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REPORT OF THE NATIONAL SCIENCE BOARD

TO THE

SUBCOMMITTEE ON SCIENCE, RESEARCH AND TECHNOLOGY

OF THE COMMITTEE ON SCIENCE AND TECHNOLOGY

U. S. HOUSE OF REPRESENTATIVES

REGARDING PEER REVIEW PROCEDURES

AT THE

NATIONAL SCIENCE FOUNDATION

NOVEMBER, 1977

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TABLE OF CONTENTS

INTRODUCTION

The report of the Subcommittee on Science, Research and Technology of the Committee on Science and Technology of the U. S. House of Representatives raised a number of concerns about peer review procedures at the National Science Foundation (NSF). Specifically, the Subcommittee recommended that the National Science Board (NSB) should:

1. Study the support of innovative research and report to Congress.

2. Study the support of young scientists and report to Congress.

3. Study the funding of research at undergraduate-teaching institutions without graduate departments (colleges) by the Foundation and report to Congress.

4. Study the extent to which the Foundation should rely on peer panel review and report to Congress.

5. Establish an internal Foundation program to monitor problems arising from the mismatch between the size of the scientific community and the amount of Foundation funds available for support of that community, and should report periodically to Congress.

6. Study the question of whether the National Science Foundation should have formal procedures for considering appeals of decisions made on award applications and should report to Congress.

7. Study the effects of publication of the list of reviewers used by the Foundation and consider whether publication of the list in a less aggregated form might be desirable.

8. Collect further information concerning effects on the peer review system of the level of confidentiality in which peer reviewers' names and verbatim comments are held. The Board should report the information and any conclusions that may be drawn from it to Congress. Further changes in the level of confidentiality of the Foundation's peer review system should be made slowly if at all.

The Board has now completed its studies and herein transmits its findings to the Congress.

The peer review process is used to select for funding those projects offering both the highest quality of science and the greatest prospect for resultant benefits. The Board is particularly aware that the peer review process should be open, objective, and free from bias, especially in this era of increased competition for research funds. The Board also believes that the peer review process should continue to preserve the traditional benefits of peer evaluation of intrinsic scientific merit. At the same time, it is essential that the research community perceive the peer review process to be fair, and equitable as well as accessible to all qualified persons--both as research applicants and as reviewers. These are longstanding and continuing concerns of the Board.

During the past 2 years, the Board has recommended a number of means to strengthen the Foundation's peer review process. Some of these were provided as informal suggestions to individual programs; others, however, have resulted in the establishment of formal policies and practices within the Foundation. During the past 2 years, the Board and Foundation have made the following specific changes in the peer review process:

- o Establishment of a formal reconsideration process within each of the scientific directorates, with right of final review by the Deputy Director of the Foundation;

- o Annual publication of the names and institutional affiliations of all reviewers;

- o Provision to applicants of information on the basis for NSF actions and, when requested, verbatim comments of the peer reviewers;

- o Development of an extensive list of names of qualified individuals in 4-year colleges who are willing to review proposals and serve on advisory panels, as well as administrative procedures to monitor the utilization of reviewers from 4-year colleges;

- o Publication of the entire Grant Policy Manual in the Federal Register, with copies available upon request, as a means to further inform the research community and the public of the Foundation's policies and procedures;

- o Initiation of a study to determine the effectiveness of reviewing proposals in which all references to the proposers and their institutions remain unknown to the reviewer.

These and other recommendations are contained in formal expressions of policy and practice by the National Science Foundation Important Notice of January 1976 (see Appendix B) and National Science Board Resolutions dated June 1975 (Appendix C) and March 1977 (Appendix D).

To monitor the status of the various scientific disciplines the Board has established a formal planning environment review which is designed to link this information to the Foundation's long-range planning and budgeting processes. The Foundation has also established an evaluation system whereby each program's planning and grant award decisions are reviewed periodically by an outside group of scientists.

During the course of the Board's studies of the eight areas of concern identified by the subcommittee, the Foundation requested that the National Academy of Sciences (NAS) undertake a detailed assessment of the NSF peer review system. Although the NAS study has not yet been released, a discussion of the preliminary findings by Cole, Rubin, and Cole in Scientific American states:

> Our results to date find little evidence in support of the main criticisms that have been made of the peer-review system. On the contrary, we have tentatively concluded that the NSF peer-review system is in general an equitable arrangement that distributes limited funds available for basic research primarily on the basis of the perceived quality of the applicant's proposal. In particular, we find the NSF does not discriminate systematically against noneminent scientists in ways that some critics have charged.[1]

The Board's findings are summarized below:

1. Study the Foundation's Support of Innovative Research

- A study of four fields of science identified some 85 significant advances made during the past 20 years. The NSF supported, wholly or in part, the following percentages of these advances:

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1. Cole, S., Rubin, L., and Cole, J. R., "Peer Review and the Support of Science," Scientific American, October 1977. A copy of this article appears in Appendix E.

in mathematics	50%
in earth sciences	35%
in astronomy	29%
in chemistry	12%

- o The above percentages of NSF support to innovations are larger than the NSF portion of basic research support in each of the respective fields.
- o University investigators accounted for over 70 percent of the significant advances during the past 20 years.
- o Only about half of the significant advances resulted directly from explicit research proposals; the other half came as an unexpected event or from a general line of research.

2. Study the Foundation's Support of Young Scientists

- o There will be increasingly severe competition among young research scientists and continued diminishing demand by academic institutions for faculty appointments until at least 1990.
- o The ability of young scientists to secure research support tends to vary from discipline to discipline.
- o Specialized NSF efforts aimed at establishing young scientists in emerging research areas(e.g., the Cellular Biology Program) have been successful, but indicate that case-by-case development is required.

3. Study Foundation Funding of Research at Undergraduate Teaching Institutions Without Graduate Departments

- o Many members of college faculties are capable of highly productive research.
- o The success ratio of awards to applications is about the same among all types of institutions.
- o Additional efforts are being made to increase the use of college faculties as reviewers and advisory group members.

4. Study of the Extent to Which the Foundation Should Rely on Peer Panel Review

o The Board and Foundation have completed some peer system studies, e.g., Perceptions of the NSF Peer Review Process (Hensler, 1976) and Reviewer and Proposer Similarity and Its Effect on Award Decisions (Office of Planning and Resources Management, 1976) and others are in progress. The Board has given careful attention to the peer review system at a number of its meetings, and two comprehensive resolutions have resulted (Resolution on Peer Review Information, June 1975, and Policy Regarding Peer Review, March 1977).

o Foundation programs in the biological sciences rely significantly (85 percent of proposals) on a combined individual mail and panel review system for proposals. Since the end of 1975, six additional advisory panels have been established in this area, and all major program activities now have an advisory panel that is used for proposal review. Foundation programs in the mathematical, physical, and engineering sciences rely heavily (90 percent of proposals) on ad hoc mail reviews for proposal evaluation.

o No single system -- be it panel review or individual peer review -- is adequate for the diverse set of NSF programs, which ranges from small basic and applied research projects to those that are large and complex.

o Whether the proposal evaluation is accomplished by individual reviewers or via a combined individual/panel review, the NSF program manager makes the recommendation whether or not to fund a proposal.

5. Establish an Internal Foundation Program to Monitor Problems Arising From the Mismatch Between the Size of the Scientific Community and the Amount of Funds Available for Support

o There is a continuing problem of disparity in academic science between resources and claimants.

o The Board, recognizing the need for improved quantitative analysis, has sought to develop indicators, and also, to obtain more complete analysis of trouble spots in science through

Science Resources Studies -- the main source of descriptive data concerning the Nation's science base

Science Indicators -- a periodic quantitative description of some output and input trends

Science at the Bicentennial, A Report from the Research Community, Report of the National Science Board 1976 -- a self-analysis by research practitioners of trouble spots in science.

State of Academic Science, The Universities in the Nation's Research Effort by Bruce L. R. Smith and Joseph J. Karlesky -- a recent special study that documents a deteriorating relationship between the academic community and the Government.

- The Board has instituted a new planning process (the Planning Environment Review) which is designed to strengthen the linkage between programmatic needs and longer term trends in science.
- The Foundation has established outside reviews for each of its principal research activities as a means of assessing the quality of program decisionmaking under conditions of limited resources.

6. Study Whether the NSF Should Have Formal Procedures for Considering the Appeal of Decisions Made in the Peer Review Process

- On January 27, 1976, the Foundation instituted a formal procedure for reconsideration of adverse actions on proposals that includes appeal to its Deputy Director.
- NSF policy now requires that the proposer be given specific information regarding the basis for any adverse decision, including verbatim comments from the peer review.
- The Foundation has determined that there is a need for better understanding of its peer review process by the academic community. It is meeting this need through various publications, including a listing of reviewers and their institutions, and arrangements for expanded participation by 4-year college faculty members in the peer review process.

7. Study the Effects of Publication of the List of Reviewers Used by the Foundation and

8. Collect Further Information Concerning Effects on Peer Review System of the Level of Confidentiality in Which Peer Reviewers' Names and Verbatim Comments Are Held

- o NSF has published "Listing of Peer Reviewers Used by NSF Divisions October 1975-September 1976", which provides the research community with information regarding the reviewer base, and will continue to publish such a list annually.

- o The Board has established a policy of providing applicants reviewers' comments verbatim but will preserve the anonymity of reviewers in order to continue to secure candid and frank evaluations.

- o A Foundation study of 75,000 reviews found little relationship between (academic) status of applicant's institution and reviewers.

- o The National Academy of Sciences is conducting a detailed study to try to determine the desirability and feasibility of peer review in which the names and institutional affiliations of proposers remain unknown to the reviewer.

PEER REVIEW

I. PEER REVIEW SYSTEM

SUBCOMMITTEE RECOMMENDATIONS AND NSB FOCUS OF ACTION

The Subcommittee on Science, Research, and Technology recommended that the National Science Board (NSB) study eight specific areas relating to the National Science Foundation's (NSF) use of peer review (see Appendix A). This paper focuses on four of these areas--those relating to the research community's perception of objectivity and openness in the peer review process. In the words of the subcommittee, the NSB was requested to:

- Study the extent to which the Foundation should rely on peer panel review and report to Congress.

- Study the question of whether the National Science Foundation should have formal procedures for considering appeals of decisions made on award applications and should report to Congress.

- Study the effects of publication of the list of reviewers used by the Foundation and consider whether publication of the list in a less aggregated form might be desirable.

- Collect further information concerning effects on the peer review system of the level of confidentiality in which peer reviewers' names and verbatim comments are held. The Board should report the information and any conclusions that may be drawn from it to Congress. Further changes in the level of confidentiality of the Foundation's peer review system should be made slowly if at all.

This paper describes how the NSF peer review system operates, current practices concerning the use of panels for review, mechanisms for appeal, and means for respecting reviewer confidentiality.

During the past several years, the NSB has conducted a thorough examination of the Foundation's peer review system. Based on this examination, the Board has made a number of recommendations for improving the peer review process. These recommendations were adopted into formal expressions of policy and practice by the National Science Foundation Important Notice of January 1976 (see Appendix B) and National Science Board Resolutions dated June 1975 (see Appendix C) and March 1977 (see Appendix D). These policies provide individual proposers greater access to information regarding the basis for NSF actions and, where necessary, further means for discussing adverse actions with Foundation officials. So that the Board can better insure the adequacy of the review process, it has requested that the NSF provide specific information regarding the names and organizational affiliations of proposers and the numbers of formal appeals initiated in each program area. On July 29, 1977, the Foundation published its entire Grant Policy Manual in the Federal Register and will make copies available to all upon request.

Board examination of the peer review process is ongoing. A National Academy of Sciences (NAS) study of the proposal ratings procedures is almost complete.[1] A recently awarded contract has enabled the NAS to expand its study to include a determination of the consequences (if any) of peer review in which the name of the individual proposer and organization remain unknown to the reviewer.

Characteristics of the NSF Peer Review

The Foundation considers approximately 26,000 proposals for funding each year. Because the proposals vary widely based on the nature of the proposed research, they require different kinds of evaluation. All proposals, however, are reviewed through a peer review process designed to solicit evaluation by experts regarding the quality of the proposed research and its intrinsic merit to the advancement of science. The sequence of steps to review a proposal was detailed in the NSF testimony to the Senate Subcommittee of the Committee on Appropriations (HR 7554, pp. 210-250). The decision to fund an individual proposal is based on the individual program manager's recommendation, followed by reviews by the appropriate section head, Division Director, and, at times, the Directorate Assistant Director. The recommendation is also reviewed by an Action Review Board composed of Foundation officials external to the specific program area to which the proposal applies.

The Foundation uses three principal methods of peer review: (1) *ad hoc* mail review; (2) panel review by an assembled group of experts; and (3) a combination of *ad hoc* mail and panel review. Use of these forms of peer review varies among the NSF directorates as detailed in Table I.1.

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1. Although the NAS study has not yet been released, the preliminary findings are discussed in "Peer Review and the Support of Science," *Scientific American*, October 1977. A reprint of this article appears in Appendix E.

Table I.1--NSF Proposal Review Methods By Directorate

October 1976 - September 1977 (percentages)

	AAEO	BBS	MPE	RA	SE	STIA
Ad Hoc Mail Review Only	61	13	90	92	1	80
Combined *Ad Hoc* Mail and Panel Review	35	85	10	3	50	3
Panel Review Only	4	2		5	49	17
Number of Proposals Reviewed FY 77 through 8/31/77	1,823	4,174	5,979	774	2,713	546
Average Number of Reviewers per Proposal	6.5	6.2	4.2	6.5	8.0	6.5

AAEO = Astronomical, Atmospheric, Earth, and Ocean Sciences
BBS = Biological, Behavioral, and Social Sciences
MPE = Mathematical and Physical Sciences and Engineering
RA = Research Applications
SE = Science Education
STIA = Scientific, Technological, and International Affairs

Ad hoc mail reviewers are chosen by the program director following policies set forth in the Board resolution of March 1977 (section III). Advisory committee (panel) members are appointed by the Assistant Director. Efforts are made to utilize the broadest possible cadre of reviewers and panelists. The list of qualified reviewers is updated continually. Membership on advisory panels is limited to 2- or 3-year terms.

For *ad hoc* mail review, the program manager selects 3 to 10 reviewers deemed qualified to evaluate the proposal. These reviewers are sent copies of the proposal, reviewing forms, and general criteria for use in evaluating the proposal. The reviewers are requested to provide (1) an objective evaluation of the proposal (from excellent to poor) and (2) written comments with regard to the stated criteria.

For panel review, panelists are sent a package of individual proposals several weeks before the appropriate panel meeting and asked to consider the package of proposals. These panels, composed of 5 to 12 individuals, usually meet 3 times a year for 1- to 3-day sessions. At the meetings the members consider any mail reviews, compare their assessments, and then make an overall panel recommendation. When the number of proposals is large, the program director requests selected panel members to act as "primary reviewers" of each proposal. Any panel member, however, may review any proposal.

The Foundation uses various combinations of *ad hoc* mail and panel review procedures to accommodate the needs and traditions of the various scientific disciplines and to correspond more closely to other agencies' means of conducting reviews. In the physical sciences, *ad hoc* mail review has been and continues to be the dominant means by which the MPE directorate conducts reviews. Within the biological and social sciences, it is customary to place heavy reliance upon detailed discussions of individual proposals by assembled panels, supplemented by *ad hoc* mail reviews. During the past 2 years, the BBS directorate has sought to increase the use of panel reviews, so that, at present, nearly all the BBS programs use review panels.

The number of reviewers asked to consider each proposal also varies (see Table I.1). In the MPE directorate, which is highly dependent upon mail review, an average of 4.2 experts reviews each proposal. For panel review, the number of reviewers (including panelists) is somewhat larger. STIA directorates, with their large numbers of interdisciplinary or multidisciplinary proposals, require the most reviewers. In certain instances, such as those involving the support of major laboratories or facilities, two or more panels may be sent to the site and the Board itself and its program committee may participate in review discussions.

Evaluation of Review Procedures

The Subcommittee recommended that the Board "Study the extent to which the Foundation should rely on peer panel review and report to Congress." In March 1977, the Board issued a formal resolution regarding Foundation peer review (see Appendix D). The resolution requires external peer review of all formal proposals for funding (with only a few exceptions, such as proposals submitted in response to formal solicitations that are governed by Federal procurement regulations). Each Foundation program must select a "primary method" for peer review as the minimum review to be accorded all proposals in that program. The method can be *ad hoc* mail review, review by an assembled panel of peers, or a combination of the two. (The primary method can be supplemented with additional reviews, site visits, and so forth, as needed.)

The justification for the Board's decision not to make panel review mandatory was the finding that the quality of Foundation decisionmaking in the various programs does not appear to vary with review techniques. Comparisons made among programs by senior Foundation staff members, NSF advisory committees, and Board members do not suggest that any one peer review procedure is preferable. It is believed that to impose uniformity would disturb long-established evaluation patterns that are well understood in the various scientific communities. Panel review is most successful when considering proposals that are relatively homogeneous in format and scope and when interchanges among experts in different areas are required (examples include Engineering Research Initiation Grants, Predoctoral Fellowships, Comprehensive Assistance to Undergraduate Science Education (CAUSE), and the many "special projects" and RANN proposals that deal with complex, often interdisciplinary and highly heterogeneous proposals). Competent review of proposals of this type often requires site visits, numerous *ad hoc* specialist reviewers, interagency discussions, and other appraisal methods. A panel suitably constituted for review of a specific interdisciplinary proposal would rarely be appropriate for others.

Ad hoc mail review provides access to specialized knowledge not usually available from a balanced panel. It is being used increasingly in conjunction with panels to obtain expert assessments of a particular research approach. Because the Board recognizes the wide range of proposals that are submitted to the Foundation, it permits the Foundation to select the method of review most appropriate to the nature of the research.

To complement these review mechanisms, advisory groups or panels are used to determine an optimum program balance and to define scientific priorities. They do not review individual proposals. Advisory panels also attempt to facilitate interaction between the Foundation and the scientific community by providing a direct channel of communication between research supporters and practitioners.

