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Mathematics and the U.S. National Science Foundation

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Dans le contexte du débat actuel sur l'évolution du CNRS, le comité de rédaction de la Gazette *a sollicité cet article sur le subventionnement de la recherche mathématique par la National Science Foundation aux États-Unis.*

In November 1944, as the war was drawing to a close, President Franklin D. Roosevelt wrote Dr. Vannevar Bush, the Director of the Office of Scientific and Research Development, the wartime agency which served to mobilize civilian researchers, asking for a report on how the U.S. Federal government might promote scientific progress in the post-war era. Roosevelt felt that the lessons learned from this mobilization could be profitably employed in times of peace for the improvement of the nation's health, the creation of new enterprises bringing new jobs and the betterment of the national standard of living. He asked Bush to respond to four questions : How to foster the diffusion of scientific knowledge gained in the war ? How to deploy science against disease ? How to stimulate science in the public and private sector ? How to encourage the development of trained scientific talent ?

Bush's report, *Science — The Endless Frontier*, was published in 1945. His vision for the role of science and engineering in modern society serves as a blueprint for U.S. investment in scientific research and education even today. The central theme of the report was that the national health, economy and military security required the deployment of new scientific knowledge ; that the federal government had an obligation to ensure basic scientific progress and the production of trained scientific manpower ; and that a new federal agency should be established, funded and authorized to promote these ends.

The report stressed that the proposed agency had to preserve the « freedom of inquiry » needed to recognize that scientific progress results from the « free-play of free intellects working on subjects of their own choice, in the manner dictated by their curiosity for an explanation of the unknown. »

The report was very much based on Bush's wartime experience as well as his previous experience as a faculty member at MIT. He could envision how what seemed impractical and eccentric could have profound impact on weaponry, health and the economy. He firmly believed that the wartime production of

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technological miracles (atomic bomb, penicillin, etc.) had depleted the reservoir of fundamental knowledge and the supply of individuals capable of generating new knowledge. He was particularly aware of the inclination, due to America's practical culture, to foster applications of knowledge rather than advancement of knowledge. Prior to the war, government (agriculture, military) and industrial investment in research was ten times that available for academic research. Further, Bush felt to advance fundamental science it needed to be freed from the clutches of the military and to be centered at the universities under civilian control.

The report received an enthusiastic response from the media and the academic scientists. However, the response by Congress was not so enthusiastic and there was a desire for more government control than envisioned by Bush. In 1950, in response to the report, the National Science Foundation (NSF) was established and its mission was along the principles enunciated by Bush. NSF's charter called for it to concentrate on basic science and engineering. While a sister agency, the National Institutes of Health (NIH), was given the responsibility for health sciences. However, the lapse of time enabled the military to advance their funding of civilian research and for several decades the Office of Naval Research (ONR) had a much larger budget than did NSF. The ONR funded free inquiry research with the quiet understanding that if the Navy had needs, the civilian scientists should respond. The early part of my own career well illustrates the funding of pure mathematics by ONR. I am a number theorist. In the late forties, part of my graduate education was funded by ONR ; in 1952, I was offered a postdoctoral fellowship by both the NSF and ONR, and in the 1960's I had a number of postdoctorates funded by ONR.

Not to be outdone by the Navy, the Army and the Airforce also established offices to fund civilian researchers, although they had an emphasis on problems of interest to the military. The Defense Advanced Research Project Agency (DARPA) came later and only lately has funded mathematics. About the same time, it was decided to put the nuclear effort under civilian control and the Department of Energy (DOE) was established and assumed a major role for the funding of nuclear and high energy physics. DOE has a small mathematics program. The National Aeronautical and Space Agency (NASA) has funded space based observatories but no mathematics. Thus in short order there was a proliferation of agencies supporting civilian scientists at universities. Indeed, except for Mathematics and the Social Sciences, even today, NSF provides less than 40% of federal funding of academic researchers, quite opposite to Vannevar Bush's plan. About 15 years ago the National Security Agency (NSA) established a small grants program in mathematics. It is not unusual in the United States to have an initiative funded by several agencies and by several political units. This can be advantageous if one unit falls in disfavor or low interest.

DOE, NASA and the defense agencies have supported free standing research laboratories. Among them are the Naval Research Lab, Los Alamos National Lab, Lawerence Berkeley Lab, and NASA-Ames Lab. These have rather specific missions. None were mathematically oriented, although all had mathematical groups and most supported mathematics postdoctorates and had many mathematicians as consultants. In 1988, and 1990, the NSF had competitions to fund

Science and Technology Centers. These centers, limited in number, were established to attack a specific class of problems, were associated with a university and involved industrial collaborators. They had a maximum of eleven years of NSF funding. The Geometry Center at University of Minnesota and the Center for Discrete Mathematics and Computer Science at Rutgers University were mathematically oriented. Both of these have come to the end of NSF funding. The NSF did have another S & T competition in 1999 and it is doubtful that any mathematical center will be funded.

