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PHYSICS AND THE NATION IN A CRYSTAL BALL

Physics in the US today faces a series of problems that are causing both students and the public to lose interest. Some solutions are offered at the 1980 APS meeting.

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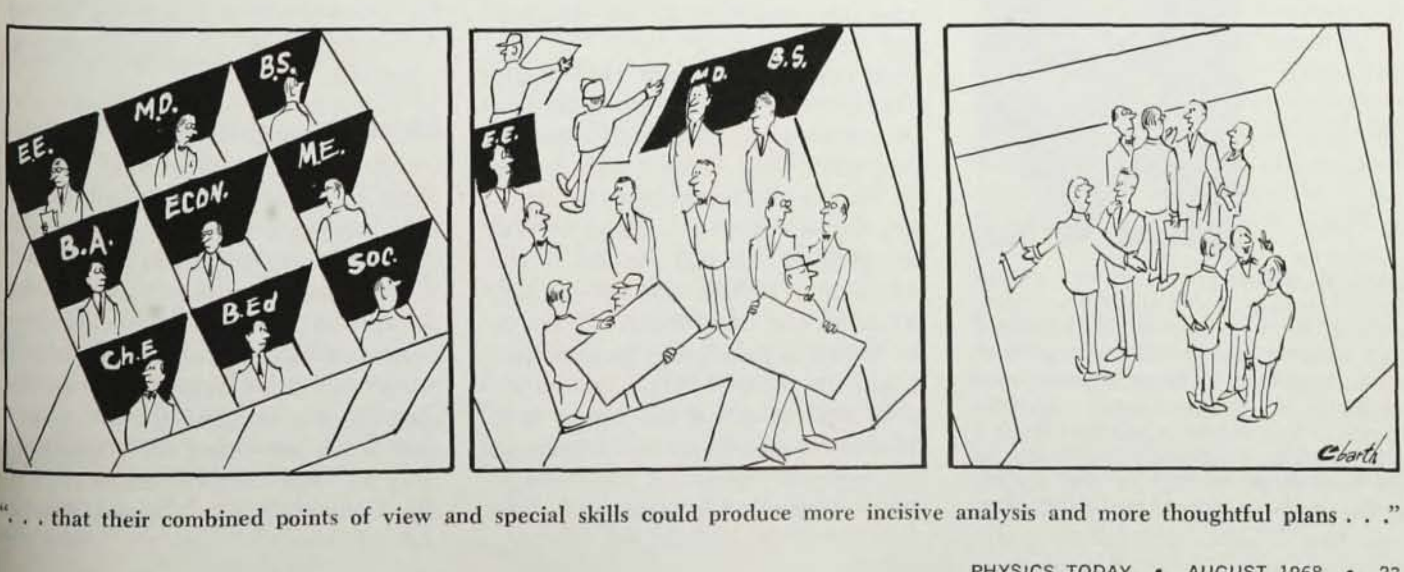
THE UNITED STATES appears obsessed with self-doubt concerning its ability to solve its problems in a manner consistent with its self-image. This doubt flourishes despite a revolution of far-reaching social legislation that embodies at every hand the intention to apply the power of scientific research to the solution of our problems; many of the alienated among us tend to identify our troubles with technology. They see science, and perhaps especially physics, as encouraging a mindless, mechanical approach to life that is dehumanizing our society. Yet the record shows that scientists and, I believe, particularly physicists have consistently led efforts to awaken our society to the dangers of the misuse of technology, of the arms race, of the pollution of our environment, of the choking of our transportation and the physical decay of our cities. The social conscience of the physicist is rooted in the personality of American physics. Knowing the limitations of our expertise, but sure of the soundness of our motives, we are concerned to define correctly the character of our profession and its place in the life of our society.

