was accepted as a national goal. As the experimental sciences became increasingly sophisticated in the equipment they used, the mounting costs led, in certain outstanding instances, to the creation of national research centers that would serve scientists from many campuses. Thus we have Kitt Peak National Observatory, the National Center for Atmospheric Research, the National Accelerator Laboratory, and many others.

There were also research institutes that were established when an agency needed to focus on research applied to a particular problem. These were usually associated with universities, either as integral parts of the institution or as independent organizations living in proximity to a university.

Thus what has been called our national science policy came into being. It recognized science as a national resource that must be nurtured by the government; it supported the best and most creative scientists, as well as a host of less brilliant but significant workers; it financed science generously at the most prestigious institutions and attempted to build new centers of excellence in every region of the country; it recognized the advantage of sponsoring research at universities where graduate education was benefited by its presence; it encouraged all departments and agencies of the federal government that rely on science to provide support for its growth; and it encouraged the growth of institutes devoted to applied research that were in proximity to universities (*9*). It must be noted that, over the years, the largest part of the support received by universities for research has been received not from the NSF, which, in 1967, provided only 15 percent of this support, but from the mission-oriented agencies, whose funds were earmarked for specific purposes associated with their statutory missions.

What was the influence of the patron as federal support of university research evolved? The effect of the science policy I have described on the fields in which scientific research has focused has been commented upon by many observers (*10*). When I first became interested in supporting work that would develop the analytical tools to make the computers that were under development more significant in support of astronomical research, I could find only a handful of astronomers interested in questions related to trajectories. Now, with the stimulation of the field by NASA, the number is legion. Similarly, the International Biological Program could find few ecologists with the sophistication to design some of their biome studies. Although this is a field in which we now have real manpower needs, it was not fashionable in the past. There have always been fashionable and unfashionable fields of research—usually determined by the internal logic of the discipline, but often reflecting the tastes and interests of the acknowledged leaders. Federal support, however, has now become a force in determining the fields in which scientists will concentrate. For example, whole departments were set up in response to NASA's interest in space studies. Among the opinions expressed to the House Committee on Government Operations in 1965, when it was investigating the effect of federal support of academic research on choice of field, are two that emphasize not only the lure of additional income, but also the effect of agency policy and the degree to which established scientists on proposal-appraising committees influence activities in a given field. The first opinion (*11*):

> In many fields, especially the social sciences, career choice, or the decision about what line of scholarship to pursue, is almost inevitably distorted by the knowledge that one line of inquiry is eligible for support and will bring in $2000 or $3000 more income, whereas another must, at worst, be wholly without research compensation or, at best, take the chance of ad hoc summer grants from foundations or university fluid funds.

The second opinion (*12*):

> I doubt whether federal research programs have done more than add marginally to the imbalance already there. . . . It is not so much that the "hard science" departments are being supported, but that the "hard" outlooks are being supported within every field, including the humanities. The academic judgments as to what is "research" and the judgments as to

what are the appropriate methods for discovery tend to become stereotyped as a result of the anxieties of young researchers lest they not be pursuing the approved formulas—approved, that is, within their academic subguild. . . . When I consider the work of the federal agencies I know best . . . it seems to me that federal officials are more sensitive to innovation than, on the whole, is the case with the academicians. Yet the federal officials frequently delegate their power to allocate funds to academic men.

So much for the influence of government funds on choice of field or subfield of research. Another effect of federal support became increasingly clear as agency scientists and university scientists became accustomed to working together. Agency personnel needed to be in touch with scientific developments, and with the scientists responsible for them, so that they would be better able to identify and exploit scientific findings to advance their agency's program. The relationship between the staff of the Office of Naval Research and the research contractor was the most significant element in ensuring that imaginative scientists saw the intrinsic interest and excitement of some of the questions the Navy needed to have answered and that opportunities to exploit new scientific findings were embraced by the Navy. While it is simplistic to expect to avoid those uses of scientific results that we judge to be in conflict with our social purposes merely by refusing to accept research support from the military or other disapproved agencies, it is fruitless to deny that an agency that supports research will often influence the interests of the researcher and will have access earlier to the potential uses of his research results.

There are often scientific advantages in having a researcher in close contact with an agency's problems, for this provides an easy flow back and forth between basic research and applications and provides the researcher with the excitement that comes from seeing his often abstract results translated into significant uses. Even for mathematicians, John von Neumann argued the value of contact with empirical reality (*13*):

It is a relatively good approximation to truth . . . that mathematical ideas originate in empirics, although the genealogy is sometimes long and obscure. But, once they are conceived, the subject begins to live a peculiar life of its own and is better compared to a creative one, governed by almost entirely aesthetical motivations. . . . There is, however, a further point which, I believe, needs stressing. As a mathematical discipline travels far from its empirical source . . . it is beset with . . . a grave danger . . . that the stream, so far from its source, will separate into a multitude of insignificant branches.

In assessing the influence of government support of research, I can speak best of mathematics. It is true that new fields, such as operations research, linear and nonlinear programming, and game theory and convex spaces with applications in logistics, were developed and that old fields, such as numerical analysis, finite projective planes and latin squares, and fluid mechanics with applications to subjects like flood control and weather forecasting, were revived with the encouragement of the government. But it is also true that the period of support by mission-oriented agencies saw a flowering of research in fields such as differential topology, mathematical logic, and Lie groups and nonassociative algebras, which were responsive solely to the tastes and interests of mathematicians. I believe that the principle of project support from mission-oriented agencies has intrinsic merit over and above the advantages of diversity of support and greater total funds. The fact that large amounts of money have been provided by the Department of Defense has diverted attention from the advantages of relating some research to questions that must be answered and areas of study in which more knowledge is needed if we are to advance our social purposes.