The costs of advisory panel operations of peer review processes fall directly upon the research community. The Foundation does not compensate _ad hoc_ reviewers financially. Most research panel members (and usually site visitors) are paid a modest daily honorarium to serve on the panel (they also receive travel allowances). Members of science education "one-time" panels are paid travel compensation but receive no honoraria. In FY 1977, the estimated costs paid for transportation and honoraria for advisory panels used by the NSF totaled about $900,000. Most researchers consider participation in the NSF review process an honor and professional responsibility and participate willingly.

Formal Appeals Procedures

This section summarizes actions arising from the Subcommittee recommendation that the Board:

> "Study the question of whether the National Science Foundation should have formal procedures for considering appeals of decisions made on award applications and should report to Congress."

On January 27, 1976, the Director of the Foundation instituted a formal procedure for the reconsideration of adverse actions on proposals (see Appendix B). This procedure requires that applicants be given certain explicit information regarding the basis for the decision as well as permission to ask Foundation officials to reconsider adverse actions. The process provides for three levels of review within the Foundation up to and including its deputy director.

The steps of the formal procedure are as follows:

1. Upon request, the program director must show cause for an adverse action by providing the applicant with information "concerning the basis for NSF action including, when requested, verbatim comments of the peer reviews." Only the name and other identifying data of individual reviewers may be deleted. The program director must afford the applicant an opportunity to respond to critics' comments. If the situation cannot be resolved to the satisfaction of the applicant, then,

2. The applicant may formally request in writing that the proposal be reviewed and reconsidered by the appropriate assistant director. Failing satisfactory resolution,

3. The home institution of the applicant may formally request that the proposal be reconsidered by the Deputy Director of the Foundation.

On March 30, 1977, the Board codified and extended the Foundation's policy regarding the use of peer review by requiring that "...the primary method of peer review in each program, including the evaluation criteria reviewers are requested to consider in reviewing proposals, shall be suitably announced."

The Board notes that a liberal "resubmissions" policy is an important adjunct to the review procedure. An effective peer review system makes use of and encourages the resubmission of research proposals. Most scientists are willing to assist their colleagues in improving proposals, and most researchers--after taking into consideration the technical comments of peers--will modify proposals. This feedback process is an important element in the operation of a peer review system and one that provides for substantially strengthened research proposals.

In a special study prepared for the NSB,[2] 1,552 randomly selected reviewers and 3,256 applicants were asked, "Would you approve or disapprove of NSF setting up a formal standing appeals panel in which prospective principal investigators could submit a written appeal in response to a decision on funding which they thought was unfair?" Three-quarters of the respondents said they would favor such an appeals system. Most respondents felt such an appeals mechanism would provide a remedy for mistakes and misjudgments. The principal reason given by those opposed was that any such formalized arrangement would further bureaucratize the peer review process.

Much of the interest in an appeals system may represent a desire for more information regarding deficiencies of the initial proposal. Foundation peer review procedures now provide for more detailed feedback, including verbatim comments of the reviewers. In addition, the Foundation now publishes a list of reviewers and their institutions aggregated by directorate. These new measures have done much to supply applicants information that they felt was not previously available. In addition, the Foundation has sought to enlarge the cadre of available reviewers and to make it more representative of nondoctorate institutions.

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2. Hensler, Deborah R., "Perceptions of the NSF Peer Review Process," National Science Board, December 1976.

The Board intends to monitor Foundation progress in expanding its review base and has requested that the Foundation provide it a list of all reviewers used by each division and office as well as statistical analyses of the peer review process.

In the year following the establishment of the reconsideration procedure, a total of 46 appeal actions were initiated throughout the Foundation. This is a very small fraction of total NSF actions. In those program areas (such as RANN) where extensive use is made of preproposals, significantly fewer decisions were appealed. The Board believes that, with a greater awareness of the right of appeal, and with continued increasing competition for research awards, it is likely that formal requests for reconsideration will increase.

Reviewer Identification and Confidentiality

The Subcommittee recommended that the Board:

- o Study the effects of publication of the list of reviewers used by the Foundation and consider whether publication of the list in a less aggregated form might be desirable.

- o Collect further information concerning effects on the peer review system of the level of confidentiality in which peer reviewers' names and verbatim comments are held. The Board should report the information and any conclusions that may be drawn from it to Congress. Further changes in the level of confidentiality of the Foundation's peer review system should be made slowly if at all.

The most thoroughly discussed issue of the subcommittee hearings centered on confidentiality--the extent to which openness in the decisionmaking process can co-exist with the effective evaluation of grant applications. Conflict arises because of the dual needs of providing the individual proposer information relevant to the Foundation's decision and, at the same time, maintaining the anonymity of individual reviewers. Individual reviewers and members of peer panels have long argued that anonymity is essential to obtaining candid reviews. They have expressed severe reservations regarding the release of signed comments. Many have indicated that they would withdraw from any review process that entailed direct reviewer identification. Peer panel members usually have refused to release verbatim comments traceable to individuals, but have willingly signed their names to a joint panel recommendation. The Board understands these concerns and believes that the new policy of providing unsigned verbatim reviewer comments strikes the best available balance between confidentiality and complete information.

Confidentiality is also a concern of applicants. Several maintain that an unbiased review process can be achieved only if all information regarding the identity of proposers and their affiliations is secreted. To assess the potential for prejudice toward applicants, the Foundation has asked the NAS to conduct an experiment to determine the effects and desirability of reviewing proposals in which the names and affiliations of applicants remain unknown to the reviewers. Proposals from four representative program areas will be reviewed in three different manners: (1) following the usual Foundation peer review process, (2) by a suitably constituted panel of experts from the NAS, and (3) by mail review in which the name of the proposer and home institution are removed. Results of the three forms of review will then be compared to determine what differences in results, if any, emerge.

The Foundation has also sought to determine the potential for favoritism on the part of reviewers due to similarities between the reviewer and applicant. An internal NSF study of 75,290 reviews made during FY 1974 found:

- little to no discernible relationship in ratings traceable to the locations of the proposer's institution and the reviewer's institution and,

- little effect on ratings from the relationship between the academic status of the proposer's institution and the reviewer's institution.[3]

To enable research applicants to judge the quality of the reviewers utilized, the Foundation now publishes the names and institutions of all reviewers who have participated in reviews of Foundation proposals during the past year. The first publication, "Listing of Peer Reviewers Used by NSF Divisions, October 1975 - September 1976," is available and an updated version is being prepared. Data are aggregated by directorate.

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3. National Science Foundation Office of Planning and Resources Management, "Reviewer and Proposer Similarity and Its Effect on Award Decisions," March 1976.

INNOVATION

II. INNOVATION

SUBCOMMITTEE RECOMMENDATIONS AND NSB FOCUS OF ACTION

The Subcommittee recommended that the National Science Board "Study the support of innovative research and report to Congress." The subcommittee further specified that:

> The study should include at least: (1) a detailed analysis of the issues, starting with those covered in this report, (2) a retrospective look at some major scientific innovations--with emphasis on this century--how they were funded and how they came to be accepted, (3) an assessment of the adequacy of decision-making procedures used by National Science Foundation programs for finding and funding innovative research, and (4) recommendations, if necessary, for modified procedures or new programs designed to ensure that innovative research is funded.

This paper reports the results of an effort to determine the NSF's role in funding research leading to innovations. The study identified a sample of 85 significant advances in 4 disciplines made during the past 20 years and found that NSF support of these innovations exceeded the NSF portion of Federal funding for basic research in each field. Specifically, the NSF supported wholly or in part the following innovations:

In mathematics	50 percent
In earth sciences	35 percent
In astronomy	29 percent
In chemistry	12 percent.

RESEARCH DESIGN AND METHODOLOGY

The research design for studying the history of innovations included an attempt to identify the degree of Foundation support in research innovation. Theoretically, the design concept was simple; the objective was to identify both the significant innovations in a discipline that have taken place since the Foundation's inception and the degree to which the Foundation supported the development of these innovations. Operationally, however, the concept became complicated. There was uncertainty as to what constituted innovations and what represented support.

Designation of significant innovations within each discipline was done by researchers active in the respective fields. The Foundation staff selected this group of scientists based on recommendations from sources such as NSF program staff members, editors of major journals, and the relevant section of the National Academy of Sciences. About 30 individuals were approached in each of the 4 fields. The key portion of the request for assistance mailed to these individuals read as follows:

> We would like to obtain from you a listing of what you consider to be the most significant innovations since about 1955 in the field of ____________________, with special attention to those parts of the field most familiar to you. (We hope you will come up with about 6 to 10 items.) In your consideration, please be sure to include significant:
>
> theoretical developments
> empirical findings and discoveries
> developments in instrumentation
> developments in analytical methods.
>
> An innovation should be considered significant to the extent that it has contributed to, or itself constitutes, a major conceptual, instrumentational or analytical advance in the field.

The experts were thus asked an open question that left a major term, "significant innovation," undefined. This approach of allowing for increased subjectivity seemed superior to a more limiting questionnaire, and resulted in a wide range of responses. The initial mailing was followed by reminders. In a few cases, additional individuals were identified and contacted in an effort to achieve balance among subfields within a discipline. Table II.1 illustrates the solicitation response and indicates the number of outside opinions on which the lists of innovations were based.

In view of both the number of innovations cited by some respondents and the mixed nature of the particular advances identified, it was decided to limit the analysis to those innovations mentioned by two or more experts. Table II.1 shows these to be 20 percent of the total number of innovations identified (85 out of 426). Because such small numbers make statistical inference difficult, a validity check was performed by conducting a parallel analysis of the once-mentioned innovations in chemistry. The results of this analysis appear on pp. II-20.

The lists compiled for each discipline should not be considered definitive; they both contain and omit specific items that could be

Table II.1--Innovation Study Sample, Returns and Field

	Astronomy	Chemistry	Earth Sciences	Mathematics	Total
No. of scientists queried	28	30	30	31	119
Total no. of scientists providing listings	16	13	21	17	67
Total no. of innovations mentioned	94	74	140	117	426
No. of innovations mentioned by at least two scientists	21	17	29	18	85
Total no. of investigators mentioned	218	130	261	177	786
No. of investigators affiliated with innovations mentioned by at least two scientists	55	24	51	22	152

viewed differently by other competent authorities. Although there may be disagreement with some of the items, the composite choice probably does capture an accurate sample of the advances in each field. As a check on this, a comprehensive review was commissioned of significant developments in each discipline over the past 20 years. Papers were prepared by researchers or writers who were familiar with the content of each field.[1] These papers varied in length from 50 to 100 pages and provided fairly rich detail on a broad range of scientific advances in each field. The papers were used as support materials to assist the NSF staff in collating and correlating the over 1,000 pages describing innovations submitted by the research practitioners.

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1. These papers are: "A Survey of Mathematical Research, 1950-1975," prepared by Lynn Steen, Professor of Mathematics, St. Olaf College; "The Earth Sciences, 1956-1976," prepared by Ursula Marvin, Research Scientist, Smithsonian Astrophysical Observatory; "Discovering the Universe: Major Developments in Astronomy and Astrophysics During the Past Quarter Century," prepared by William J. Kaufman III, Glendale, Calif., and "The Development of the Field of Chemistry, 1950-1976," prepared by George Kauffman, Professor of Chemistry, California State University at Fresno.

As it turned out, 66 of the 85 innovations (78 percent) mentioned by 2 or more of the expert panelists were specified in the history papers as significant developments. By field, the percentages were: astronomy (81); chemistry (76); earth sciences (66); and mathematics (94).

In summary, although the innovations lists cannot be considered definitive statements of progress in each field, they do represent an accurate sampling of progress and innovation and provide an adequate basis for examining the Foundation's role therein.

The NSF Record in the Support of Major Innovations in Science

Relevant Foundation activity was identified by a review of grant records. All basic research grant files were searched for the names of investigators identified by the outside experts as producers of innovations. This procedure was followed for each discipline.

The search for Foundation funding of identified innovators was based on computer review of existing grant records on file for the period 1968-1976, and review of specially created files for the period 1952-1967. Because the use of old and existing resources was coupled with a computer search using investigator names, some errors were inevitable. Although results were reviewed and checked by knowledgeable program staff members, it is possible that the results misstate the actuality to some minimal degree. Any such error would be in a conservative direction, however, resulting from the exclusion of grants to investigators due to some quirk of recordkeeping or computer search. Another significant source of error could have derived because the research design would not have identified Foundation-financed facilities used in the course of research leading to innovation. In both the fields of astronomy and earth sciences, for example, there is some probability that Foundation-financed facilities or instrumentation played a role that would not necessarily be revealed by examining the funding source for the individual project.

Telephone Interviews With Project Investigators

In order to arrive at a clearer understanding of the circumstances of the research and sources of support, a telephone survey of the investigators was conducted. This survey sought to obtain information on how the discovery came about--whether, for example, the discovery was the intended object or unintended result of the research project--and what sources of funding had been solicited for the project.

Of the total of 152 investigators associated with the 85 major innovations, it was determined that there were 85 principal investigators or persons primarily responsible for obtaining funds. Of these 85, 59 were contacted and interviewed. (Twenty-four were not contacted because they were either deceased or living in foreign countries. The remaining two could not be contacted despite repeated attempts.) Where the principal investigator could not be contacted, at least one other investigator affiliated with the innovation was interviewed to obtain information. Because of possible problems of recall, the telephone information on sources of support was checked against the source of support reported in the publications.

ANALYSIS AND RESULTS

Patterns of Support for the Innovations

The patterns of NSF and other sources of support for the innovations identified are shown in Table II.2 by field of science and type of institution at which the innovation took place. The table reports instances of support for a given innovation. Thus, in astronomy, though there were 21 innovations, 23 instances of support are shown. While the numbers are small, the disciplines show distinct patterns of support that are clearly related to the overall patterns of research support for the disciplines. Astronomy innovations derive overwhelmingly from federally supported projects. Federal agencies provided support for over two-thirds of the earth sciences and mathematics projects and for a little over half of the chemistry projects. Industry was a very significant funder of major innovations in chemistry (nearly one in three) and made a small contribution to earth sciences, but none to mathematics. Private foundation support was highly significant in mathematics (mostly Sloan Foundation fellowships), and played some role in chemistry, a small role in earth sciences, and none in astronomy. Research funded solely by the university at which the scientists held an appointment was negligible in all fields except chemistry.

Universities were the predominant locales in which major innovations were produced. In mathematics they were the sole performers. Nearly half of the innovations in astronomy occurred in federally funded research and development centers (FFRDC's) and Government laboratories. Nearly one-third of the chemistry innovations took place in industrial settings; most earth science projects were conducted outside universities.

The NSF incidence of support for all innovations identified ranged from a high of 50 percent of the innovations in mathematics, to 35 percent in earth sciences, to 29 percent in astronomy, and to a low of 12 percent in chemistry. If the foreign and industrial innovation locales are

Table II.2--Sources of Support for Innovations Mentioned by Two or More Panelists

Performing Institutions	Astronomy (21)* NSF	Other Gov't	Foundation	Institutional	Industry	NA	TOTAL	Chemistry (17) NSF	Other Gov't	Foundation	Institutional	Industry	NA	TOTAL
University	3	6		1			10	2	7	3		1		13
Government & FFRDC	3	5					8		1					1
Industry		1			2		3					5		5
Foreign						2	2						3	3
TOTAL	6	12		1	2	2	23	2	8	3		6	3	22

Performing Institutions	Earth Sciences (29) NSF	Other Gov't	Foundation	Institutional	Industry	NA	TOTAL	Mathematics (18) NSF	Other Gov't	Foundation	Institutional	Industry	NA	TOTAL
University	9	10	2	2	1	1	25	9	4	7	2		2	24
Government & FFRDC	1	2					3							
Industry					3		3							
Foreign						5	5						3	3
						2	2							
TOTAL	10	12	2	2	4	8	38	9	4	7	2		5	27

*Figures in parentheses indicate number of innovations mentioned by two or more panelists.

isolated and only NSF's traditional clients, i.e., universities, FFRDC's, and Government laboratories, are considered, NSF's contribution to the major advances in each field becomes slightly larger. In summary, NSF's direct support of projects that resulted in major innovations varied considerably by field.

NSF's Share of Federal Support for the Fields

The above figures, of course, are in part a function of the degree to which the innovative investigators actually applied to NSF for support for their work. From the telephone survey of principal investigators, it was determined that in only one case of innovation not supported by NSF the investigator had attempted unsuccessfully to obtain NSF support. Those investigators not supported by NSF said they had not applied to NSF because they had adequate sources of funds.

NSF's increasing share of the total Federal support for academic R&D in the four fields is described by the data in Tables II.3 and II.4. Table II.3 shows the relative involvement of NSF in Federal support of basic research in the four fields. In all four fields, NSF's share of the total virtually doubled between 1963 and 1976. While NSF provided nearly half of all Federal funds for support of basic research in mathematics in 1976, the Foundation provided between one-fifth and one-quarter of Federal support for basic research work in chemistry, astronomy, and earth sciences.

Given the increasing proportion of NSF's share of total Federal support, it would seem logical to suppose that NSF's share of support of major innovations also should rise. Table II.4 shows that this is indeed the case in three of the four disciplines. In mathematics, however, NSF's rate of direct support of innovations dropped from nearly 60 percent in the period 1950-1968 to 35 percent in the period 1968-1976.

When all four fields are considered together, NSF supported 20 percent of the pre-1968 innovations and 67 percent of the innovations from 1968-1976. Both of these figures exceed the NSF share of Federal funding for basic research in these areas during these time periods.

Relationship of Innovation to Project Funding Rationale

The data and discussion above emphasize the correlation between NSF support and projects that resulted in major advances. Although this could be attributed to the ability of agency program managers to select proposals likely to result in innovation, this is not the case. Table II.5 shows the results of telephone interviews with the principal investigators of innovative projects. These interviews were conducted to determine, among other things, whether the project funds were solicited with an explicit

Table II.3--NSF Percentage of Federal Obligations for Basic Research, Selected Fields and Years

	Astronomy	Chemistry	Earth Sciences	Mathematics	Total All Four Fields
1963	12	12	10	27	14
1967	14	19	20	29	19
1969	13	18	13	30	17
1971	19	17	11	33	18
1973	23	20	20	39	23
1975	18	26	28	47	26
1976	20	23	25	47	26

Table II.4--NSF Share of Innovations: 1950-67, 1968-76

	Astronomy		Chemistry		Earth Sciences		Mathematics		All Fields		
	Total	NSF	Total	NSF	Total	NSF	Total	NSF	Total	NSF	(NSF%)
1950 to 1967	16	4	15	-	21	2	12	7	64	13	(20)
1968 to 1976	5	2	2	2	8	8	6	2	21	14	(67)

Source: NSF, Science Resources Studies, Special Tabulation expectation of the subsequent major advance. Of the 65 projects for which these facts could be determined (out of a total of 85), only 28 (43 percent) contained in the proposal for funding an explicit and direct reference to the expected advance. Support for another 26 of the innovations (40 percent) was derived from programs for broadly defined research in the general area of the innovation. Finally, 11 innovations (17 percent) occurred that were related neither directly nor generally to the justification for the funds used to support the project.