Innocent and naïve

The character of contemporary American physics was forged in events of enormous importance. The 20th-century conceptual revolution in physics that culminated with the birth of quantum mechanics found American physics, which was nurtured in Europe, ready to exploit on its own ground this scientific opportunity. Our debt to Europe was incorporated into the lifeblood of our science during the 1930's, when so much of Europe's best talent fled fascism to become leaders in American science. These roots gave us part of the personality of American physics: idealistic, sensitive, cosmopolitan and international. Flowering with American talent, working in young, ambitious and flexible institutions, our physics was also vigorous, imagina-



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tive, competitive, innocent and sometimes naïve.

The innocence was lost with the detonation at Trinity. Naïveté lasted until the late Senator McCarthy from Wisconsin taught us that many of our fellow citizens harbored deep fears of science and mistrusted its practitioners. In 1953 the AD-X2 battery-additive affair saw the director of the National Bureau of Standards fired for the failure of NBS to include the "play of the marketplace" in testing procedures for automobile batteries. We learned that opposition also could be heard from some elements of the business community: Beware of letting science come between the manufacturer and his customers.

Considering those difficult and rather recent days, the subsequent degree of accommodation between science and both business and government has been quite remarkable. Technology is now acknowledged to be the driving force for increases in productivity in our economy. I need not describe the panoply of mechanisms for inflicting scientific advice on the executive branch of the government.

20% growth "normal"

The Soviet Union provided a major assist toward the science–government partnership by demonstrating dramatically its conviction that superiority in science could be a source of national pride and superiority in technology the route to power and wealth.

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This conviction has been largely accepted in the US. The 1950's and 1960's saw extraordinary growth of public investments in research and development. We came to accept 20% annual growth rates for physics support as normal, much like the lady in Boston who, on the one lovely spring day each year, says: "At last, a typical Boston day!"

In the middle 60's the federal support curve began to level off. As federal academic research and development investments reached the $\$2 \times 10^9$ mark, many began to face the implications of growth rates of federal science dollars that continued to exceed the growth of federal revenue and the Gross National Product. Congress asked, "How much research is enough? When we have all we can afford, how do we choose among investment opportunities in different fields?" Scientists looked at their unrealized opportunities for scientific advances and wondered if nation number 1 was really in danger of finding out how it feels to be number 2.

Grant system questioned

Concurrently with the tightening of research dollars came changes in the political acceptability of federal aid to higher education. Since the presidential election of 1964, the Office of Education has grown enormously and now sponsors many programs of aid to universities. But today graduate education in physics still receives the bulk of its extra-institutional support from the federal government through the system of project grants and contracts. This array of tens of thousands of individual transactions representing the purchase of research information by the government is increasingly regarded as an anachronism.

Yet we physicists are exceedingly reluctant to see the project-grant system attacked. It introduced a quality competition and fluidity into American science that is the envy of scientists the world over. Thus we are faced with a practical question whose answer may reshape the science programs of our universities: What is the federal responsibility for academic research in science? How can the obvious inefficiencies of the almost total reliance on project grants be reduced and regional aspirations for development of quality institutions be encouraged without losing the essential emphasis on quality that is symbolized by the project-grant system?

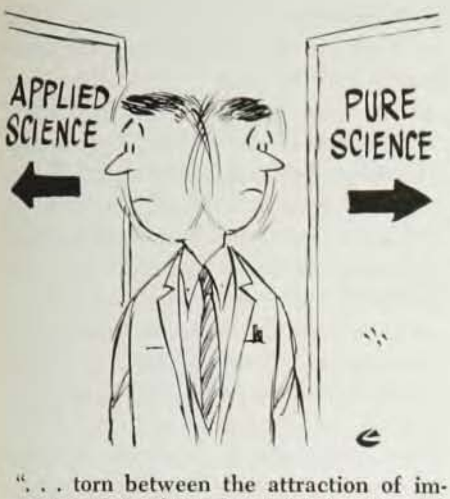
Who speaks for physics?