Although the commitments that the universities assume, like our national priorities themselves, will change with time, at this point agencies concerned with cleaning up the environment, or with the problems of the cities, or with the delivery of health care—with all the desperately important problems that surround us—will be welcome if they offer project support. But unless such agencies have a program of support for research at universities, and unless they solve the problem of translating research results into useful and usable technologies with something like the skill the military services have shown, the hope of continuing mutually beneficial relations between the federal government and academic science would seem to be minimal. Since the costs of some important aspects of research in the sciences are too great to compete with the costs of other projects on campus that must be met within an institutional budget, it becomes important to have support from appropriately chosen mission-oriented agencies. Moreover, to ensure the continuation of a strong program of research that is completely self-motivated, it is important that the basic research component of the NSF budget be adequate to finance some fields of scientific research that are very costly.

I have discussed extensively the interplay of influence between sponsor and researcher because I believe that this relationship can serve to ensure that the results of research are used for the welfare of people. But the system that supports individual projects rather than the institution as a whole has also come in for its share of criticism. Many have testified that the project system has deprived the university of needed autonomy, that the faculty member has tended to look toward his sponsor rather than toward his campus in determining his commitments and shaping his career, and that the university president has lost control of his institution's budget. While recognizing that the university administration is certainly at fault in some instances, the NSF and other agencies have, within the past decade, sought to restore the balance through programs of institutional grants that have been designed to encourage institutional rather than personal planning. In these attempts to expand institutional support, not only has the project system, with its peer evaluation, been retained for a substantial portion of the research on campus, but at the same time increased flexibility and scope have been provided campus authorities to encourage young researchers, or those in unfashionable fields, or those whose work is part of the university's planning for its own development. In all of these programs of institutional grants, the awarding of funds and the amount of the grant are tied to a careful evaluation of the quality of the research available in the institution and the climate for achieving the institutional goals that are sought.

Unfortunately, these institutional programs have tapered off, but there has been sufficient experience with them for me to believe that institutional support for the sciences can be designed in such a way as to maintain quality while bolstering institutional autonomy. What of institutional grants intended to contribute to the support of any or all parts of the institution? If such grants are provided—and this is already done in some states—then institutional goals and the quality and appropriateness of programs to serve public purposes should be subject to public scrutiny.

An exhaustive evaluation of goals and quality involving both agency personnel and outside educators and scientists was accepted as appropriate in connection with the NSF development grants, which were limited to a few science departments. But this practice applied to all colleges and universities and across the entire range of institutional commitment is horrible to contemplate. However, if public funds are provided by formula for the support of private institutions, decisions at the level of purpose, program, and quality that involve expenditures to be charged to the public will be made by faculty, students, administrations, and boards on many campuses. If I am right in my belief that there should be greater responsiveness among colleges and universities to the needs of their regions and greater specialization in their programs, it may be that public funds should be provided to an institution only after a judgment on the suitability of institutional or program objectives has been made at the state or regional level. The problem we must face is how to avoid a damaging erosion of institutional autonomy, while preserving the financial viability and the quality of our institutions, on the one hand, and how to guarantee the appropriate use of public funds, on the other. Above all, in seeking solutions we should work for stability and continuity of support.

All this seems to argue several things. The plight of many of our institutions is so serious that federal funds are desperately needed. If such funds are provided for broad, general support that is not tied to other national goals, then the appropriate device for providing funds would be revenue sharing, with proper safeguards to ensure that the funds are used for the intended purpose and that adequate account is taken of the objectives and the quality of the institutions receiving support. Steps should be taken to require that all federal agencies which rely on research results in any field of learning for the effective performance of their mission (and particularly those agencies concerned with outstanding social problems) manage programs of research project grants. The basic research budget of the NSF must be protected to assure that the level of basic research continues to be adequate for our national purposes.

Over the past 25 years, the scientific estate has prospered and grown. It is a major glory of the intellectual life of this nation. It can live with the changed priorities of national life. As we move into the lean years ahead, scientists must recognize that academic science can flourish only if the academy itself is healthy, and universities and scientists alike must find ways to influence and adjust to the political, organizational, and economic realities of America in transition.

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The Apollo 16 Lunar Samples: Petrographic and Chemical Description

Apollo 16 Preliminary Examination Team

Introduction

More than four-fifths of the surface of the moon consists of a profoundly cratered, irregular surface designated terra or highlands by analogy with the terrestrial continents. These terra regions have much higher albedos than the physiographically lower and much smoother mare regions. The difference in albedo can now be ascribed to a fundamental difference in the chemical and mineralogical character of these two regions. Lunar samples from landing sites in the mare regions and high-resolution photographs taken from lunar orbit have shown that the lunar maria are underlain by extensive lava flows. Isotopic dating of samples from four mare regions (*1*) indicates that mare volcanism covered a time span of 600 million years beginning about 3.7 billion years ago. The intensely cratered character of the terra regions is due to both the greater antiquity of these parts of the moon and the higher flux of incoming objects that hit the moon during its very early history (*2*). In contrast with the mare region, the origin of the underlying material of the terra is not easily inferred from physiographic criteria. The surface manifestations of early plutonic or extrusive igneous activity—if indeed they ever existed—were erased from the terra regions by the intense early bombardment of the lunar surface. There are some portions of the highlands that may be exceptions to this generalization, in particular, large craters such as Ptolemaeus, Hipparchus, Albategnius, and Alphonsus. The regions bounded by these craters are much smoother than the typical densely cratered highlands. It is generally assumed that these regions are physiographic lows that have been filled with younger material by some poorly understood mechanism. On the basis of detailed studies of the physiographic and albedo characteristics of the basin material, it has been suggested (*3*) that