Table II.5--Relationship of Project Funding to Innovation

		Type of Relationship			
	Total No. of Innovations	Direct	General	Indirect	Not Determined
Astronomy	21	8	7	5	1
Chemistry	17	5	7	2	3
Earth Sciences	29	10	7	3	9
Mathematics	18	5	5	1	7
TOTAL	85	28	26	11	20

Note: Several innovations could not be reviewed due to the unavailability of investigators, particularly where the innovations were based abroad or where the investigator was deceased.

One implication of this finding, of course, is that some significant portion (in this case, 17 percent) of advances in scientific knowledge cannot be foreseen at all, while another, larger portion only can be discerned in terms of the potential in a general area of inquiry. Only 4 out of 10 innovations were funded with the funding agency having explicit knowledge about the expected innovation.

Patterns of Support for Innovative Investigators

Focus on support of investigators rather than on innovations yields a somewhat different picture. Table II.6 shows, by field, the number of investigators affiliated with innovations supported by NSF and by other sources. In addition, the table shows the number of investigators involved in non-NSF supported innovations who had received some NSF support prior to their innovation. These data can be interpreted as a

Table II.6--Number of Investigators Affiliated with Innovations Supported by NSF and by Other Sources

Numbers of Investigators

		NSF SUPPORTED INNOVATIONS	NON-NSF SUPPORTED INNOVATIONS		
ASTRONOMY	Total	Affiliated Investigators	Affiliated Investigators	Investigators w/Prior Support	Investigators w/current or Prior NSF Support
University	33	7	26	8	
Gov't. Labs & FFRDC's	13	6	7	0	
Industry	6		6	1	
Foreign	5		5		
TOTAL	57	13	44	9	39 (22/57)
CHEMISTRY					
University	12	2	10	3	
Gov't. Labs & FFRDC's	2		2		
Industry	6		6		
Foreign	5		5		
TOTAL	25	2	23	3	20 (5/25)
EARTH SCIENCES					
University	35	21	14	2	
Gov't. Labs & FFRDC's	4	3	1		
Industry	3		3		
Foreign	7	1	6		
Non-Profit	3		3		
TOTAL	52	25	27	2	52 (27/52)
MATHEMATICS					
University	18	10	8	4	
Gov't. Labs & FFRDC's					
Industry					
Foreign	4	1	3		
TOTAL	22	11	11	4	68 (15/22)
ALL FIELDS					
TOTAL	156	51	105	18	44 (69/156)

measure of NSF recognition of scientists who have the potential to achieve major advances in science prior to their performance of these specific advances. Defined in this way, NSF's rate of support becomes 44 percent for all investigators. This relationship is to be expected because NSF provides a broad range of support in most fields, including not only specific project support, but also fellowships, travel grants, and provisions for facilities and instrumentation.

Characteristics of Innovations

The section on research methodology referred to a number of problems in the identification of major innovations in science, and warned that a definitive listing was not possible. Table II.7 illustrates one of those problems, namely, the time-boundedness of judgments about major advances. While part of the frequency distribution of innovations by 5-year periods may be due to differential rates of advance in the various fields, it is unlikely that this would account for the low frequencies in the 1971-76 period. More likely, this distribution is a function of the perceptions of the judges, who may be unwilling to make judgments on the more recent events.

Table II.7--Number of Innovations

Year	Astronomy	Chemistry	Earth Sciences	Mathematics	All Fields
1950-55	1	3	4	1	9
1956-60	6	4	5	6	21
1961-65	6	5	10	5	26
1966-70	6	4	9	-	19
1971-76	2	1	1	6	10

Many scientific innovations may have appeared to be the key to future advance in an area, only to encounter unforeseen difficulties or to be superseded by another advance. This would appear to be the case in the advance in chemistry on the Lanthanides Shift. In any event, the problem of the time-boundedness of perceptions of major advances can be solved only by providing sufficient temporal perspectives.

It should be noted that, when requested to write background papers on major developments over the past 25 years, no person primarily qualified as an historian of science would accept the task. None would deal with subject matter more recent than the beginning of the 20th century. Scientists with interests and achievements in the history of science were eventually recruited but all expressed strong reservations about definitive identification of recent advances in science.

Characteristics of Innovative Investigators

It is commonly held in the world of science that the young see through established convention to the truth. One might dub this, "the Emperor's Clothes" principle. Table II.8 reveals that 61 percent of the investigators associated with the major innovations were less than 35 years old at the time of their discovery. Nearly three-quarters (73 percent) were less than 41 years old. This did not vary much by field in mathematics, astronomy, and chemistry; all had approximately the same proportion of innovative investigators under 35--from 52 to 55 percent. Innovators in earth sciences, however, tended to be older.

Table II.8--Age of Innovators (percentages)

Age at Time of Innovation	Astronomy	Chemistry	Earth Sciences	Mathematics	Total
23 - 28	11	10	22	15	14
29 - 34	41	43	15	40	31
35 - 40	20	29	28	20	22
41 - 46	12	14	17	15	14
47 - 52	9	4	6	5	7
over 52	7	-	11	5	7

These data can be compared with similar data for all investigators in the under-35 age group in the four fields. In 1973, the percentage of all doctoral scientists and engineers under 35 in the four fields who were employed in 4-year colleges and universities was: physics/astronomy (32); chemistry (33); earth sciences (24); and mathematics (39).[2]

These data lend moderate support to the "Emperor's Clothes" hypothesis. Further investigation, however, is necessary to determine the extent to which these young scientists were acting autonomously or in close interaction with older colleagues in pursuit of their research objectives.

The question of patterns of collaboration addresses both the structure of scientific careers as well as the organization of scientific work. Table II.9 depicts the distribution of the number of investigators per innovation. Thus, 45 out of 85 innovations (53 percent) were created by individual scientists. Pairs of investigators produced 25 innovations (29 percent). Teams of three or more accounted for 17 percent but only in astronomy and earth sciences and produced nearly half of the innovations in those fields. Pairs of investigators were most important in chemistry (8 out of 17 innovations). Mathematics remained the bastion of the individual innovator, with only 4 out of 18 innovations stemming from collaborative efforts.

A closer look at the age make-up of 21 of the 25 pairs of investigators revealed that 13 (60 percent) were roughly age peers (within 9 years of each other's age) and 8 (40 percent) were junior-senior partnerships (more than a 9-year difference).

In democratic societies, science is often accused of being elitist. The accusation generally relates not to the social origins of scientists, but to the character of the institutions in which top scientists are trained and do their work. Tables II.10 and II.11 address this issue.

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2. NSF 75-312A, Characteristics of Doctoral Scientists and Engineers in the United States, 1973, Table B-5. The choice of 1973 was somewhat arbitrary as the age distributions have undergone some changes during the period under study (1950-1975). It is unlikely, however, that the shifts would be large enough to affect these findings. The comparative percentages for innovative investigators and all doctoral scientists and engineers under 40 years of age are, respectively: physics/astronomy, 72/53; chemistry, 82/53; earth sciences, 65/45; mathematics, 75/59.

Table II.9--Innovations by Field, and Number of Investigators per Innovation

No. of Investigators per Innovation	Number of Innovations: Astronomy	Chemistry	Earth Sciences	Mathematics	Total/Percent
1	6	9	16	14	45/53
2	6	8	7	4	25/29
3	2		5		7/8
4	4				4/5
5	2				2/2
6					
7	1		1		2/2
Total	21	17	29	18	85/99

Table II.10--Institutions From Which the Innovative Investigators Received Their Highest Degree

Institution from which Highest Degree was obtained*	Astron.	Chem.	Earth Sci.	Math.	TOTAL
1) Harvard	4	5	1	3	13
2) Calif. Inst. of Tech.	7	1	4	-	12
3) U. Calif., Berkeley	2	2	6	1	11
4) U. Chicago	3	-	4	4	11
5) Columbia	2	1	6	1	10
6) Princeton	5	1	3	1	10
7) MIT	2	1	4	-	7
8) UCLA	2	1	1	-	4
9) Stanford	-	2	1	1	4
10) U. Michigan	-	-	-	3	3
11) U. Texas	-	1	1	-	2
12) Yale U.	1	-	1	-	2
13) Rice	1	-	1	-	2
14) N.Y.U.	1	-	1	-	2
15) U. Iowa	1	-	-	-	1
16) Ohio St.	1	-	-	-	1
17) Cornell	1	-	-	-	1
18) Duke	1	-	-	-	1
19) U. Tenn.	-	1	-	-	1
20) U. Wisconsin	-	-	1	-	1
21) U. Illinois	-	-	1	-	1
22) U. Miami	-	-	1	-	1
23) Michigan State U.	1	-	-	-	1
24) George Washington	-	-	1	-	1
25) Central Union College	-	-	1	-	1
26) San Diego State	-	-	1	-	1
27) Polytech. Inst. Brooklyn	1	-	-	-	1
28) Johns Hopkins	1	-	-	-	1
TOTAL (U.S.)					107
Foreign Institutions	17	4	5	6	32

II.11--Affiliation of Investigators at Time of Innovation

	Astron.	Chem.	Earth Sci.	Math.	TOTAL
ACADEMIC					
1) Calif. Inst. of Tech.	10	-	5	-	15
2) Princeton	9	-	2	2	13
3) Columbia U.	-	2	9	2	13
4) U. Calif., Berkeley	2	5	1	4	12
5) U. Chicago	1	-	5	3	9
6) MIT	4	-	2	2	8
7) Cornell	4	-	-	1	5
8) Scripps Inst. of Ocean.	-	-	5		5
9) Harvard U.	-	2	-	1	3
10) U. Illinois	-	1	-	2	3
11) U. Calif., Santa Cruz	2	-	-	-	2
12) U. Calif., San Diego	-	-	2	-	2
13) Woods Hole Ocean. Inst.	-	-	2	-	2
14) Southern Ill. U.	-	1	-	-	1
15) Stanford	-	-	-	1	1
16) U. Hawaii	-	-	1	-	1
17) U. Wisconsin	-	1	-	-	1
18) U. Washington, Seattle	1	-	-	-	1
GOVT. & FFRDC's					
1) NRAO	5	-	-	-	5
2) Brookhaven	3	-	-	-	3
3) U.S.G.S. Menlo Park	-	-	3		3
4) Livermore Radiation Lab.	2	-	-	-	2
5) Lincoln Lab.	2	-	-	-	2
6) Oak Ridge Lab.	-	2	-	-	2
7) Naval Research Lab.	1	-	-	-	1
8) Naval Electronics Lab.	-	-	1	-	1
INDUSTRY					
1) Bell Tele. Labs.	2	2	-	-	4
2) Amer. Sci. & Engineer. Inc.	3	-	-	-	3
3) Varian Asso.	-	2	-	-	2
4) Texas Instru. Inc.	1	-	-	-	1
5) Hughes Res. Lab.	-	1	-	-	1
6) IBM	-	1	-	-	1
7) Geophysical Service Inc.	-	-	1	-	1
8) Petty Geophysical Inc.	-	-	1	-	1
9) Shell Development Co.	-	-	1	-	1
NON-PROFIT					
1) Geophysical Lab., Carnegie	-	-	3	-	3
FOREIGN					
1) All Institutions	5	5	4	7	21

Table II.10 shows that most U.S. investigators (79 percent) received their highest degree from one of 10 U.S. universities. Table II.11 shows that most U. S. investigators (64 percent) were employed by one of 10 academic institutions at the time of their innovation (7 by the former and 3 others).

Table II.11 also depicts the shares of innovative investigators among the institutional performing sectors. Nearly three-quarters (72 percent) were employed in 18 academic institutions; one-seventh (14 percent) worked in Government laboratories or FFRDC's; one-tenth (11 percent) worked in industry; and three were affiliated with a nonprofit laboratory.

PROBLEMS AND ISSUES IN STUDYING INNOVATIONS IN SCIENCE

Unexpected Advances

A substantial number of the 85 innovations considered here represents situations in which funding was obtained for purposes other than the research explicitly targeted or the subsequent innovation. In some instances the breakthrough occurred unexpectedly in the course of other research; in other instances the breakthrough was made possible by funding for general purposes or to sustain investigations in a broad area. Despite the limitations of the investigation, the significance of the frequency of unplanned advances emerges clearly. As summarized in Table II.5, above, nearly 60 percent of the innovations were not specifically identified in advance to funding agencies.

Good Research

At the same time the subcommittee requested that study and thought be given to Foundation participation in innovative science, it also inquired concerning what can be termed "good" research. In order to learn as much as possible within existing time and resource constraints, a limited study was conducted concerning good research through examination of Science Citation Index materials on publications in the field of chemistry.[3] Citations in the research literature, when properly qualified, provide a reasonable measure of research quality.

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3. Source of Support for Highly Utilized Chemistry Research, study conducted by Computer Horizons, Inc., based on NSF Contract PRM 7682 712, August 1977. A summary of this study and references to the literature on science citation studies is shown on pp. II 21-26.

NSF Funding of Investigators Subsequent to Their Innovation

Major research innovations set off a wave of additional research within a field. There is an almost immediate effort to extend and define the findings, to use the breakthrough to modify other understandings, and to seek to apply the results in other areas. It is the investigators themselves, of course, who are the prime sources of such work, and these continued efforts require additional funding. A search for Foundation grant awards to investigators after major research innovations showed a high incidence of support. On the basis of two or more awards made subsequent to publication of significant innovation, the percentage of Foundation funding of these investigators was: astronomy (41); chemistry (46); earth sciences (45); and mathematics (60).

Peer Review of Innovative Research

A central question regarding NSF's support of innovative research is the ability of the peer review process to accept and foster new ideas. The Foundation's record of identifying and supporting research subsequently judged to be a significant achievement must be measured by considering both earlier support to the investigator and any funding to the actual discovery. A study conducted in this manner found that a large percentage of identified innovations were unplanned and over half of the discoveries never existed in the form of an "innovative" proposal. None of the innovations identified derived from outside the mainstream of scientific thought, including the revolutionary advances identified in earth sciences and astronomy.[4]

Conclusion

Two important characteristics of major innovations in research stand out: (1) their very small number in relation to the total volume of activity within the discipline; and (2) the fact that approximately half of them turn out not to be directly related to specific requests for funds. These characteristics suggest that, although efforts should continue to promote innovations, it is not clear how the design of Foundation decision-making systems should effect this.

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4. This study identified only one instance of a Foundation declination of a proposal for research that subsequently produced a significant advance. This case concerned the so-called "four-color problem" in mathematics. This problem is a famous one and had remained unsettled for nearly 100 years. The Foundation declined a proposal to try to solve it with extensive use of computers. The proposal was declined in part because the approach was not thought to be of great mathematical interest, and in part because it was thought that a solution would have little influence or effect on further mathematical developments. The proposers nevertheless continued with computer support from their institution and did achieve a solution by computer applications of long-established methods.

The Board takes the position that the support of good research is most important. The selection of good research across many fields of science is the major means through which the Foundation fosters scientific innovation.

Foundation decisionmaking procedures must continue to operate effectively to support good research and must not overlook quality proposals and investigators. The peer review system is an important determinant of research progress and quality but the allocation of funds to fields of science is an equally important determinant. The Foundation's task is to monitor the state of the various sciences and the condition and viability of their various enabling institutions, and to make the case for adequate funding. Wise allocation of funds helps minimize the need to reject good proposals. The rejection of good research may well affect future rates of innovation in science.

DETAIL ON STUDIES IN INNOVATION

Study of Single-Mention Innovations in Chemistry

The decision to limit detailed examination of innovations to only those mentioned by two or more expert panelists raised questions about the validity of a sample of only about 20 percent of all the items mentioned.

The distributions by field of the choices of the expert panelists are shown in Table II.12. The 20-percent figure for all items chosen by two or more panelists is consistent across all four fields--from a low of 15 percent in mathematics to 23 percent in chemistry. It is also interesting to note that an average of only 6 percent of all items mentioned across all fields received 4 or more mentions. Finally, no single item in any field received the maximum possible number of choices (i.e., a mention by all of the responding panelists in that field). This would suggest not so much that there is little consensus in given fields of science (for few scientists would deny that the items chosen are not highly innovative), but rather, that, limited to relatively few choices, the number of legitimate possible candidate items is rather large, and thus, that the chances of two judges in a given field mentioning the same item are considerably reduced.

In any case, it was decided to compare the characteristics of the once-mentioned and twice-or-more-mentioned items in one field to see whether any significant differences would emerge. The field of chemistry was chosen because of the smaller number of items (and the lower cost of contacting the principal investigators).

Table II.12--Distribution of Choices by Expert Panelists for Major Innovations, All Fields

Frequency of Mentions	All Fields	Number of Innovations			
		Astron. (16)*	Chem. (13)	Earth Sci. (21)	Math. (17)
12	2	2			
11	2	1		1	
10					
9	1	1			
8	3			3	
7	1	1			
6	6	1		3	2
5	3		2		1
4	9	3	3		3
3	13	4	4	2	3
2	45	8	8	20	9
1	340	73	57	111	99
TOTAL	425	94	74	140	117

*Figures in parentheses indicate the number of panelists, thus representing the highest possible frequency of choices in a given discipline.

All of the 57 single-mention items in chemistry were examined by 9 program officers in the NSF Chemistry Division. They were asked to select those items which they believed to have most significantly advanced the discipline of chemistry. The program officers chose 47 of the 57 items as meeting this criterion. The same analyses were then performed on these 47 innovations as for the twice-mentioned items treated above in the text. The results are reported in the following tables, which are numbered so that they can be compared readily with their corresponding tables in the section Research Design and Methodology.