Physicists in the 1960's are also troubled by the growing political visibility of congressional appropriations for science activities. Who makes up the constituency that will ensure sufficient support and sound policy for science? Shall we be sympathetic or hostile to those who press for wider geographical distribution of federal resources for science? Must we, as the editorial writers warn us at every opportunity, take a realistic but cynical attitude toward politics and lobby for support of physics? If so, what will this competition do to our science and what will it do us, the scientists? Will the spectre of heightened conflict-of-interest thwart the effective access by the government to scientific advice?

Other problems face the physics community. The nation has developed a set of great national laboratories, which have demonstrated the capability to attack and find technological solutions to a range of urgent national problems, mostly related to defense, energy and space. Now we hear fears expressed that having done the job for which they were assembled they will lose their value unless given new tasks of comparable urgency. Yet the need for such resources to be available to the country has never been greater. Very slow progress is being made toward solutions of the technical problems associated with eliminating pollution, developing more effective transportation, making better use of the electromagnetic spectrum, finding new sources of water, modifying the weather and assisting in the desperate plight of the developing countries.

Disappointing response

Of all the problems facing physics today, perhaps the most perplexing is the disappointing response of high-school students to the study of physics. This problem, too, may have its roots at least in part in the public conception of the role of physics in our society. In the wake of the public chagrin over the first sputnik, physicists led a movement for educational reform. The Physical Sciences Survey Committee was a major innova-



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tion in science teaching. A new spirit of excitement about science was abroad. Yet the fraction of college students who choose physics as their major course of study continues to slump (although the actual number of physics majors has now begun to increase). Is the study of physics so inherently difficult that only the gifted and motivated student responds? Is physics therefore talent limited? Or have we physicists failed to convey to the students the challenge of physics in a context that appeals to this generation of students? Do students see physics darkened by the shadow of a mushroom cloud? Or does the problem really lie in the shortage of teachers of physics at the high-school level who are capable of transmitting to the students a sense of the intellectual excitement of physics, its importance and its potential for constructive contribution to our society?

Physicist's dilemma

A scientist can be torn between the attraction of immersing himself in his field for its own sake and the attraction of applying the benefits his field offers to the world around him. This dilemma is posed clearly when we ask: What is the responsibility of academic science for systems analysis? What is the responsibility of academic science for anticipation of the future impact of technology as the government plans new programs? It is clear that the present planning mechanisms of government, both legislative and executive, are not adequate to the task of foreseeing the future consequences of present decisions.

This problem can be restated as follows: How can public policy be grounded in a full appreciation of the true costs and benefits of the application of technology on such a scale that interactions with the other goals of our society become nonlinear? Obviously, this kind of analysis requires a degree of farsighted judgment and the confluence of so many areas of specialized knowledge that some form of institution that aggregates multidisciplinary professional talent is required. Is this the national laboratory? Is this a responsibility of universities? If physicists in universities become involved in such studies, what will their injection into the arena of political controversy do to their requirement for intellectual freedom as basic scientists?

Most of us, of course, see both aspects of physics—the intrinsic and the extrinsic—as its attractions. Our heroes, such as Fermi and von Neumann, were capable of setting the highest standards in both aspects of science. But, while the introverted approach alone does not fulfill all of the promise of physics, and certainly does not meet the full expectations of the society that supports it, the extroverted approach takes us out of isolation and confronts us with new problems for which our traditional professional values do not entirely suffice. We look back on the uncomplicated days with some wistfulness.

In personal terms

Eugene P. Wigner, in an interview in Look Magazine[1] puts this problem in very personal terms:

"It was much nicer to be somewhat looked down on as a queer guy who works for science and who does something impractical and who isn't to be taken very seriously. Science is to some degree an escape . . . It is something that you can immerse yourself in, find beauty and pleasure in, without harming anybody, without having much effect. To be taken very seriously deprives one of freedom to think fully, to say clearly what one believes—because it may be unpolitical. And I don't think this is good for the scientist."

My purpose here is to look to the future—to the place of physics in the decade of the 1970's. Where shall I find solutions to this list of problems that have already challenged the ability of more experienced and knowledgeable scientists than me?