The cold war and in particular Sputnik led to substantial increase in federal funding of science and to increases in the NSF budget. By the mid-sixties essentially every active academic mathematics researcher had summer funding from some federal agency — however this situation did not long prevail. This emphasis on research in universities as well as the emphasis on training large numbers of scientists completely changed American universities and led to the creation of the research university. Prior to World War II research occurred in the major universities, but on a very small scale. It was not the dominant factor in determining promotions that it has become today. Funding of lab instruments fell to universities and private foundations.

Summer funding is perhaps a peculiarity of the United States. Until well into the twentieth century, the U.S. was an agrarian country ; indeed until about ten years ago its largest export has been agricultural products. As a consequence, many customs and practices have an agrarian origin. In earlier days, farm children were expected to help on the farm — even as late as 30 years ago, many school districts closed in October for the potato harvest. Hence, elementary and secondary schools only operated for 8 or 9 months and teachers were only paid for those months. This practice carried over to the colleges and universities and even today faculty are nominally paid only for the academic year, although they may be paid in 12 installments. Prior to the late fifties, science and engineering researchers sought summer consultantships in industry or other work. For academic research to flourish, it was highly desirable to support such in the summer, and hence federal agencies began to provide summer funding.

Included in the charge to both NSF and NIH was the development of scienctific manpower. In the 50's and 60's they did so by having national graduate fellowship competitions and by providing large training grants to leading departments. The result was that by 1970 the universities were producing more scientists than the market could support, especially since the large growth in postsecondary education enrollment had come to an end. This growth was due to substantial educational aid to veterans and to the increased birth rate immediately following the war. As a consequence of the over supply, the NSF ended its traineeship program and the emphasis shifted from funding education and research to only funding research. The lab sciences were able to make the case that they could not carry on their research without graduate and postdoctoral assistants and so their grants contained funding for such positions. The mathematicians couldn't or wouldn't make the same case and were content to provide support for graduate students via teaching assistantships. One consequence was the funding for mathematics didn't keep pace with that for the lab sciences and engineering. The use of graduate students to meet teaching needs led to an emphasis on selecting mathematics students with a strong interest and ability in teaching. This led the mathematics students to over focus on academic careers to the exclusion of other career opportunities.

Following the David Report of 1984, the NSF returned to supporting graduate students and postdoctorates in mathematics in a small way, and in 1998 the Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)[2] program was initiated and greatly increased such funding. Nevertheless, funding for graduate students and postdoctorates in mathematics still greatly trails that for the other sciences. In the last five years there has been a growing emphasis by the NSF on the integration of research and education and this is reflected in the goals of the VIGRE program. The VIGRE program provides support for research activities involving undergraduate students, graduate students and postdoctorates and seeks to create with the faculty a community of scholars with a minimum of walls between groups. It also seeks to broaden the education of mathematics students in the other sciences.

The scientific community was often quite critical of the Vietnam War and a fair number of researchers funded by the Defense agencies were quite outspoken. The net result was that Congress passed the Mansfield Amendment that limited the defense agencies to funding research directly related to their mission. In particular, the ONR had to end its funding of such areas as number theory, topology, geometry, and non-applied analysis. This loss of funding was not picked up by the NSF or other agencies.

Since the cold war, the defense agencies have steadily reduced their funding of mathematics to the point that the NSF now provides over 70% of the federal funding for mathematics. In the last two years, NIH has shown an interest in funding multidisciplinary research involving mathematics and this may reverse the discipline's growing dependency on NSF for funding. Presently, only one-third of active researchers in academic mathematics departments receive federal funding while two-thirds of the active researchers in academic physical science departments receive federal funding and an even larger percent do in engineering and the biological and medical sciences. Those mathematicians without funding do do research, but often in their spare time and except for small grants from their universities have little funding for travel or equipment. They are indeed very dedicated researchers who persist with little financial encouragement.

While the NSF has done a reasonable job in keeping to Vannevar Bush's ideal of free inquiry, the NSF has never been as apolitical as Bush sought or as mathematicians generally believe. In particular, in the last eight years essentially all increases in the NSF budget have been targeted toward areas the Office of the President sees as promoting the economic welfare of the nation. Thus, there has been funding for high performance computing, materials science, internet development, to name a few. All the increase in Fiscal Year 1998 was for Knowledge and Distributed Intelligence (KDI) and the requested increase in Fiscal Year 2000 is for Information Technology (network and software development, terraflop computer) and Biocomplexity. Mathematicians have had and do have a role to play in these targeted areas, but it is a supportive role and is not one

[2] Program Announcements for specific programs such as VIGRE can be found on the NSF/MPS/DMS web pages.

that warms the average mathematician's heart. KDI had three components — a major one being Computational and Mathematical Modeling. This emphasis on targeted research has undermined the funding of the core of most disciplines.