While there are slight shifts in the percentages of innovations mentioned that occurred before 1960 (see table II.7 above and II.7A below) and of chemical investigators who made their major discoveries after age 40 (tables II.8 and II.8A), there are no discernible differences in the characteristics of the innovations or the investigators. While by no means conclusive, the similarity of these results increases confidence in the validity of the analyses of the twice-mentioned items.

Innovation and Citation Utilization in Science

Innovative research consists of contributions to knowledge in science; such contributions provide improved understanding of the extent, content, and workings of nature. Contributions can consist of discoveries of new things in nature or properties of things, new instruments to observe nature, new techniques to observe or analyze nature, or new theories and languages in which to study and express nature. Thus, innovation in science, in the broadest sense, includes any contribution to the understanding of the nature of the world.

As innovations are introduced, other scientists use these innovations as data bases or guides for research direction, theories, techniques, or instruments for their further studies. A customary indication of such use of prior research innovations by a scientist is citations or references in the published work reporting the results of these further studies. Thus, a citation to a prior publication is one direct indicator of the use of prior work in later work. However, the citation itself does not tell what use was made, perfunctory or ceremonial, or the extent or significance of the use. Each citation must be examined in the context of the citing article to determine the exact kind of use the citation indicates. For this reason, there has been much discussion and disagreement as to the interpretation of citation studies.[5] However, studies have shown two general features of citation patterns:

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5. Moravcsik, M. J. and Murugesan, P., "Some Results on the Function and Quality of Citations," Social Studies of Science 5, 1975, pp. 86-92.

Table II.2A--Performers of Major Innovations in Chemistry (Once-Mentioned) and Their Sources of Support

Performing Institutions	NSF	Other Gov't.	Foundation	Institutional	Industry	Not Applicable	TOTAL
University	9	16	2	2		5	34
Govt. & FFRDC		4					4
Industry					8		8
Foreign						11	11
TOTAL	9	20	2	2	8	16	57

Table II.4A--NSF SHARE OF SUPPORT FOR CHEMISTRY INNOVATIONS: 1950-67, 1968-76

	Total	NSF
1950 to 1967	39	6
1968 to 1976	8	3

Table II.5A--RELATIONSHIP OF CHEMISTRY PROJECT FUNDING TO INNOVATION

Total Number of Innovations	Direct	General	Indirect	Not Determined
47	8	17	3	19*

*Note: Eleven out of 19 innovations were foreign and investigators affiliated with them were not available for interview.

Table II.6A--Number of Chemistry Investigators Affiliated with Innovations by NSF and by Other Sources*

	NSF SUPPORTED INNOVATIONS		NON-NSF SUPPORTED INNOV.
	Total Number of Investigators	# Affiliated Investigators	# Affiliated Investigators
University	37	14	23
Govt. Lab. & FFRDC's	6	-	6
Industry	8	-	8
Foreign	18	-	18
TOTAL	69	14	55

*No data on prior support.

Table II.7A--Number of Innovations

Year	Number of Innovations
1950-55	11
1956-60	11
1961-65	13
1966-70	5
1971-76	7

Table II.8A--Age At Time Of Innovation

Age of Innovator	Percentage
23 - 28	15
29 - 34	31
35 - 40	25
41 - 46	17
47 - 52	6
Over 52	6

Table II.10.A--Institution From Which Highest Degree Was Obtained

1)	Calif. Inst. of Tech.	5
2)	Harvard	4
3)	UCLA	4
4)	MIT	4
5)	U. Ill.	3
6)	Stanford	2
7)	U. Calif., Berkeley	2
8)	U. Michigan	1
9)	U. Maryland	1
10)	Columbia U.	1
11)	U. Chicago	1
12)	U. North Carolina	1
13)	U. Pittsburgh	1
14)	U. Wisconsin	1
15)	U. Iowa	1
16)	Johns Hopkins	1
17)	U. Oklahoma	1
18)	Northwestern	1
19)	McGill U.	1
20)	U. Chicago	1
	Foreign Institutions	13
		50

- Most citations are positive as opposed to negative (refuting) or perfunctory uses (e.g., indicating use of some prior data or some technique, etc.);

- As the number of citations to a cited article increases over time the article is most likely being cited for positive reasons (highly cited articles).

Highly cited articles thus are usually reports of innovative research; just exactly how innovative, however, cannot be determined without examination of each article. But statistically, the likelihood is very great that a highly cited article will denote a significant innovation.

One can conclude that articles that have received large numbers of citations have been useful to scientific communities. Accordingly, the following generalizations can be made:

- All innovative research is highly utilized by the scientific community and usually highly cited for a time;

- Highly cited papers are innovative to some degree, but the exact degree cannot be determined without examination of the individual paper and the patterns of its citations.

Procedure. The field of chemistry was chosen to examine patterns of NSF support of highly utilized research by the citation analysis technique. Chemistry publications appearing in 1972 were identified and citations to these publications were then ordered according to the total number of citations each article received in the subsequent 4 years (1973-76). This order set of 1972 chemistry publications was then further partitioned into four groups, called successively the highly cited group, moderately highly cited group, moderately cited group, and low-cited group.

The highly cited group consisted of the 1972 papers with the highest total number of citations (starting from the highest and descending) until one-fourth of the total number of citations in the whole set was accumulated. The moderately highly cited group consisted of the next descending set of ordered 1972 papers until the next quarter of total citations was accumulated. The same procedure was applied to arrive at the moderately cited group and the low-cited group.

In this way, the 1972 papers were partitioned into four sets of ranked papers, each set accounting for roughly one-fourth of the total citations that the 1972 papers had accumulated by 1976. Next, these four sets were sampled on an equal and random basis by selecting a citation in one of the sets, looking up the 1972 paper cited, and identifying the funding sponsor where identified in the paper. It thus became possible to estimate the proportions of citation utilization of the 1972 chemistry literature that was sponsored by different funding sources, and, in addition, to estimate the proportions of the highly, moderately highly, moderately, and low-cited papers sponsored by the different funding sources.

Results. Figure II.1 shows the percentage-support by various sponsors of citations in chemistry articles (1973-76) to chemistry articles published in 1972. Figure II.2 shows the percentage-support of citations in all fields of science (1973-76) to the chemistry articles published in 1972. For chemistry-citing-chemistry, NSF sponsored about 27 percent of the highly cited articles. For all-science-citing-chemistry, NSF sponsorship is about 15 percent. The two figures also illustrate the difference in agency mission between the NSF and NIH biochemistry and biological sciences that use chemistry information. The NSF mission is to support science broadly and while an important sponsor of chemistry and biology, the NSF is not the only sponsor. In biological sciences and biochemistry, NIH is the dominant Federal sponsor.

Measurement of sponsorship of utilization of science by science (in the case of chemistry for the published results of 1972) has provided one indicator of performance by both NSF and NIH relative to their different missions vis-a-vis chemistry. In using such measures it is important to delineate the citing domain in close correspondence with the missions of the sponsoring agency. For example, our study concentrated on basic research and private profit sponsors of chemistry (industrial chemical research) consequently ranked low in proportion partly because industrial research is dominantly applied and the journals of chemical engineering and applied chemistry were not included in our citing set.

Histories of Major Innovations

The tables that follow depict the major innovations from 1950 to 1976 in astronomy, chemistry, earth sciences, and mathematics. These innovations received two or more citations by the experts. Figure II.3 is a key to the abbreviations used in the tables.

Figure II.1.--Fraction of Utilization Versus Quartile for Selected Support Sources -- Citing Set Chemistry

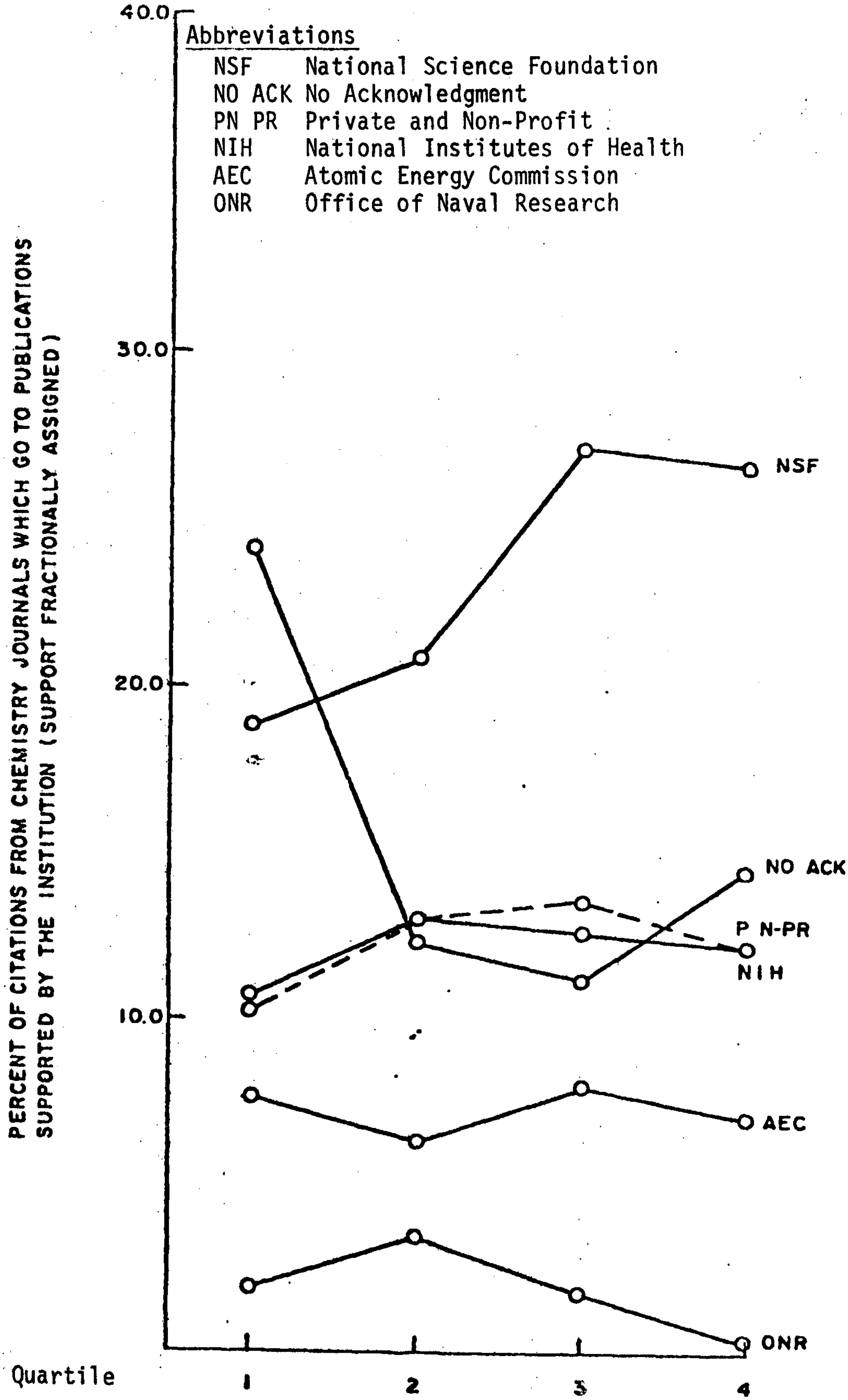
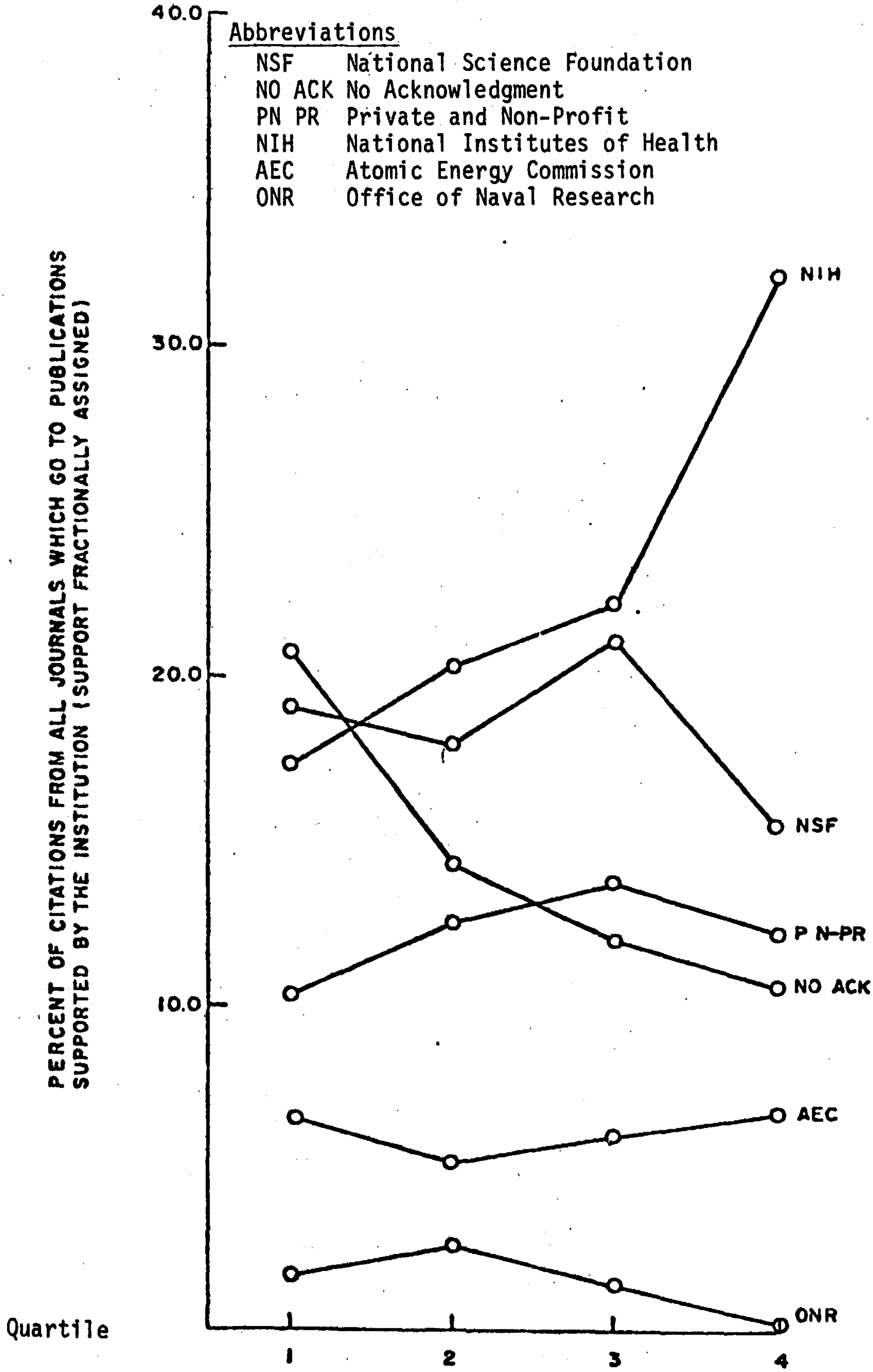


Figure II.2.--Fraction of Utilization Versus Quartile for Selected Support Sources -- Citing Set All of Science



Key to Abbreviations Tables II.13-16

Institutional Type:

A = academic institutions

G = government labs, FFRDC's

I = industry

F = foreign institutions

NP = nonprofit institutions

NSF Other Prior Funding:

GF = graduate fellowship

G = grant

Relationship of Funding to Innovation:

D = direct; an explicit and direct reference to the expected advance in the proposal for funds

G = general; broadly defined programs of research in the general area of the innovation

I = indirect; related neither directly nor generally to the justification for the funds that were used to support the project

NA = not available

Table II.13.--Histories of Major Innovations in Astronomy, 1950-1976

Title of Innovation	Investigator(s)	Date	Institutional Affiliation of Investigator	Institutional Type A	G	I	F	NP	Sources of Support for Innovation	NSF Prior Funding GF	Other Funding G	Relationship of Funding to Innov D	G	I	NA
1. Theory of Stellar Evolution	Hoyle, F.	1955	Princeton	x					ONR				x		
	Schwarzschild, M.			x							x				
2. "	Sandage, A.	1957	Caltech	x					Hale Obs.			x			
3. Stellar Nucleosynthesis	Burbidge, E.M.	1957	Caltech	x					ONR & AEC				x		
	Burbidge, G.			x											
	Fowler, W.A.			x											
	Hoyle, Fred			x											
4. Existence of Solar Wind	Parker, E.	1957	U. Chicago, E. Fermi Inst.	x					OSR; Geophysical Res. Directorate, Air Force						x
5. Spiral Nature of Our Galaxy	Kerr, F.J.	1958	CSIRO, Austral.				x		Dutch Found. for Radio Astronomy			x			
	Oort, J.H.		State U. Leiden				x								
	Westerhout, G.						x								
6. Henyey Method	Bohm, K.A.	1959	U. Ca., Berkeley	x					AEC; OSR, Air Force			x			
	Henyey, L.G.			x											
	LeLevier, R.E.		Livermore Lab.		x										
	Levee, R.D.				x										
	Wilets, L.		U. Washington	x											
7. Discovery of Quasars & Large Redshifts	Greenstein, J.	1960-63	Caltech	x					ONR		x			x	
	Matthews, T.A.			x											
	Sandage, A.R.			x											
	Schmidt, M.			x											
8. Infrared Detector & Telescope: HgGe Bolometer	Low, Frank J.	1961	Texas Instrum.			x			Texas Instrum.				x		