I will gaze in a crystal ball and tell how, at the 1980 New York meeting of the American Association of Physics Teachers and the American Physical Society (which that year was held in Boseman, Mont.), we physicists solved the problems I have discussed. I looked over a number of crystal balls, and decided to pick one that gave a very optimistic picture. I shudder to think of the picture of disarray that was reflected in the most pessimistic. Please imagine that it is January 1980 and this talk is entitled: "A Retrospective Look at How Physics has Changed in Relation to Society in the Past Twelve Years."

THE VIEW FROM 1980

In the late 1960's we discovered that the discouraging response of students to physics resulted from too much narrow professionalism at the college level, too few good teachers at the high-school level and above all, from a lack of the fun that physics can be—at least as seen by the students. We found that a teacher who had never had the fun was scarcely able to lead the students to it. It was clear that Jerrold Zacharias, Ed Purcell and Eric Rodgers could not teach all of the kids themselves; so we tackled the real problem: the teachers.

Rapid expansion of college level education, especially the junior colleges, took away from the high schools many of the small number of good science teachers. The fraction of high-school students who enrolled in a physics course had declined from 23% in 1890 to less than 5% in the 1960's.[2] Discouraged by dwindling numbers of physics majors and the inability of the teachers' colleges and education schools to solve the high-school physics-teaching problem alone, physics departments set about making physics fun for students. While stretching the ability of the best students through advanced work and research opportunities, we also found out how to give the not-so-brilliant student the satisfaction that comes from a mastery of physics at his own intellectual level. Able to find satisfaction in physics himself and accepted by the faculty as a man with an important role to play in his science, he was able to see the appeal of sharing this satisfaction with the younger generation. By making physics fun for the future teacher, we enabled him to make it fun for the kids.

Closing the gap

Of course there was still the serious gulf that separated our educational system between the 12th and 13th student years. None of the flexibility characteristic of the transition from the undergraduate college to the graduate school of a university was available between high school and college. We realized that this gulf was an historical vestige of the old days when only the privileged went to college. It seemed an anachronism with 85% of high-school graduates going on to college. We discovered that as more able teachers joined the good high schools, many were well qualified to contribute new materials and new techniques to physics teaching. Some teachers enjoyed trying their hand occasionally at a lower level college course. Educational research grants became available to selected high-school teachers, encouraging collaboration with physicists in neighboring colleges. Some high schools became associated with community colleges and others introduced 13th-grade elective courses so that advanced seniors could take college-level work. A substantial increase resulted in the professional standing of physics teaching below the college level.

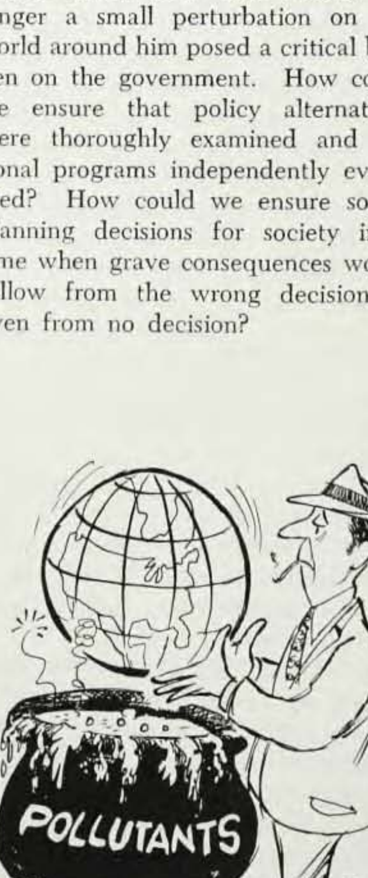
The final acceptance of women was another important change in the social structure of physics. We knew for years that they won all the science fairs and as school children showed themselves very adept at science. With Russians leading the way, we finally tapped the neglected 50% of our potential talent. The effect on the quality of science teaching was almost immediate.