To obtain funding from NSF and NIH, the individual investigator or a team of investigators makes a proposal to a disciplinary division to work on a certain class of problems, describing the significance and probable impact of the proposed research and the method to be used in the attack. The proposal might call for support of graduate students, postdoctorates, consultants, equipment, as well as summer support of the senior researchers — usually proportional to academic salary.

The proposals are then reviewed by a peer group familiar with the proposed area of research. Finally, the Program Officers fund proposals they deem to be the strongest within the limits of their allocated budgets. Often there is negotiation as to the size of the budget.

Besides these individual investigator awards, the Division of Mathematical Sciences (DMS) funds some research conferences, several research institutes such as MSRI, IAS, IMA, a competitive postdoctoral program, and as of 1998, the VIGRE program which provides block grants to Departments for support of undergraduates, graduate students and postdoctorates. In every case there is a competition. For example, DMS is about to complete a recompetition for research institutes. The Foundation has a number of competitions that cut across disciplines, e.g., KDI.

Budgets for Divisions and programs are to a considerable extent based on history, with modest changes between programs reflecting changing quality of proposals. However, what is funded within a program changes rather dramatically over a five to ten year period reflecting new directions of research.

Proposed budgets for Divisions are in the domain of the Assistant Directors of the various Directorates and reflect suggestions of and negotiations with the Division Directors. There are seven research Directorates within NSF. DMS is in the Mathematical and Physical Sciences Directorate (MPS) which consists of five divisions : DMS, Chemistry, Physics, Astronomy, and Materials Research. The Assistant Directors makes budget proposals to the Director, who in turn arrives at a proposed budget. This is submitted for discussion to the Office of Management and Budget (OMB) of the Office of the President in June. Discussions over the next three months leads to a refined proposed budget. Between October and January, OMB with the President determine what the President will recommend in his budget message to Congress in late January. Congress disposes with these recommendations, as it seems fit, subject to Presidential veto. The NSF allocation is included in the Independent Agencies Appropriation Bill. The Independent Agencies include NSF, NASA, Housing and Urban Development (HUD), Veterans Hospitals and Americorp, a domestic analog of the Peace Corp. While funding for science is usually favorably received by both political parties, scientists are poor lobbyists and often science funding looses out to the pressure from veterans and from housing advocates. Once a bottom line budget for NSF has been determined, the Director determines the bottom line for each Directorate ; the Assistant Directors of the Directorates do the same for the Divisions and the Division Directors do so for the various Programs in the Division. The process from early discussions in the Directorates to program allocations takes about 22 months.

For Fiscal Year 1999, the NSF Operating Budget is $3.68 billion. In contrast, that for NIH is $15 billion. For Fiscal Year 1999, the Operating Budget for DMS will be $101 million. Approximately $15 million will go to support the VIGRE and the postdoctoral fellowship program ; $15 million will support graduate students and postdoctorates on individual awards, $6 million will support research institutes and the remainder will support individual investigators. Attached to any individual investigator award are funds which go to the university for costs incurred in research such as space, heat, light, janitor services, and library. Typically, that charge is about 30% of the grant but could be more or less depending on negotiations the university has had with the federal government.

Typically, NSF investigator awards provide senior investigators with 2/9ths of academic year salary for 2 months of summer research — it is presumed that the university pays for research during the academic year. For over a decade the DMS has provided the full 2 months of summer salary only for young researchers and for those senior researchers judged by NSF to be leaders and innovators in their field. Other DMS funded researchers receive less than 2 months of summer salary, usually one month. This policy is contrary to recommended NSF policy to fully fund those it funds, and was instituted in response to the demands of the mathematical community that more researchers receive at least some support. Acquiescing to these demands may have been a strategic mistake since it relieves pressure for greater funding of mathematics.

The DMS budget is the smallest of any of the divisional budgets within MPS, and DMS provides a larger percentage of the federal investment in that discipline than do the other divisions. Further, the mathematics academic community is larger than are those of the other MPS divisions. Part of this difference in budget is due to the need of the lab for sciences for significant investments in equipment. The underfunding of the mathematical sciences compared to other sciences has been debilitating. The mathematical community has not found an advocate that can make the case for more funding, in contrast to the other disciplines. Mathematicians have been ineffective in showing to the general populace that they are making the contributions Roosevelt saw for science during times of peace : improved wealth and health. One glimmer of hope lies in the fact that as science attacks more complex problems, mathematics must play a more essential role. If mathematicians choose to become involved in multidisciplinary research, the other sciences might become advocates for mathematics.