Table II.13--cont'd

Title of Innovation	Investigator(s)	Date	Institutional Affiliation of Investigator	Institutional Type A	G	I	F	NP	Sources of Support for Innovation	NSF Other Prior Funding GF	G	Relationship of Funding to Innov D	G	I	NA
9. X-Ray Sources: Extra-solar, Galactic, Extra-galactic	Rossi, B.R.	1962	MIT	x					Air Force Cambridge Research Lab.				x		
	Giacconi, R.		Amer. Sci. & Eng. Inc.			x									
	Gursky, H.					x									
	Paolini, F.R.					x									
10. "	Friedman, H.	1964	U.S. Naval Res. Lab.		x				NRL (ONR & NSF)		x		x		
11. Detection of Interstellar OH Molecule	Barrett, A.H.	1963	MIT	x					U.S. Army; NASA; ONR & OSR, Air Force					x	
	Meeks, M.L.		Lincoln Lab.		x										
	Weinreb, S.				x					x	x				
12. Density Wave Theory	Lin, C.C.	1964	MIT	x					NSF					x	
	Shu, F.			x											
13. Microwave Background Radiation (3K)	Penzias, A.	1965	Bell Labs.			x			Bell Labs.					x	
	Wilson, R.W.					x				x					
14. Very Long Baseline Interferometry	Bare, C.	1967	NRAO		x				NRAO (NSF); ARPA (DOD)			x			
	Clark, B.G.				x					x					
	Kellerman, K.				x										
	Cohen, M.H.		Cornell	x											
	Jauncey, D.L.			x											
15. Discovery of Pulsars - Rotating Neutron Stars	Pacini, F.	1967	Cornell	x					NSF				x		
16. "	Gold, T.	1967	Cornell	x					ONR		x		x		
17. "	Bell, J.	1968	Mullard Obs., England				x		Science Research Council, England					x	
	Hewish, A.						x								

Table II.13--cont'd (3)

Title of Innovation	Investigator(s)	Date	Institutional Affiliation of Investigator	Institutional Type A	G	I	F	NP	Sources of Support for Innovation	NSF Other Prior Funding GF	G	Relationship of Funding to Inno. D	G	I	NA
18. Solar Neutrinos	Bahcall, J.N.	1968	Caltech	x					ONR	x		x			
	Harmer, D.S.		Brookhaven		x				Brookhaven;						
	Davis, R. Jr.				x				Homestead Mining Co.						
	Hoffman, K. C.				x										
19. Discovery of Inter-stellar Organic Mole-cules	Buhl, D.	1969	NRAO		x				NRAO (NSF)		x	x			
	Snyder, L.E.				x						x				
20. Ultraviolet Spectro-metry from Copernicus Satellite	Drake, J.F.	1972	Princeton	x					NASA			x			
	Dressler, K.			x											
	Jenkins, E.B.			x						x					
	Morton, D.C.			x						x					
	Rogerson, J.B.			x											
	Spitzer, L. Jr.			x						x					
	York, D.G.			x											
21. Lick Observatory Image Dissector Scanner	Robinson, L.B.	1972	U. Ca. Santa Cruz.	x					NSF		x	x			
	Wampler, E.J.			x							x				

Table II.14.--Histories of Major Innovations in Chemistry, 1950-1976

Title of Innovation	Investigator(s)	Date	Institutional Affiliation of Investigator	Institutional Type A	G	I	F	NP	Sources of Support for Innovation	NSF Other Prior Funding GF	G	Relationship of Funding to Innov. D	G	I	NA
1. Nuclear Magnetic Resonance	Gutowsky, H.S.	1951	U. Illinois	x					ONR; Res. Corp.			x			
2. Stereoregularity in Polymers	Natta, G. Ziegler, K.	1955	Italy Germany				x x		NA						x
3. Crossed Molecular Beam Chemistry	Datz, S. Taylor, E.	1955	Oak Ridge Nat'l. Lab.		x x				AEC				x		
4. "	Herschbach, D.R.	1962	U. Ca., Berkeley	x					AEC	x			x		
5. "	Bernstein, R.B.	1964	U. Wisconsin	x					AEC; Sloan Found.				x		
6. Matrix Isolation Spectroscopy	Milligan, D. Pimentel, G.	1958	U. Ca., Berkeley	x x					Amer. Petrol. Inst.; OSR, Air Force			x			
7. Infrared Chemiluminescence	Cashion, J.K. Polanyi, J.C.	1958	U. Toronto				x x		U. Toronto						x
8. Lasers	Schawlow, A.L. Townes, C.	1958	Bell Labs. Columbia U.	 x		x			Bell Labs.			x			
9. "	Maiman, T.	1960	Hughes Res. Lab.			x			Hughes Res. Lab.			x			
10. Reactivity of Inert Gases	Bartlett, N.	1963	U. Brit. Columbia				x		NA						x
11. Chemical Lasers	Kasper, J.V.V. Pimentel, G.	1965	U. Ca., Berkeley	x x					OSR, Air Force; Eastman Kodak Fellowship to Kasper	x				x	
12. Woodward-Hoffmann Rules	Hoffmann, R. Woodward, R.B.	1965	Harvard U.	x x					NIH		 x			x	

Table II.14 -- cont'd (2)

Title of Innovation	Investigator(s)	Date	Institutional Affiliation of Investigator	Institutional Type					Sources of Support for Innovation	NSF Other Prior Funding		Relationship of Funding to Inno.			
				A	G	I	F	NP		GF	G	D	G	I	UA
13. Tunable Dye Lasers	Sorokin, P.	1966	IBM			x			IBM				x		
14. Fourier Transform NMR Spectroscopy	Anderson, W.A. Ernst, R.R.	1966	Varian Asso.			x x			Varian Asso.				x		
15. Picosecond Spectroscopy	Rentzepis, P.P.	1966	Bell Tele. Labs.			x			Bell Tele. Labs.				x		
16. Lanthanide Shift Reagent	Hinckley, C.C.	1969	Southern Ill. U.	x					NSF Instrumentation Grant to S.I.U.				x		
17. Laser Induced Fluorescence Internal State Distribution	Zare, R.N.	1972	Columbia U.	x					ARPA; OSR, Air Force; NSF	x	x	x			

Table II.15.--Histories of Major Innovations in Earth Sciences, 1950-1976

Title of Innovation	Investigator(s)	Date	Institutional Affiliation of Investigator	Institutional Type: A	G	I	F	NP	Sources of Support for Innovation	NSF Prior Funding: GF	Other Prior Funding: G	Relationship of Funding to Innov.: D	G	I	NA
1. Electron Microprobe Analyzer	Castaing, R.	1951	U. Paris				x		NA						x
2. "	Smith, J.V.	1965	U. Chicago	x					NSF; Calif. Res. Corp.; ARPA		x	x			
3. Topography & Layering of Ocean Floors	Ewing, M. Heezen, B.	1952	Columbia, Lamont Geol. Obs.	x x					Lamont Geol. Obs.				x		
4. Carbon 14 Dating Method	Libby, W.F.	1952	U. Chicago	x					U. Chicago						x
5. Mathematical Signal	Robinson, E.A. Treitel, S.	1955	MIT	x x					Petroleum Co.(s); Res. Asst.(s)			x			
6. "	Backus, M.	1959	Geophy. Service, Inc.			x			Geophys. Serv.			x			
7. Development of Solid Buffers	Eugster, H.P.	1957	Geophys. Lab., Carnegie Inst.					x	Geophys. Lab.			x			
8. ^{129}Xe Anomaly of Chrondrite Meteorites	Reynolds, J.H.	1960	U. Ca., Berkeley	x					AEC			x			
9. Demonstration of Existence of Worldwide Ridge System	Heezen, B.	1960	Columbia, Lamont Geol. Obs.	x					ONR; Bureau of Ships				x		
10. Development of New High Pressure Equipment	Boyd, F. England, J.L.	1960	Geophys. Lab., Carnegie Inst.					x x	Geophys. Lab.			x			
11. Statement of Theory of Sea-Floor Spreading	Dietz, R.S.	1961	Naval Elect. Lab.		x				Naval Elect. Lab.						x
12. "	Hess, H.H.	1962	Princeton U.	x					NA		x				x

Table II.15--cont'd (2)

Title of Innovation	Investigator(s)	Date	Institutional Affiliation of Investigator	Institutional Type: A	G	I	F	NP	Sources of Support for Innovation	NSF Other Prior Funding: GF	G	Relationship of Funding to Innov.: D	G	I	NA
13. Statement of Theory of Sea-Floor Spreading	Wilson, J.T.	1965	U. Toronto				x		NA						x
14. Linear Magnetic Anomalies	Mason, R.G. Raff, A.D. Vacquier, V.	1961	Scripps Inst. of Oceanography	x x x					ONR				x		
15. First Measurement of Free Oscillations of the Earth	Benioff, H. Press, F. Smith, S.	1961	Caltech	x x x					OSR		x			x	
16. Common Reflection Depth Point Stacking	Mayne, W.H.	1962	Petty Geophys. Eng. Co.			x			Petty Geophys.			x			
17. Significance of Magnetic Lineaments	Matthews, D. Vine, F.J.	1963	Cambridge U.				x x		ONR; Cambridge U.						x
18. " "	Heirtzler, J.R. Pitman, W. III	1968	Columbia U., Lamont Geol. Obs.	x x					ONR; NSF		x		x		
19. Time-Scale of Geomagnetic Polarity Reversals	Cox, A.V. Dalrymple, G.B. Doell, R.R.	1963	U.S.G.S., Menlo Park		x x x				U.S.G.S.; NSF	x		x			
20. Maturation of Hydrocarbons in Petroleum Source Beds	Philippi, G.T.	1965	Shell Develop. Houston			x			Shell Develop.						x
21. "	Tissot, B.	1966	I.F.P., France				x		NA						x
22. "	Vassoevich, N.B.	1967	State U., Moscow				x		NA						x
23. New Global Techtonics & Seismology	Isacks, B. Oliver, J.E. Sykes, L.R.	1968	Columbia U., Lamont Geol. Obs.	x x x					Dept. Comm.; NSF; Air Force Cambridge Res. Lab; ARPA; NASA; Lamont - R.A. to Isacks	x			x		

Table II.15--cont'd (3)

Title of Innovation	Investigator(s)	Date	Institutional Affiliation of Investigator	Institutional Type A	G	I	F	NP	Sources of Support for Innovation	NSF Prior Funding GF	Other Funding G	Relationship of Funding to Innov. D	G	I	NA
24. Concept of Rigid Plates & Independent Plate Motions	LePichon, X.	1968	Columbia U., Lamont Geol. Obs.	x					ONR; NSF				x		
25. "	Morgan, W. J.	1968	Princeton U.	x					ONR; NSF	x			x		
26. Development of Inversion Theory	Backus, G.E.	1968	U. Ca., San Diego	x					NSF; ONR	x	x			x	
	Gilbert, J.F.			x						x	x				
27. Programmable Magnetic Field Mass Spectrometer	Papanastassiou, D.	1969	Caltech	x					NSF		x	x			
	Wasserburg, G.J.			x											
28. Rate of Sea-Floor Spreading by Dating Methods in S. Atlantic - JOIDES	Andrews, J.E.	1970	U. Hawaii	x					NSF		x	x			
	Boyce, R.E.		Scripps. Inst.	x											
	Milow, E.D.			x											
	Hsu, K.J.		Swiss Fed. Inst.				x								
	Saito, T.		Columbia, Lamont	x											
	Maxwell, A.E.		Woods Hole Ocean. Inst.	x							x				
	Von Herzen, R.P.			x							x				
29. Discovery of Isotopic Heterogenieties in Solar Nebula	Clayton, R.N.	1973	U. Chicago	x					NSF; NASA; Res. Corp.; Louis Block Found. - U. Chicago		x			x	
	Grossman, L.			x											
	Mayeda, T.			x											

Table II.16.--Histories of Major Innovations in Mathematics, 1950-1976

Title of Innovation	Investigator(s)	Date	Institutional Affiliation of Investigator	Institutional Type A	G	I	F	NP	Sources of Support for Innovation	NSF/Other Prior Funding GF	G	Relationship of Funding to Innov. O	S	I	NA
1. Groups of Lie Type	Chevalley, C.	1955	Columbia	x					Air Force		x	x			
2. Discovery of the Seven Dimensional Sphere	Milnor, J.W.	1956	Princeton U.	x					Sloan Foundation	x			x		
3. Singular Integral & Pseudo Differential Operators	Calderon, A. Zygmund, A.	1957	U. Chicago	x x					OSR, Air Force			x			
4. "	Hormander, L.	1959	U. Uppsala				x								x
5. Proof of Weil Conjecture	Grothendieck, A.	1958	I.H.E.S. Paris				x		NA						x
6. "	Dwork, Bernard	1960	Princeton U.	x					NSF				x		
7. "	Deligne, P.	1974	I.H.E.S. Paris				x		NA						x
8. Poincare Conjecture	Smale, S.	1960	U. Ca., Berkeley IMPA, Rio de Janiero	x					NSF postdoc; Sloan Foundation				x		
9. Solvability of Groups of Odd Order	Feit, W. Thompson, J.G.	1963	Cornell U. U. Chicago	x x					Army Res. Off.; NSF; Esso Educ. Found; Sloan; IDA	x					x
10. Forcing - Continuum Hypothesis	Cohen, Paul J.	1963	Stanford	x					Sloan Found.; NSF	x			x		
11. Index Theorem	Atiyah, M. Singer, I.	1963	Oxford U. MIT	 x			x		NSF; Sloan Found.		x	x			
12. Resolution of Singularities	Hironaka, H.	1964	Harvard U.	x					OSR; NSF			x			
13. Harmonic Analysis on Semi-Simple Lie Groups	Harish-Chandra	1965	Columbia, IAS	x					NSF						x
14. Foliations	Lawson, H.B.	1971	U. Ca., Berkeley	x					Sloan; IMPA						x

Table II.16--cont'd (2)

Title of Innovation	Investigator(s)	Date	Institutional Affiliation of Investigator	Institutional Type: A	G	I	F	NP	Sources of Support for Innovation	NSF Other Prior Funding: GF	G	Relationship of Funding to Inn.: D	S	I	NA
15. Foliations	Thurston, W.	1971	U.Ca., Berkeley	x					NA						x
16. Complexity of Algorithms: N-P Completeness	Karp, R.M.	1972	U. Ca., Berkeley	x					NSF					x	
17. Higher K-Theory	Quillen, D.	1973	MIT	x					Sloan Found.; NSF	x		x			
18. Four-Color Theorem	Appel, K.I. Haken, W.	1976	U. Illinois	x x					U. Illinois		x x		x		

YOUNG SCIENTISTS

III. SUPPORT OF YOUNG SCIENTISTS

SUBCOMMITTEE RECOMMENDATIONS AND NSB FOCUS OF ACTION

The Subcommittee recommended that the National Science Board "Study the question of support of young scientists and report to Congress." Its report further noted that,

> Although it is widely acknowledged that the best scientists in each generation should be identified and funded whenever possible and that employment problems for young scientists are currently severe (and likely to remain so in the foreseeable future), there is little information available about the distribution to young scientists of funds for scientific research or about the effects on science of the difficulties of young scientists.

This paper reviews the statistics regarding the distribution of young scientists in academic research and reports on several studies of allocation of NSF support to young scientists. Although these studies provide evidence of the success of young scientists in obtaining NSF support, different patterns of support among the various scientific disciplines are evident. The results appear to be attributable to varying patterns of grant seeking activities among the scientific fields and different age characteristics of scientists in each discipline.

The Subcommittee Report notes various difficulties faced by young scientists but focuses on the essential question: Has the NSF been furnishing adequate opportunities for younger scientists to do research at a time when the Nation's graduate schools continue to produce significant numbers of new scientists, many of whom are unable to find employment in universities? In addressing this question, the Board has sought to focus attention on young scientists in the academic community and the Foundation's support of these researchers in the university research sector.

Size and Location of Population of Young Scientists

In 1975, the population of doctoral scientists and engineers in the United States numbered about 278,000.[1] Approximately one-half held appointments in universities and 4-year colleges; just under one-fourth

1. "Projections of Science and Engineering Doctorate Supply and Utilization, 1980 and 1985," NSF-75-301.

were employed in industrial organizations. Most others held positions in Federal Government agencies, hospitals, or nonprofit organizations (see Table III.). Those scientists and engineers under 35 years of age constituted one-quarter of the total population. Nearly half of all doctoral scientists and engineers were under 40. Because Federal funds for research decreased during the past decade, this population of young scientists has experienced a diminished availability of research support. Projections by the National Science Foundation and the U. S. Office of Education indicate that there will be an increased supply of doctorates throughout the 1980's.[2]

Current employment opportunities for young scientists in the Nation's universities and colleges are very limited. Indications are that the academic job market will become even tighter in the next 2 decades. University department chairmen are currently projecting reduced academic demand for new doctorates, and there have been some suggestions of negative demand for doctorates in academe during the late 1980's.[3] As a result it is expected that:

- o Increasing numbers of young graduates will have to seek nonacademic employment;
- o The average age of faculties in the major research universities will increase steadily; and
- o New institutional mechanisms--such as nonfaculty research positions --will have to be further developed if increasing numbers of scientists are to conduct basic research at the Nation's colleges and universities.

During 1975, 25 percent of the approximately 148,000 doctoral scientists and engineers employed in 4-year colleges and universities indicated their primary work activities involved research and development, not teaching.[4] Approximately 8,000 held temporary post-doctoral positions. Most of these research positions were funded from temporary

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2. Ibid.

3. Atelsek, F. J. and Gomberg, I.L., "Young Doctorate Faculty in Selected Science and Engineering Departments, 1975 to 1980, August 1976.

4. NSF 77-309, p. 38.

Table III.1.--Number of Doctoral Scientists and Engineers by Age and Employer

Age	Total	Educational Institution	Industry/ Business	Basic Research
24 or under	30	18	*	30
25-29	10,026	5,916	2,129	3,280
30-34	58,168	31,989	15,117	11,616
5-39	56,229	32,037	14,113	9,133
40-44	42,004	24,499	10,274	5,130
45-49	35,233	20,655	8,090	3,965
50-54	29,921	16,843	7,476	2,770
55-59	19,452	11,164	4,610	1,827
60-64	12,754	6,804	2,734	807
65-69	7,804	2,672	867	465
70 and over	5,452	539	357	82
no report	444	113	109	16
TOTAL	277,517	153,249	65,876	39,121

*Age noted on response to questionnaire.