Early in the 1970's it was widely accepted that training in physics up through one or two years of graduate course work was the appropriate basic training for future astronomers, geophysicists and others in what may be called "applied" physics. Undergraduate students were given an opportunity to see physics in the context of a great range of problems that added interest and relevance to their education.

Effective collaboration

The most radical change in the sociology of physics took longer; this was achievement of effective collaboration with the social scientists. Social scientists finally found the courage to escape their narrow professionalism; physical scientists began to appreciate the need for more than amateur judgments of human factors in the urgent sociotechnical problems of society. Both physicists and social scientists found themselves forced to work together because of the growing importance of making optimal technological choices in public policy.

The great accomplishments of physical research in the early '70's created an enormous number of alternative courses of action for society. Yet each avenue for action produced interaction with other avenues. The coupling coefficient was the human factor, the reaction of society itself. This strong nonlinear interaction of man with his environment during a period when man was clearly no longer a small perturbation on the world around him posed a critical burden on the government. How could we ensure that policy alternatives were thoroughly examined and national programs independently evaluated? How could we ensure sound planning decisions for society in a time when grave consequences would follow from the wrong decision or even from no decision?



". . . man was clearly no longer a small perturbation on the world around him . . ."

Nicholas E. Golovin of the Office of Science and Technology had proposed back in 1968 a fourth branch of government to fulfill this technically sophisticated evaluative function. His idea, however, was ahead of his time, and became bogged down in the constitutional debate over the prerogatives of the Congress. For all practical purposes we continued to make national decisions concerning interlocking matters—for example supersonic transports, city planning, ground transportation and air pollution—independently of one another. Similarly we could find no sensible relation among federal plans for construction of desalting plants, for 100% treatment of sewage with clean water recovery, for financing irrigation and water-storage projects through sale of hydroelectric power and for investments in controlled thermonuclear and fast-breeder power.

Schools meet challenge

In the end the universities rose to the challenge. Their graduate schools became interdisciplinary in fact as well as in name. Physicists, social scientists and humanists found the time and the tolerance to discover that their combined points of view and special skills could produce more incisive analysis and more thoughtful plans than could the harried government executives supported by part-time academic advisers.

The national laboratories and, occasionally, industry carried out most of the detailed systems analyses. But the academic community led public discussion of the merits of the conflicting alternatives and conclusions. With enough universities contributing to this public discussion, political decisions could be made in a more traditional, and therefore more acceptable, way. Effective participation by the university community was made possible by changes in the mechanisms of support for science faculties, and made effective by the increasing political sophistication of scientists and the improved technical competence of government, especially in congressional committee staffs. Students were the first beneficiaries of this increased capability and willingness of university faculties to come to grips with the current problems of society; for at once their educational experience became more relevant, and they found an avenue for self-expression in a constructive context.

Federal labs' role

The federal government also found a way to use the large physics laboratories more effectively in the development of technological alternatives for the solution of public problems and the analysis of the benefits and consequences of these alternatives. A number of the laboratories were combined with NSF into a national agency for R and D policy. This agency evolved legislatively from the NSF and the OST. It did not undertake continuing responsibility for major development programs well established by Congress, such as space, nuclear power and military R and D. Accordingly it was not called the Department of Science but the National Science Policy Agency. The agency did, however, support the basic science capability of the country and provide national research facilities. It conducted grant, contract and in-house research-systems analysis to provide the basis for government decisions on larger-scale operational programs. Often a small-scale research endeavor grew into a major operational program ready for independent legislative support. Such activities were split off and set up within other appropriate operating departments. In this way the National Science Policy Agency remained stable in scope and size; in return, Congress empowered the executive branch to utilize up to a specified fraction of the agency resources for exploratory research in any area of technology without prior specific approval of Congress. Several Federal Contract Research Centers were assigned to the agency. Their independence and flexibility proved invaluable. Indeed, Oak Ridge has thrived under this new system. At last count, Al Weinberg reported that the economists and biologists now outnumber the physicists there, and they have to call in consultants on reactor-design questions.

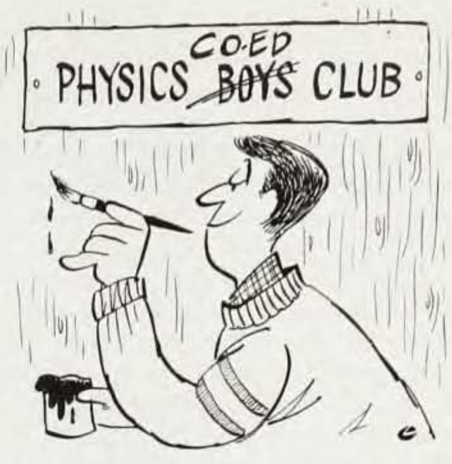
Physics and planning

Finally, the federal government began to find more effective ways of incorporating the best judgment of the physics community into its own strategic technical planning. Joint government–university research centers, institutional support for universities, a more current and relevant orientation of university studies, and better R-and-D management of the government agencies to a great extent erased the jealousies that back in the 1960's impaired the healthy coöperation between the in-house and out-of-house research communities. In those days each community was insecure; professors were uncertain of their support and influence; civil servants uncertain of their standing and acceptance.

The real break came in Congress. In the mid-70's scientists finally figured out why the public prefers to elect lawyers rather than physicists to office. The public trusts the lawyer because they know he has a common base of experience with the voter; he is therefore more predictable. Who wants to elect a candidate whose actions in Congress may reflect his own professional expertise to a greater degree than his desire to relate to his constituents? A few courageous scientists then ran for office and were elected, not as scientists, but as practical, down-to-earth fellows prepared to speak and act at their constituents' level of interest. It turned out that the congressmen–scientists were extremely effective at grilling agency heads at appropriations hearings and could pursue the proposals for R-and-D programs with much greater sophistication than could the lawyers. Physicists were then elected in appreciable numbers and the legislative branch at last began to deal effectively with complex technical issues.

Where the money goes

One of the biggest quarrels back in the late 1960's was over geographical distribution of federal research money. The private universities already were having serious financial support problems at a time when pressures for wider geographical distribution seemed to threaten their ability to continue to lead as quality institutions. People were particularly distressed at the hint of things to come in the eligibility criteria contained in a set of grants called "Project Themis." Eligibility was tied to institutions that had won very few Defense Department competitive project grants. There were those who pointed out that the whole program could be looked upon as a vote of no confidence in the judgment of service-agency program managers, for Themis criteria appeared to give preference to proposals from individuals who had been unsuccessful, and presumably judged less qualified, in the competition for support in the past.



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The geographical-distribution arguments were also complicated by dissension over the proper normalization for comparing geographical distribution. What did constitute fairness? Equal distribution among states? Surely not. Distribution by total population? By PhD production? Perhaps by some more complex evaluation of the merits of the case presented by each region for the value to the nation of an improvement in its educational and research capability?

Fortunately, we were led out of this morass by a distinguished scientist and expert on physics and polity.[3] Harvey Brooks, who went on to serve with great distinction as first head of the National Science Policy Agency, realized that the political obstacles to subjective evaluation of the merits of the proposals of different regions were overwhelming. Instead, he called attention to the fact that some three fourths of the professors in PhD-granting departments had federal research support of some kind already, and said, "Let's invent a formula that can be enacted into law and can be used to distribute institutional grants to existing institutions in such a way that initially it will reflect the status quo." The formula therefore contained consideration of size of present faculty, numbers of students, amount of project-grant support and numbers of graduate degrees given over a recent period. Every accredited institution with advanced-degree programs received something; the places with sustained output of PhD students over a period of years, large faculty–student ratios and extensive research activity got the most. In addition, a program like the science-development grants of NSF was continued to provide one-time quality steps and to encourage innovation in graduate education. Most important, the program permitted special treatment for the new institutions that were badly needed in burgeoning metropolitan areas.