Source: "Characteristics of Doctoral Scientists and Engineers in the United States, 1975," NSF 77-309.

or "soft" grants and contracts. Between one-third and one-half of these nonfaculty scientists had been in their positions for 5 years or more; many expect to remain there in the future.[5]

The situation is especially difficult for the young scientists seeking employment leading to tenure in the academic community. This is basically a problem of limited availability of faculty appointments. It is questionable whether Federal intervention could alleviate such difficulties. Although increased Federal research funds could help universities maintain their research staffs, the colleges and universities themselves must bear the major responsibility for issues such as faculty tenure and retirement. Each college and university and each department must determine for itself the organization of its research effort and the relation of the research to instructional programs.

Young Scientists in Competition for Federal Research Support

It was decided to determine how active young scientists are in submitting proposals for support of their research and whether the changed financial environment of science has led to different patterns of behavior. While young scientists might be more reluctant to expend the considerable effort entailed in proposal writing because of diminishing expectations of success, at the same time, the number of young faculty members at major universities is smaller than it has been, and increased career and promotion pressures may stimulate the drive for research support.

A review of proposals to the NSF Chemistry Division for the period 1970-1975, found that proposal submissions from young scientists have declined. An NSF Chemistry Division memorandum noted:

> (Another) trend indicated by the data is that the number of proposals decreases as success ratios decline. The NSF Chemistry Division received 939 proposals in 1971; that figure declined to 839 by 1975. It is interesting to note that most of this decline took place among proposals from young investigators. In fact, the number of proposals submitted by young investigators dropped from 235 or 29 percent of the total in 1970 to 191 or 23

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5. Kruytbosch, C. and Messinger, S., "Unequal Peers: The Situation of Researchers at Berkeley," American Behavioral Scientist, 11, May-June 1968.

percent in 1975. Over the same period the proposals submitted by established investigators increased from 577 or 71 percent of the total to 648 or 77 percent of the total."[6,7]

It should be remembered that many young scientists (especially experimentalists) spend the first few years of their research careers working within the framework of institute or center programs or under "umbrella" grants or as coinvestigators or research associates with senior faculty members. Thus, data on proposals from or even grants to young scientists do not show the total pattern of support for the group.

A recent study found that most scientists perceive the peer review process to be biased against young scientists (see Table III.2).[8] Many potential investigators believe that reviewers and program managers would prefer proposals from more senior and established scientists over those of younger researchers. The evidence on actual outcomes, however, is inconclusive. A recent study found a small but persistent significant negative correlation between career age and grant getting.[9] The author attributes this to "the small youthful bias of the granting systems." This conclusion is supported by 1972 and 1973 data on age and success in grant getting in the cancer research field at the NIH.[10] Preliminary data from an as yet unreleased study by the National Academy of Sciences of NSF proposals and awards in 10 program areas suggest no significant correlation between age of proposer and success in obtaining awards. Rubin, Cole, and Rubin, writing in the October 1977 issue of Scientific American, note no significant biases against young scientists.

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6. NSF Chemistry Division, "Data on Grants in the Division of Chemistry," Memorandum, January 19, 1976. The data exclude conferences, withdrawals, supplements, and amendments to continuing grants.

7. This is also cited in Smith, B. and Karlesky, J., The State of Academic Science, Change Magazine Press, New Rochelle, N.Y., 1977, pp. 91-92.

8. Hensler, D., "Perceptions of the NSF Peer Review Process," National Science Foundation, December 1976.

9. Liebert, Ronald J., "Research Grant Getting and Productivity Among Scholars," Journal of Higher Education, Vol. 68, No. 2, March-April 1977, pp. 185-186.

10. "The Impact of the National Cancer Act on Grant Support," Cancer Research, 35, March 1975, p. 480.

TABLE III.2.--Reviewer Perceptions of Outcomes by Academic Generation, Region, and Institutional Affiliation (percentages)

	ACADEMIC GENERATION*			REGION				INSTITUTIONAL AFFILIATION**		
	Before 1960	1960-1969	1970 on	North	South	Mid-west	West	Top 20 in Research Funds	Ph.D. Granting	Other Academic
Does the Peer Review Process Favor Well-Established P.I.'s Over Not-Yet-Established P.I.'s?										
Both have an equal chance	19.4	18.7	11.3	15.3	18.8	21.2	19.7	20.3	18.9	13.9
Young, not-yet-established P.I. has better chance	6.3	3.2	1.4	4.7	2.8	5.9	4.5	6.9	4.1	4.2
Older, well-established P.I. has better chance	54.9	65.2	74.6	60.7	64.3	56.4	61.9	57.1	61.0	69.4
Don't know	19.4	12.9	12.7	19.3	14.1	16.5	13.9	15.7	15.9	12.5
TOTAL RESPONDENTS	506	434	71	295	213	236	244	261	439	72

*Date of Ph.D. degree.

**Excludes respondents at nonacademic institutions.

Source: Hensler, D., "Perceptions of the National Science Foundation Peer Review Process," NSF, December 1976, p. 47.

But contradictory evidence shows that the population of NSF awardees has aged faster than the total population of academic doctoral scientists and engineers. In a supporting study for this paper, a small sampling was conducted of the ages of NSF awardees. The study found that:

- o The age and academic rank characteristics of NSF-funded principal investigators did not change significantly between 1972 and 1974; and

- o NSF-funded principal investigators tend to be older, have held the Ph.D. longer, and are more senior in academic rank than the general academic science population.[11]

A National Research Council study documented a similar finding of a significant increase in the professional age of NSF social science awardees between 1965 and 1974.[12]

The Hensler study discussed above also provides data on age and success in obtaining NSF awards. The survey was based on a 20-percent random sample of the first-named investigators on proposals acted upon by NSF during FY 1975. The results are shown in Table III.3. The Hensler data appear to show a bias against younger investigators. A more detailed, albeit limited, assessment in the NSF Chemistry Division shows that the success ratio for proposals received in FY 1975 was essentially the same for young and established investigators. The Chemistry Division data exclude committed renewals, i.e., annual requests for funding that were previously committed.

NSF has also gathered data on the age distribution of scientists receiving some form of Federal support (see Table III.4). In 1973, approximately 51 percent of the 78,000 doctoral scientists and engineers engaged in research in U.S. colleges and universities reported some form of Federal support.[13] Senior investigators (those who had received their doctorates more than 7 years ago) reported a slightly higher percentage of Federal support than their younger colleagues--52 percent compared with 50 percent. The young/senior scientist ratio of

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11. Dean, Burton, unpublished study.

12. National Research Council, "Social and Behavioral Science Programs in the National Science Foundation: Final Report 1976," Appendix B, p. 96.

13. NSF, 75-302.

Table III.3--NSF Awards and Declinations By Age and Prestige of Institution of Current Employment of Proposer During FY 1975 (percentages)

Institution Type	Top 20 Universities (research funds)			All Other Institutions		
Age of Proposer*	Young	Middle	Old	Young	Middle	Old
Awardees	54.4	68.9	78.3	48.6	55.5	61.6
Declinations/Withdrawals	45.6	31.1	21.7	51.4	44.5	38.4
(N)	(57)	(167)	(221)	(401)	(890)	(558)

Note: Because about 15 percent of all proposals are submitted by two or more coinvestigators, this sample slightly underrepresents the total community of NSF investigators. Also, it seems probable that the first-named investigators tend to be the more senior member of the team. If this is so, then the sample underrepresents junior investigators.

*Young = Ph.D. received in the 1970's
Middle = Ph.D. received in the 1960's
Old = Ph.D. received prior to 1960.

support was 0.96 for all fields. There was, however, considerable variation among the major disciplines. In the biological and physical sciences, the percentage of young researchers with Federal support exceeded that of senior researchers (young/senior ratio of 1.06). In mathematics, the percentage of young researchers reporting Federal support was less than three-fourths that of their senior colleagues. The proportion of social scientists and mathematicians reporting Federal support was also found to be substantially below that for researchers in other fields.

In summary, various studies undertaken by different investigators in different fields of science indicate conflicting evidence regarding the success of young scientists in obtaining NSF support. The results appear to vary by the grant seeking activities of the scientific fields and the different age characteristics of scientists in each discipline.

Table III.4--Federal Support For Young and Senior Academic Researchers, 1973*

Researchers with Federal Support (Percent) Young	Senior	Field	Young/Senior Ratio
68	62	Biological Sciences	1.06
58	52	Physical Sciences	1.06
50	51	All Fields	0.96
28	30	Social Sciences	0.94
50	61	Engineering	0.81
27	36	Mathematics	0.74

* Young investigator: Ph.D. received within past seven years.
Source: NSF, Science Resources Studies, Director's Program Review, June, 1974.

Conclusions

There are no simple solutions to the problems confronting the Nation's young scientists. Responsibility for helping to solve these problems, however, must be shared between the Federal Government--the principal funder of basic research in the Nation--and the Nation's universities and colleges--the principal homes of performers of basic research. Increased funding for research would help alleviate some of the difficulties, but the essential questions of accepting continuing support and of establishing nonfaculty appointments would be solved best by the individual colleges and universities. A major strength of the U. S. research system is its diversity and adaptability to change. Given the inherent uncertainties of forecasting the long-term supply and demand for research scientists, it appears that the strategy with the greatest promise is that of systematically increasing the possibilities for exchange of personnel among the academic, private, and government sectors.

The Board, however, continues to seek means to insure that younger scientists have equal access to NSF research funds. As noted in Section V of this report (Mismatch), the Board and the Foundation have long sought to monitor the essential needs of the various performers--including those of young scientists--and to implement appropriate programs to alleviate difficulties. Three specific areas where NSF programs have been initiated primarily for young scientists include:

- o Engineering Research Initiation Grants
  (FY 1977, 61 grants totaling $1.25M)

- o Fellowships at the Princeton Institute for Advanced Studies
  (FY 1977, 30 fellowships totaling $300K)

- o Human Cell Biology Program
  (established in FY 1972 to assist young investigators; no longer targeted to young scientists).

In each instance, a unique combination of circumstances argued for initiation of the program. The Board will continue to encourage the Foundation to seek other opportunities for young scientists.

FOUR YEAR COLLEGES

IV. NSF FUNDING OF RESEARCH AT UNDERGRADUATE TEACHING INSTITUTIONS (4-YEAR COLLEGES)

SUBCOMMITTEE RECOMMENDATIONS AND NSB FOCUS OF ACTION

The Subcommittee recommended that:

> The National Science Board should study the funding of research at undergraduate-teaching institutions without graduate departments (colleges) by the Foundation and report to Congress.
>
> The study should provide data on the distribution of Foundation research funds to colleges, analyze the data to determine the suitability of the distribution and give conclusions and recommendations for Foundation procedures, as indicated . . . . .

This paper discusses these concerns and considers the Foundation's support of research at U.S. colleges. The NSB believes that:

- o The Nation cannot afford to overlook, or to judge prejudicially, high quality research of investigators located in colleges;
- o The future health of American science depends on the quality of teaching at all levels, including the undergraduate level, where a substantial number of students in science can benefit from participating in or observing research; and
- o Qualified faculty members in colleges should have a fair opportunity to participate in the peer review process and to receive just evaluations from it and from NSF officials.

The Board also notes that many research scientists and engineers first develop their interest in scientific careers while attending 4-year colleges.[1] It is important that the access of these is equal to that available to university faculty members. A study on NSF funding of

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1. See Tidball, M. Elizabeth and Kistiakowsky, Vera, "Baccalaureate Origins of American Scientists and Scholars," Science, 193, August 20, 1976, pp. 646-652.

Table IV.1.--Number of Institutions and Share of Enrollment American Higher Education, 1970, By Type of Institution

Institutional Type	Number of Institutions Public	Private	Total	Percent of all Enrollment
The College Sector	336	836	1172	37.5
Comprehensive I	223	98	321	24.7
Comprehensive II	85	47	132	4.7
Liberal Arts I	2	144	146	2.2
Liberal Arts II	26	547	573	5.9
The University Sector	108	65	173	31.5
University I	30	22	52	12.9
University II	27	13	40	7.2
University III	34	19	53	7.6
University IV	17	11	28	3.8
Two-year and a few specialized institutions	869	613	1482	31.0
TOTAL	1,313	1,514	2,827	100.0

Source: A Classification of Institutions of Higher Education, technical report sponsored by the Carnegie Commission on Higher Education, McGraw-Hill Book Co., Highstown, N. J., 1973.

colleges found that the ratio of awards to applications (the success ratio) was about the same for both 4-year college institutions and university scientists. The Board maintains, however, that greater efforts should be made to involve scientists from 4-year colleges in the review process and to encourage proposals from them. The Board does not favor any sheltered competition for scientists in 4-year colleges.

Distribution of NSF Research Support

To determine the distribution of NSF support among researchers at the Nation's colleges and universities, two questions should be addressed:

- How are scientific researchers in the various types of colleges faring in the NSF peer review competition?

- Are investigators located in predominantly undergraduate institutions receiving a "fair" share of NSF research support?

Table IV.1 shows the number of colleges and universities in each of the major types of institutions and the distribution of public and private schools in each category. The undergraduate teaching institutions were divided into the following four sectors (by slightly renaming categories of the Carnegie Commission on Higher Education):

Comprehensive College I. Public and private institutions with two major professional programs, such as engineering or business administration, in addition to a liberal arts program. Many of these colleges offer a master's degree, but they have little or no doctoral work. Examples: (public) California State University, Long Beach, enrollment 26,000; (private) University of Bridgeport, enrollment 9,000.

Comprehensive College II. Public institutions with over 1,000 students and private institutions with over 1,500 and at least one major occupational program, such as teacher training or nursing. Many are former teachers colleges that have broadened their programs to include a liberal arts curriculum. Examples: (public) Glassboro State College, enrollment 10,000; (private) Saint Olaf College, enrollment 2,600.

Liberal Arts College I. The higher quality liberal arts colleges, as identified by relatively high scores on indicators of student quality. Nearly all are private. Example: Swarthmore College, enrollment 1,200.

Liberal Arts College II. All other liberal arts colleges, again mainly private. Examples: (public) State University of New York College at Purchase, enrollment 400; (private) Bethel College, Indiana, enrollment 500.

The universities were similarly grouped into four major classes--University I, II, III, and IV--based on the amount of Federal financial support of academic science and number of Ph.D. degrees awarded. (Institutions awarding fewer than 10 doctorates in 1970 were assigned to one of the college categories.)

Data on the distribution of research funds from all sources to the different types of colleges and universities are given in Table IV.2. Tables IV.3 and IV.4 compare the number of research proposals submitted to the NSF from each type of institution and the number of awards received. Table IV.5 provides data on the number of scientists and engineers employed by the Nation's colleges and universities.

It is essential to keep in mind that NSF support of scientific research is complemented by funding from a variety of other sources, both private and public. More than a half dozen other Federal agencies also provide significant funds.

The Federal Government has remained the main source of direct support of scientific research in colleges and universities since World War II. The Federal share generally ranges between 60 and 80 percent among 16 categories of colleges and universities (the 8 sectors defined above divided into public and private components). Only the second level private liberal arts colleges fall measurably below the rest in Federal proportion of funding (only 42.7) as well as in Federal dollar sums (see Table IV.2). Generally lacking State appropriations, private institutions (undergraduate and graduate) are relatively more dependent on Federal agencies and, secondarily, on private foundations for research support than public institutions.

Among types of academic institutions, the distribution of Federal research funds is highly concentrated. Analyses made by NSF for FY 1975 show that nearly 98 percent of Federal agency research and development funding to the academic sector went to doctorate-granting institutions, and less than 3 percent to colleges.

Table IV.6 shows that, within the college sector, the relatively small share of Federal research funds that the four institutional categories received also was highly concentrated in one category.

Table IV.2--Total Research Expenditures in Colleges and Universities, by Source, FY 1975, in Thousands of Dollars*

Institutional Types	Total, All sources	Federal	State Gov	Local Gov	Private Foundation	Industry	Other Sources	Institutions Own Funds
				Source of Funds				
1) Public								
Comp Col I	104,155	67,850	13,849	1,037	3,332	4,188	1,353	12,546
	(100)	(65.3)	(13.0)	(1.0)	(3.0)	(4.0)	(1.3)	(12.5)
Comp Col II	6,620	4,316	862	94	201	319	205	623
	(100)	(65.0)	(13.3)	(1.0)	(3.2)	(4.0)	(1.5)	(12.0)
Lib Arts Col I	3,605	2,262	11	--	182	--	--	1,150
	(100)	(62.7)	(0.3)		(5.0)			(32.0)
Lib Arts Col II	1,911	1,508	35	67	120	5	3	173
	(100)	(79.0)	(2.0)	(3.5)	(5.0)	(0.3)	(0.2)	(9.0)
Univ I	1,145,257	727,611	145,325	3,009	38,196	29,357	24,740	177,019
	(100)	(64.0)	(13.0)	(0.3)	(3.5)	(2.5)	(2.0)	(15.5)
Univ II	427,221	224,646	102,284	2,218	10,354	20,041	10,749	56,929
	(100)	(52.6)	(24.0)	(0.5)	(2.4)	(4.7)	(2.5)	(13.3)
Univ III	190,258	114,586	28,444	2,174	7,009	7,425	3,832	26,788
	(100)	(60.2)	(15.0)	(1.1)	(3.7)	(4.0)	(2.0)	(14.0)
Univ IV	53,840	28,199	8,746	271	1,999	3,237	1,946	9,442
	(100)	(52.4)	(16.2)	(0.5)	(3.7)	(6.0)	(3.6)	(17.6)

*Figures in parenthese indicate percentages of total from all sources. Where percentages do not total 100 percent, difference is due to rounding.

Table IV.2--cont'd

2) Private

Comp Col I	23,253	17,830	472	82	1,652	1,625	388	1,204
	(100)	(77.0)	(2.0)	(0.35)	(7.1)	(6.9)	(1.7)	(5.0)
Comp Col II	1,780	1,489	187	--	59	10	35	--
	(100)	(83.7)	(10.5)		(3.3)	(0.6)	(2.0)	
Lib Arts Col I	9,314	6,521	300	2	1,256	264	364	607
	(100)	(70.0)	(3.0)	(0.02)	(13.5)	(3.0)	(4.0)	(6.5)
Lib Arts Col II	2,264	966	2	1	539	111	2	643
	(100)	(42.7)	(0.09)	(0.04)	(23.8)	(5.0)	(0.09)	(28.4)
Univ I	865,403	686,335	22,948	3,922	62,207	21,464	31,594	41,901
	(100)	(79.0)	(3.0)	(0.5)	(7.0)	(2.5)	(3.0)	(5.0)
Univ II	110,098	90,075	1,415	172	7,184	6,062	26,626	3,576
	(100)	(82.0)	(1.3)	(0.2)	(6.5)	(5.5)	(1.4)	(3.2)
Univ III	74,657	56,845	1,118	314	4,204	3,320	1,616	5,650
	(100)	(76.0)	(1.5)	(0.5)	(5.6)	(4.5)	(4.3)	(7.6)
Univ IV	8,453	5,252	705	185	1,243	694	3,206	828
	(100)	(62.0)	(1.2)	(2.0)	(14.8)	(8.0)	(2.0)	(10.0)

Source: The National Science Foundation, Survey of Scientific and Engineering Expenditures at Universities and Colleges.

Table IV.3.--Research Applications to and Awards Made by The National Science Foundation in FY 1974 By Type of Institution*

Institutional Type	Applications	Awards	Success Ratio	Amount Awarded
1) The College Sector				
Comp Col I	1995	711	0.356	$ 16,282,000
Comp Col II	330	148	0.448	3,451,100
Lib Arts Col I	459	226	0.493	7,110,000
Lib Arts Col II	648	276	0.426	5,520,000
2) The University Sector				
Univ I	8248	4,588	0.556	$ 319,335,000
Univ II	3251	1,608	0.495	64,293,000
Univ III	2015	865	0.429	84,886,000
Univ IV	629	252	0.400	9,106,000
Total	17,575	8,674	0.493	$ 509,983,100

*Proposals and awards consist of virtually all program grants and contracts, except proposals from foreign institutions, purchase orders, fellowships, travel awards, and proposals and awards to other Federal agencies.

Source: The National Science Foundation

Table IV.4.--Institutions Applying for and Receiving Research Grants From the National Science Foundation, FY 1974*

Institutional Type	Total Number of Institutions (a)	Institutions Applying for Awards (b)	Effort Ratio (b)/(a) (c)	Institutions Receiving Awards (d)	Recipient Ratio (d)/(a) (e)
1) The College Sector					
Comp Col I	333	265	0.796	224	0.672
Comp Col II	136	88	0.647	65	0.478
Lib Arts Col I	149	107	0.718	88	0.591
Lib Arts Col II	580	296	0.510	166	0.286
2) The University Sector					
Univ I	52	52	1.000	52	1.000
Univ II	40	40	1.000	40	1.000
Univ III	55	55	1.000	54	0.982
Univ IV	30	29	0.967	28	.933
Total	1,375	932	0.678	717	0.521

* Proposals and awards include virtually all program grants and contracts, except proposals from foreign institutions, purchase orders, fellowships, travel awards, and proposals and awards to other Federal agencies.

Source: The National Science Foundation

Table IV.5.--Ph.D. and SC.D. Scientists and Engineers Employed in Universities and Colleges, by Major Field of Employment, Employment Status, and Type of Institution: January 1976

		EMPLOYED IN ACADEMIC INSTITUTIONS GRANTING				
FIELD AND EMPLOYMENT STATUS	TOTAL	DOCTORATE IN S&E	MASTER'S IN S&E	BACHELOR'S IN S&E	OTHER DEGREES	2-YEAR INSTITUTIONS
ALL FIELDS						
TOTAL	139,936	99,132	19,992	15,219	406	5,187
FULL-TIME....................	126,160	90,570	17,914	13,757	249	3,670
ENGINEERS						
TOTAL	14,984	13,353	1,010	373	18	230
FULL-TIME....................	13,451	12,085	832	355	18	161
PHYSICAL SCIENTISTS						
TOTAL	21,979	13,983	3,425	3,294	44	1,233
FULL-TIME	20,270	13,102	3,171	3,053	26	918
ENVIRONMENTAL SCIENTISTS						
TOTAL	5,241	3,797	903	390	22	129
FULL-TIME....................	4,899	3,591	841	361	9	97
MATHEMATICAL SCIENTISTS						
TOTAL	13,386	8,445	2,487	1,843	42	569
FULL-TIME....................	12,223	7,856	2,279	1,695	26	367
LIFE SCIENTISTS						
TOTAL	42,818	32,255	3,448	2,977	77	1,061
FULL-TIME....................	39,041	32,176	3,227	2,774	48	816
PSYCHOLOGISTS						
TOTAL	13,873	7,237	3,276	2,363	78	919
FULL-TIME....................	11,438	6,155	2,734	1,957	48	544
SOCIAL SCIENTISTS						
TOTAL	27,655	17,062	5,443	3,979	125	1,046
FULL-TIME....................	24,838	15,605	4,830	3,562	74	767

Source: Manpower Resources for Scientific Activities at Universities and Colleges, January 1976. Detailed Statistical Tables, Appendix B, Table B-50 (NSF 76-321).

Table IV. 6--Federal Research Funds to Colleges (percentages)

	All Federal Funds		
	FY 1972	FY 1974	FY 1975
Comprehensive College I	77	82	83
Comprehensive College II	8	7	6
Liberal Arts College I	12	9	9
Liberal Arts College II	3	2	2

Thus, most Federal research monies went to the colleges in the category Comprehensive College I, the group most resembling universities. The same group of institutions has about two-thirds of the total enrollment of the four groups (see Table IV.1). Meanwhile, in the Liberal Arts College I group, Federal funding decreased from 12 to 9 percent, or, of total academic research and development, from about 0.5 to 0.4 percent. These colleges actually received fewer dollars in 1975 than in 1972, while the amount flowing to Comprehensive College I institutions increased from about $57 million to $85 million. (These colleges funded 32 percent of their research activities from their own resources.)

As shown in Table IV.3 (individual applications and awards) and Table IV.4 (experiences of institutions), NSF funds for academic research, like all Federal funds, go overwhelmingly to the University I category and to universities in general (as compared with colleges). Colleges, however, received 6 percent of NSF research funds going to academic institutions, compared with 3 percent of all Federal funds. But the success ratio (of awards to applications) for individual applications is relatively even among the categories. The heavy concentrations of NSF research support in universities were statistically related more to the large volume of proposals from certain types of institutions than to differential relative success in winning awards (Table IV.3). In FY 1974, over 8,000 applications for support were received from University I category institutions, compared with less than 500 from the Liberal Arts College I group. Success ratios for these two categories were 56 percent and about 50 percent, respectively. Among all eight types of institutions, the Liberal Arts College I had a relatively high success ratio of awards to applications. For institutional performance (Table IV.4), both the "effort ratio" and the "recipient ratio" show much more variation.

Although the subcommittee requested that this report address NSF research support rather than education assistance, it should be noted that the substantial reduction in NSF science education budgets in recent years had considerable impact on the colleges. The colleges have also suffered from a shift in NSF research funding from academic institutions to nonacademic organizations (including other Government agencies, private profit organizations, and federally funded research and development centers).[2]

Research Environment and Productivity

The preceding discussion centered on the actual distribution of NSF research funding among colleges and other types of academic institutions. There are, however, other questions to be considered; (1) Is the actual distribution optimal and fair; and (2) Do college faculty members perceive the distribution, and the peer review system which guides it, as equitable?

One aspect of the problem of determining the optimal pattern of distribution involves the relationship between research and undergraduate education. For a substantial portion of both teachers and undergraduate students, research strengthens education. Research grants to the colleges thus serve both educational and research needs.

The research environment varies enormously among these institutions. Some are totally hospitable to research and research training. Others are restricted by governing body or administration policy to a narrowly defined teaching function; research must take place on an individual's own time and is not a part of the regular faculty assignment.

The population of potential research grant recipients is some fraction of the staff members who have the doctorate. There is, however, no objective basis for estimating the number of qualified staff members who

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2. An NSF special analysis comparing the periods 1969 and 1975, found that of all NSF funding of research in both academic and nonacademic institutions, the academic share fell from 83.4 percent in 1969 to 74.1 percent in 1975. Of shares to academic institutions, the portion going to the "less-than-doctorate" institutions fell from 6.2 to 3.3 percent. Much of this decline reflects the introduction of the RANN program and mission-oriented basic research efforts funded outside of academic organizations.

wish to do research of the type and quality NSF programs require. Some faculty members who are interested in research and capable of doing first-class work prefer to locate at colleges rather than at universities so that they can spend a larger percentage of their time in teaching functions. At institutions that encourage research, availability of faculty time is a major determinant of research potential. Average teaching loads (class contact hours per week) are greater in colleges than in most universities. In the smaller liberal arts colleges, smaller class enrollments tend to alleviate teaching responsibilities. An informal survey of campus liaison officers, (there were 13 respondents, all members of the American Association of State Colleges and Universities that participate in AASCU's Office of Federal Programs service) found the respondents:

> . . . were unanimous in their agreement that there are severe barriers at smaller institutions to faculty research and the preparation of proposals for external funding. The problem most frequently cited is heavy faculty teaching loads: a twelve hour course load is the norm at many institutions, and faculty cannot be released from teaching duties unless personnel costs are included in the grant.[3]

NSF attempts where possible, to relieve teaching loads of researchers who receive grants.[4]

Another factor limiting the quantity of research production in the colleges is that faculty researchers often are assisted by undergraduate students. Faculty members have an educational obligation to undergraduate students, but because students at this level are relatively untrained in research procedures, the research process is likely to take longer than if the work were performed by graduate students and post-doctoral fellows, who normally assist faculty researchers in the major universities.

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3. "National Science Foundation Research Support to Four-Year Public Institutions," Unpublished report by American Association of State Colleges and Universities, August 1977.

4. "As a general policy the Foundation recognizes that salaries of faculty members and other personnel associated with the research constitute appropriate direct costs in proportion to the effort devoted to the research." Grants for Scientific Research, NSF 76-38, p. 11.

It has been suggested that NSF reviewers make allowance for the lesser quantity of previous research publications by certain applicants. Reviewers often do not recognize and allow for this factor. The Board is reluctant to impose any formal regulation regarding this matter but does believe it desirable to call this matter to the attention of ad hoc and advisory panel reviewers.

Research that requires large teams, numerous technicians and graduate research assistants, or expensive facilities and equipment is extremely difficult to conduct in 4-year colleges. Whole areas of science for which NSF has special responsibility are dominated by team research or require major facilities and therefore are rarely or never found in the colleges. Atmospheric science, physical oceanography, and high energy physics are examples. The fact that NSF allocates a large part of its budget to these fields inevitably results in a high concentration of awards in doctoral institutions. Similarly, NSF's engineering grants tend to go to institutions where most of the engineers who hold doctorates are located, i.e., universities. The Research Applied to National Needs (RANN) projects have often required large research teams and thus also have tended to concentrate in large institutions.

In many areas of biology, psychology, chemistry, and social sciences, research can be carried out by individual investigators without major facilities or numerous assistants. This type of research can be and is supported by NSF grants to colleges as well as to universities. College faculty members are encouraged to work at national centers and observatories. For several years, NSF research programs have reserved a small block of funds (about $400,000 annually) for the purpose of supplementing existing research grants at universities in order to permit college faculty members to perform as research associates on major projects. Eighty-eight such awards were made in FY 1975. Announcements in the NSF Bulletin and publicity given by college associations apparently have made availability of these funds more widely known than in earlier years.

The Ladd and Lipset survey asked the question: "How many of your professional writings have been published or accepted for publication in the last two years?" The four college sectors showed considerable differences.[5] Sixty-five percent of the faculty members in the Liberal Arts Colleges I category had at least one publication. This compares with 30 percent in Liberal Arts Colleges II, 53 percent in Comprehensive Colleges I, and 31 percent in Comprehensive Colleges II. The college and university sectors overlapped, with the 65 percent figure of the

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5. Data compilation and analysis based in part by work done under NSF contract by Burton Clark, Yale University, including Ladd-Lipset Survey of American Professors (1975).

leading liberal arts colleges ranking between the third and fourth of the four university sectors. In publishing 5 times or more in a 2-year period, all university sectors were stronger than the leading college sector. Heavy individual producers were found to be about four times more likely to appear in leading universities than in leading colleges.

In general, it appears that faculty in the college segment of American higher education do conduct research. Even in the least productive sectors, nearly a third of the faculty has published in the last 2 years. The leading college sectors have a substantially better record, enough to cause them to overlap the university sectors.

College faculties and their colleagues in many universities, however, perceive that NSF research funds are not available to them. A recent and extensive survey of the NSF peer review system[6] included the question:

> In general, if two equally and good proposals are submitted to NSF in your area, one from a well-known institution and one from a lesser-known institution, do you think both proposals have an equal chance of being recommended for funding by the peer reviewers or one has a better chance than the other?

The percentage distributions of responses from 1,036 NSF reviewers and 2,641 recent applicants are shown in Table IV.7.

Table IV.7--Perceptions of NSF Fund Availability

	Reviewers	Applicants
Both have an equal chance	28.9	15.9
Proposal from well-known institution has better chance	51.1	60.6
Proposal from lesser-known institution has better chance	2.2	2.7
Don't know	17.9	20.7

6. "Perceptions of the National Science Foundation Peer Review Process: A Report on a Survey of NSF Reviewers and Applicants," prepared for The Committee on Peer Review, National Science Board and The Committee on Science and Technology, U.S. House of Representatives by Deborah R. Hensler, December 1976, Table 14.

Thus, a majority of reviewers and applicants thought that the NSF peer review process does favor proposals from well-known institutions. Reviewers are somewhat more likely than applicants to think the system gives proposals from lesser known institutions an even chance. These perceptions reflect the views of some scientists in institutions (colleges or universities) who do not attempt to obtain NSF grants. The NSF staff has been requested to increase its use of reviewers and advisory panelists from all types of institutions and to encourage proposals from the Nation's colleges.

Peer Review Processes

One way to improve both the fairness of the review process and perceptions of its fairness is to use qualified reviewers from all types of institutions. The National Science Board has instructed Foundation program officers to seek panel and advisory group members from all types of institutions, including colleges. In the survey sample of FY 1975 NSF reviewers, slightly more than two-thirds of NSF peer reviewers were located at Ph.D.-granting universities, and about 7 percent were at 4-year colleges or institutions with limited Ph.D. programs (others were in Government or industry). It is reasonable to expect that most reviewers will themselves be active researchers and will be located in universities. However, the number of reviewers from the other institutions can be increased to this end, bio-bibliographical sketches of potential reviewers and advisory group members from colleges have been submitted to the Foundation and the Board encourages the use of suitable persons. In June 1977, the American Association of State Colleges and Universities assisted the Foundation in compiling a list of over 700 faculty persons from member institutions who would be suitable for appointment to NSF peer review panels or advisory groups.[7] Other similar lists have been sent to NSF program officers.

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7. A sample of the selected list (the names suggested to the mathematical, physical sciences, and engineering programs) has been compared with the list of reviewers the Foundation has been using in its research or education programs over the last 2 years. More than one-fourth of the names were already on the NSF list of reviewers, which perhaps indicates reasonably good mutual agreement on criteria for selection between NSF and college administrative staff.

Summary, Conclusions, and Recommendations

Concern about NSF support of research in undergraduate teaching (nondoctoral degree awarding) institutions stems from the desires to (a) foster quality research, wherever located; (b) improve the education process and permit greater numbers of undergraduates to participate in or have contact with research; and (c) insure fairness to all potential applicants and reviewers. The operational aspects of these concerns appear to be:

1. NSF research support and total Federal funding are heavily concentrated in universities with doctoral degree programs. When all academic institutions are grouped into eight categories (four types of universities and four types of colleges), research proposals from the Liberal Arts College I group have success ratios comparable with the University I group. NSF awards to the Comprehensive College I category have been increasing, but decreasing as compared to those in the Liberal Arts College I category.

2. Part of the concentration pattern is explained by the need for certain types of research to take place where there are specialized facilities, large equipment, and numerous graduate assistants. Some fields of science for which NSF has special responsibility are predominantly of this character.

3. The Board does not believe that circumstances warrant establishment of special advisory panels or separate competitions for proposals from colleges. It is possible, however, to eliminate certain problems in the review process and certain negative perceptions by:

   a. increasing Foundation use of college faculty members as *ad hoc* proposal reviewers and advisory panel members, increasing the perception of fairness college faculties have of NSF practices;

   b. recognizing and making allowance for the effect of teaching loads and for the necessity to supervise closely less experienced research assistants, both of which restrict the quantity of research output from scientists in the colleges;

c. continuing to develop arrangements that enable scientists at institutions with equipment limitations to work at well equipped laboratories part-time or during summers;

d. continuing the Board's oversight of the Foundation's review processes in order to minimize biases.

In today's strenuous competitions many very good applications cannot be funded. Funds for supporting research are inadequate to make awards for many promising scientific projects submitted by well qualified applicants from all types of institutions. The Board recognizes its responsibility, however, to insure that the available research monies are equally accessible to all performers, that all types of research performing institutions are treated objectively and equitably, and that scientists in 4-year colleges are not discriminated against.

MISMATCH

V. MISMATCH: THE PROBLEM OF THE IMBALANCE BETWEEN RESOURCES AND DEMANDS

SUBCOMMITTEE RECOMMENDATIONS AND NSB FOCUS OF ACTION

In its report, the Subcommittee recommended that:

> The National Science Board should establish an internal Foundation program to monitor problems arising from the mismatch between the size of Foundation funds available for support of that community, and should report periodically to Congress.

Examination of the Problem

The Nation began to expand its support of scientific research in the years following World War II. This expansion culminated in a massive infusion of Federal funds in the decade beginning in the late 1950's. By 1968, nearly 3 percent of the Gross National Product (GNP) was dedicated to R&D. A new scientific capability with new practitioners, new facilities, and expanded educational opportunities was created. This funding pattern also created new expectations for support. But as the Nation's priorities changed in the late 1960's, Federal support for R&D decreased. By 1976, total Federal R&D expenditures had fallen to 2.2 percent of GNP. In 1972, the Board noted that the situation represented "a challenge to which the Government, educational and research structure had not yet fully adapted". [1]

The situation is especially difficult for the basic research community, where Federal support constitutes two-thirds of total expenditures. Federal funds for the support of basic research for academic science have stopped increasing and have decreased in real dollars. (Basic research today accounts for less than 0.3 percent of the GNP as compared with 0.38 percent in 1965.) It has only been in the past 2 years that real dollar support to basic science has begun to improve. But problems remain. Despite a decade of readjustment, there remains a "mismatch" between research opportunities and available resources and a lack of continuity and stability in research support. An expanded (and still expanding) number of capable scientists - many of whom were trained during the past 2

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1. NSB Science Indicators, 1972, Washington, D. C., 1973, p. 32.

decades and who now should be in especially productive periods of their careers--find it increasingly difficult to obtain the support required to conduct their research.