Aired in Congress

Congressional debates over construction of the formula provided a thorough airing of the problem of justifying a particular growth rate for federal support of graduate education and the associated basic research. Some said that 150 universities giving the PhD in chemistry was not only enough; it was too much. But wiser politicians told the scientists not to be so agitated. Fundamentally this growth rate must rest on the aspirations of the people. These aspirations are best expressed, in our federal-democratic system, in terms of the goals and commitments for higher education that are set by local, state and foundation planners. If every metropolitan region in the country wants to be surrounded by sophisticated light industry, have an excellent university, and be enclosed within a highway numbered 128, then sooner or later federal policy will and should encourage these ambitions.

Now, of course, a federal–state partnership was required. We found we couldn't continue as we did in 1968 with every state legislature expanding facilities for public education on the assumption that the federal government would pick up the check for two ninths of the faculty salaries and for all the research costs. Clearly the federal government would encourage a regional approach for states that are sparsely populated and would emphasize the efficiency of specialization regionally or even nationally. But since much of the largest part of the total costs of higher education in the sciences was borne by the state legislatures, the private donors and the tuition-paying students, there was a limit—over and above the political one—on the leverage available to the federal government to control local aspirations. Thus the scale of the growth of academic research was determined by the complex interplay of state, local and federal desires and fiscal resources. Basic to all was the pressure of students and the aspirations of their parents.

Never formally settled

The fight over the funding of basic research, which agitated so many people back in 1968, was never formally settled. It just faded away when adequate support was budgeted separately for (a) investments in graduate education in science, (b) specific technological developments justified by the ultimate purpose, (c) the maintenance of future capabilities in large laboratories with applied missions and (d) investments in specific areas of big science judged likely to be particularly significant in terms of culture, politics or a needed future capability.

The project-grant system for supporting university physics research was never abandoned. In fact, it continued to grow slowly and provided an excellent scale for comparing quality of institutions, for testing the imagination and vitality of different disciplines and for encouraging extra effort in fields that seemed at the time particularly important to the government. The system also helped the agencies keep abreast of current developments in relevant fields of science and encouraged faculty members to take an active interest in the technical problems facing the country. But the most important changes came about as a result of the political acceptability of federal support to universities for their true educational purpose.

Institutional grants

The major growth in support came, of course, from the system of institutional formula grants, which covered about three fourths of the universities unmet needs. Since these funds were allocated within the universities by their administrations—often by the graduate deans—there was initially a great outcry by irate faculty members who trusted the Office of Naval Research project monitor more than their own academic administration. But one by one the physicists who most objected to receiving their research allocation from the dean became deans themselves, and opposition to institutional support faded. In retrospect, physicists today find it amazing that universities in the 50's and 60's were able to function as well as they did in view of the fragmentary and uncertain nature of their financial underpinnings. A great new flexibility was introduced into our graduate schools. Under the new traineeships with research funds attached, a student aiming at a high-school or lower-division-college teaching career could carry out a PhD-thesis experiment of primarily conceptual interest. A student more interested in science policy could write a thesis on a technical subject that involved economic analysis and perhaps had controversial political overtones. The majority of students, who were interested in physics research for its own sake, could follow their own interests rather than the problems selected by their advisers at the time their proposals were last written.

Physicists are now much too deeply involved in the important questions of the times, too wrapped up in the enormous opportunities for intellectual creativity and practical influence over public policy to have time to look back. Even if we wanted to, our students—now given a taste of the importance of the wise use of science to society and the responsibility of the academic community to show the way—would not let us. The changes have not produced a quiet and peaceful life either on campus or in the large laboratory. But now we are taken seriously and have won our freedom to think fully and say what we believe. Whether or not that is good for the scientist, there is no turning back.

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Obviously the preponderance of this paper is fiction, including statements attributed to real people, whose tolerance of my liberties is herewith requested.

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