The Board and the National Science Foundation have long been concerned about this mismatch. Several mechanisms have been established to insure that objective assessments are made of developing trends and that appropriate attention is given to determining the needs of research performers. As a result, new programs and administrative procedures have been created so that finite resources can be allocated better to meet the changing needs of the research community. The more significant of these monitoring mechanisms are summarized below.

Monitoring the Science Base

Science Resource Studies. The Science Resources Studies program within the Foundation maintains a comprehensive data base to determine trends and shifts among scientific and technical manpower as well as the distribution of the Nation's R&D effort. The Manpower Characteristics System provides information regarding the economic, professional, and demographic conditions of the Nation's two million scientists and engineers. The National Patterns of R&D Resources published annually provides data on the national R&D effort in terms of performers, source of funding (public/private), and manpower distribution. This report is the only source of national totals and permits an integrated assessment of trends among individual sectors.

Science Indicators. The Board surveys, compiles, analyzes, and publishes significant data regarding scientific manpower and funding in the biennial series, Science Indicators. A variety of indicators representative of the status of science and its various disciplines is reported. Particular attention has been focused on examining resources dedicated to basic research, the funding levels of private organizations and public agencies, and the location of performers. Other indicators, such as the number of publications produced by the different sectors in major fields, seek to monitor the scientific output of various sectors. Using such indicators together with its collective professional judgment, the Board seeks to determine trends and direct attention to areas requiring further study and/or action.

Annual Reports of the Board. The Board has a statutory responsibility to report annually on the health of science.[2] In recent years this

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2. Every other year this report is the Science Indicators report.

report has focused on dimensions of the gap between the needs of research performers and available resources. Science at the Bicentennial, the eighth board report, noted that, "scientific research, after a period of relative well-being, is today exposed to severe stress." A survey of hundreds of researchers, administrators, laboratory directors, and academic departments revealed significant concern over the future. The one universally identified need was for greater continuity and stability in research funding. This need, in fact, may be as significant as the problem of funding levels. This survey adds an important dimension to the Board's perception of the disparity between the capacity of the sciences base and the availability of funds.

Special Analyses by the Foundation. The Foundation also conducts or sponsors special studies to determine the impact of research funding and policies on the Nation's research base. One such recent study based on a survey of 36 universities found that the relative shrinkage of research funding has introduced considerable tensions and strains within the academic community.[3] While the full findings of the study go well beyond the problem of resource shortfall, there are two substantive findings that deserve mention here. One is the growing need of greater support for instrumentation. The other finding, less tangible, is the deterioration of Government/university relations. Much of the difficulty is traceable to funding limitations. As money has become relatively more scarce, the process of its acquisition has become much more competitive, as well as " . . . more elaborate, time consuming, and bureaucratized," One result has been an increase in overhead costs for those seeking grant support.

External and Internal Program Oversight

In addition to these monitoring mechanisms, the Foundation and Board have initiated specific program planning procedures and more extensive external oversight in order to provide a greater capacity for informed decisionmaking.

The Foundation and Board recently acted to strengthen procedures to address the challenges of the changing research environment. In April 1977, the Director established a plan for extensive evaluation and external oversight of Foundation programs. The internal evaluation activity of

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3. Smith, Bruce, L. R., and Karlesky, Joseph, The State of Academic Science, a study financed by the National Science Foundation under the auspices of the Association of American Universities.

the Foundation itself was expanded, and formal external oversight groups were established to augment the Foundation's permanent advisory committees. Composed of recognized scientists and research administrators, these committees provide advice and guidance to the major organizational subdivisions.

To this central advisory committee structure an external system was added that established oversight review for each Foundation research program. Every several years experts external to the Foundation will conduct a detailed review of each program. It is intended that these reviews will examine all aspects of the program: scientific quality and balance, decisionmaking procedures, funding decisions, and quality of program management, including the adequacy of peer review. The review teams will have complete access to all information required to accomplish this task and are expected to monitor the adequacy of the Foundation decisionmaking process under conditions of increasing proposal pressure.

The detailed procedures for these reviews are currently being developed on the basis of a trial effort in chemistry. In this study, teams of outside experts spent 2 days reviewing all project funding decisions made during FY 1975 in the eight subprograms and found:

- In all cases, the average grant size was too small;
- One subprogram had a reasonable budget; four had budgets that were much too small;
- One subprogram had a "failure of correlation" between the quality of proposals made to it and funds made available to it;
- In all eight subprograms, the selection and performance of reviewers was excellent;
- Overall, all subprograms seemed to be doing well in funding the best possible set of proposals.

On balance, the review found that despite budget tightness and severe proposal pressures, the high quality of the decisionmaking process was being maintained within the chemistry program.

These new oversight procedures and additional review mechanisms will operate most effectively if managed by a single, high-level organizational unit. Accordingly, effective October 15, 1977, the NSF audit office, evaluation staff, and oversight staff were transferred to a new

Office of Audit and Oversight. This office, which reports to the Director of the Foundation, will be better able to coordinate these functions.

But the increasing number of proposals, decreasing average grant size, and subsequent need for closer review of the award process have also created increasing workloads for NSF staff. Thus far the Foundation has coped with the problem by procedural improvements and a limited increase in the professional staff. Continued additions to the staff will be essential.

The Role of the Program Director

The NSF program directors and section heads provide much of the specialized knowledge required to assess questions of imbalance between funding and scientific opportunity in the various scientific disciplines. They help maintain awareness of the opportunities for improvement in a discipline and continually assess research, infrastructures, resource needs, unique opportunities, and actions and interests of other agencies and industrial researchers. Using a variety of techniques, including visits to locales where research is in progress and participation in various conferences and technical meetings, the program directors pay close attention to detail and quality so that they can provide the best means for optimal allocation of resources.

Planning Environment Review

The Foundation and the Board have recently instituted new procedures designed to strengthen agency-wide planning and decisionmaking. The Board requested that the Foundation provide an annual review of the various disciplines in science and assess the important factors affecting the Nation's research capabilities. This review of the planning environment concentrates on the infrastructure, manpower, funding, and political factors affecting each discipline. Introduced last year, the planning environment review has become the principal means by which the Board identifies and defines significant policy issues so that it can make informed decisions on policy and funding.

Summary

An important task of the Board and the Foundation is to monitor the various problems caused by the discrepancy between the capacity of the science research community and the resources that can be made available to support its undertakings. Both seek to carry out an accurate assessment of the many trends and developments affecting resources for science. To provide a basis for budgetary recommendations, the Board and Foundation conduct or sponsor periodic and special surveys designed to measure and interpret both funding and research output trends. New organizational arrangements have been introduced within the Foundation to help Board and Foundation officials achieve a better understanding of both the performance of and specific problems faced by all program elements of the Foundation.

APPENDICES

APPENDIX A

TEXT OF SECTION E FROM THE REPORT OF THE SUBCOMMITTEE ON SCIENCE, RESEARCH, AND TECHNOLOGY
January 1976

E. NATIONAL SCIENCE BOARD

In the course of considering peer review at the Foundation it became clear that there are many important issues which should not be judged without further careful study by persons familiar with peer review systems, further collection of information, or further analysis after the elapse of a period of time. The Subcommittee considered arguments that Congress ought to judge these issues and set Foundation policies but is convinced it is preferable to keep the responsibility for setting Foundation policies lodged in the National Science Board as legislated in the Foundation's organic act.

The Subcommittee recommends in this report that the National Science Board devote further study to eight issues. It is desirable that the Board turn its attention promptly to these issues. The Subcommittee will stay informed of the Board's progress to assure that the issues are sufficiently addressed:

Finding: There is a clear need for firm policy guidance in the management of peer review at the National Science Foundation. Experience in science and with the scientific community, as well as carefully assembled objective information, are essential to the formation of sound policies governing peer review.

Recommendation: The National Science Board should have primary responsibility for the establishment of policies governing peer review at the National Science Foundation.

The National Science Board should—

1. Study the support of innovative research and report to Congress.
2. Study the support of young scientists and report to Congress.
3. Study the funding of research at undergraduate-teaching institutions without graduate departments (colleges) by the Foundation and report to Congress.
4. Study the extent to which the Foundation should rely on peer panel review and report to Congress.
5. Establish an internal Foundation program to monitor problems arising from the mismatch between the size of the scientific community and the amount of Foundation funds available for support of that community, and should report periodically to Congress.
6. Study the question of whether the National Science Foundation should have formal procedures for considering appeals of decisions made on award applications and should report to Congress.
7. Study the effects of publication of the list of reviewers used by the Foundation and consider whether publication of the list in a less aggregated form might be desirable.
8. Collect further information concerning effects on the peer review system of the level of confidentiality in which peer reviewers' names and verbatim comments are held. The Board should report the information and any conclusions that may be drawn from it to Congress. Further changes in the level of confidentiality of the Foundation's peer review system should be made slowly if at all.

NATIONAL SCIENCE FOUNDATION
Office of the Director
Washington, D.C. 20550

Notice No. 59 June 30, 1975

IMPORTANT NOTICE

TO

PRESIDENTS OF UNIVERSITIES AND COLLEGES AND HEADS OF OTHER NSF GRANTEE ORGANIZATIONS

SUBJECT: **National Science Board Resolution on Peer Review Information**

The National Science Board has unanimously adopted a resolution that reemphasizes the need that proposals to NSF be evaluated as fairly as possible and that there be wide participation of qualified individuals in the review process. The Board reaffirms its belief that the review process should be conducted as openly as possible and with as much information to proposers as possible, consistent with the effective evaluation of proposals.

Following is the text of the resolution of the Board on peer review information:

1. The Foundation will publish annually a list of all reviewers used by each Division;
2. Program officers should seek broadly representative participation of qualified individuals as reviewers;
3. Verbatin copies of reviews requested by the Foundation after January 1, 1976, not including the identity of the reviewer, will be made available to the principal investigator/project director upon request. The question of including the identity of the reviewer will be considered further by the National Science Board;
4. The Foundation, upon request, will inform the principal investigator/project director of the reasons for its decision on the proposal.

Items 2. and 4. of the resolution are procedures that have always been employed by the National Science Foundation; items 1. and 3. represent changes in prior practices. It is expected that these changes will lead to better communication between proposers and the National Science Foundation and, in general, help clarify the basis on which decisions are made. The peer review process has well served the scientific community and is the cornerstone for the management of much of the Federal support of science and technology in the United States; the Board's resolution strengthens the peer review process, thereby, insuring the continued vigor of research and development in the United States.

H. Guyford Stever
Director

NATIONAL SCIENCE FOUNDATION
Office of the Director
WASHINGTON, D.C. 20550

January 27, 1976

Notice No. 61

IMPORTANT NOTICE
TO
PRESIDENTS OF UNIVERSITIES AND COLLEGES AND HEADS OF OTHER NSF GRANTEE ORGANIZATIONS

Subject: **Reconsideration of Proposals Declined by NSF**

1. *Purpose.* The processes by which the National Science Foundation determines whether or not to award a grant for funding a proposal have been designed to result in funding of the highest quality science. To ensure the fairness of the design, the Foundation has for many years provided methods by which such processing could be reviewed at the request of a proposer who questioned the validity of the evaluation.

This Important Notice, effective immediately, makes uniform the methods for reconsideration which have heretofore varied in different parts of the agency. The Notice describes the types of reconsideration which the Foundation makes available to individuals and institutions concerning proposals.

This Notice does not apply to procurements governed by the Federal Property and Administrative Services Act or to applications for fellowships or travel grants.

2. *Policy.* Although award of NSF grants is discretionary, it is the policy of the Foundation that an applicant for NSF grant assistance whose proposal has been declined shall have an opportunity to receive an explanation from the appropriate Program Director, and reconsideration where the applicant has reason to believe that the proposal did not receive a fair and impartial initial evaluation. Where a proposal has been declined following review by the National Science Board, only an explanation will be available. Reconsideration is not an adversary process and a formal hearing will not be provided. The Foundation cannot assure applicants that reconsideration will result in the making of a grant award even if error is established in connection with the initial evaluation.*

3. *Definitions.*

a. "Declination" is a written notice by the Foundation advising that grant assistance will not be provided to the applicant in response to a proposal application, a renewal application or a continuing application.

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* NOTE: Evaluation of proposals usually includes subjective professional judgments by peer scientists concerning scientific merit, relevance, significance to the discipline or to the problem being addressed, scientific competence and experience of the investigators, and adequacy of facilities and available support. Since funds available are usually insufficient to support all meritorious proposals, selection of proposals for funding must include consideration of the merit of a particular proposal relative to other proposals and availability of funds. Other factors considered include programmatic choices such as the relevance and significance to the NSF program from which the funds are to be allocated, and the need both to strengthen research and education in the sciences throughout the United States and to avoid undue geographical concentration.

DRAFT
Does Not Necessarily

b. "Principal Investigator" or "PI" means the individual designated by the applicant and approved by NSF to be principally responsible for the scientific or technical direction of the work described in a proposal. In some instances, the title "Project Director" is used instead of Principal Investigator.

c. "Applicant" or "Institution" means the academic, scientific, or other organization which submits a proposal. A Principal Investigator is, in most instances, affiliated with or employed by the applicant institution which submits a proposal. In rare instances, an individual may be both the applicant and the Principal Investigator.

d. "Authorized Institutional Representative" means the administrative official who is empowered to commit the applicant to the conduct of a project if NSF agrees to support it and who, by his or her signature on the proposal, is responsible for the prudent administration of the grant by the grantee institution if NSF awards a grant.

4. *Explanation by Program Director.* A Principal Investigator desiring information concerning a declination should request an explanation from the appropriate Program Director by letter, by telephone, or in person. The Program Director will furnish information concerning the basis for the NSF action including, when requested, verbatim comments of peer reviews with the names and other identifying data of the individual reviewers deleted where such reviews were solicited by NSF after January 1, 1976. Reviewer comments solicited before that date will be paraphrased. The Program Director will afford the PI an opportunity to present the PI's point of view and will take such action as is appropriate. If, after declination of award, changes are made to the proposal, such changes will not be considered in connection with reconsideration of the earlier proposal. However, the PI should be informed that a revised proposal may be submitted for consideration as a new proposal under the usual review and evaluation procedures. If the PI is dissatisfied with the Program Director's explanation, he or she may request reconsideration as provided in paragraph 5, below.

5. *Reconsideration.* The Principal Investigator may request in writing that the Foundation reconsider its action provided such request:

- follows the explanation by the Program Director; and
- is postmarked or received by the Foundation no later than 180 days following the date of the declination.

Such request shall be directed to the Assistant Director of the Directorate that handled the proposal and must set forth facts on which the Principal Investigator bases his or her belief that reconsideration is warranted. The Assistant Director may conduct the reconsideration personally or may designate another NSF official to do so provided that no official so designated shall have participated in the initial evaluation.

The Assistant Director or other official designated by the Assistant Director shall reexamine the procedures followed in the initial evaluation to determine whether the proposal had received fair consideration. Such official may request additional information from the PI and may, if deemed necessary, obtain additional peer review comments.

Within 30 days following the date of the request, the Assistant Director shall furnish to the PI in writing the results of the reconsideration. If more time is necessary, the PI will be notified in writing of the reasons therefor and of the date by which the written report is expected to be provided. If reconsideration reaffirms the declination, the Assistant Director will inform the PI of the availability of further reconsideration by the Deputy Director of the National Science Foundation and of the requirements for submitting such a request as provided in paragraph 6, below.

6. *Further Reconsideration by Deputy Director.* Within 180 days following reconsideration pursuant to paragraph 5, above, further review may be obtained by the applicant as follows:

a. *Who may request further reconsideration.* Such request may be submitted only: (1) by the institution which filed the proposal for grant assistance, or (2) where the proposal was submitted by an individual or individuals not connected with an institution, by such individual(s).

b. *Time for submitting request.* A request for further reconsideration must be postmarked or received by the Foundation within 180 days following the date of the written results of reconsideration provided for in paragraph 5, above.

c. *Form of request.* A request for further reconsideration need not be in any particular format, but it (1) must be in writing and signed by the Authorized Institutional Representative and by the PI(s), (2) must state the proposal number (if any), and the title of the proposal, and (3) must set forth the reasons why it is believed that an error occurred in the initial evaluation and all pertinent facts and circumstances in support thereof.

d. *Address request for further reconsideration to:*

The Deputy Director
National Science Foundation
1800 G Street, N.W.
Washington, D.C. 20550

e. *Who shall conduct further reconsideration.* The Deputy Director may conduct the reconsideration personally or may designate one or more NSF officials to do so provided that no official so designated shall have participated in the initial evaluation or in the earlier reconsideration.

f. *Scope of reconsideration.* The Deputy Director or the official(s) designated by the Deputy Director shall review the request and the prior NSF actions concerning the proposal. Administrative judgments previously made concerning award or declination for the proposal will be reexamined. Where such reexamination indicates that administrative judgments as to scientific merit of the proposal may have been influenced significantly by an inadequate or unfair peer review, additional peer review will be obtained.

g. *Report.* A written report of the results of the further reconsideration shall be prepared for submission to the requestor by the Deputy Director within 30 days following the date of the request. If more time is necessary, the requestor will be notified in writing of the reasons therefor and of the date by which the written report is expected to be issued.

h. *Finality.* Once reconsideration by the Deputy Director has been completed, no further reconsideration will be made of the proposal or of a substantively identical proposal submitted thereafter. This does not preclude the submission of a substantially revised proposal in the same program area for consideration as a new proposal under the usual review and evaluation procedures.

H. Guyford Stever
Director

RESOLUTION ON PEER REVIEW INFORMATION ADOPTED BY THE NATIONAL SCIENCE BOARD AT ITS 174TH MEETING ON JUNE 20, 1975

The National Science Board has examined the use of peer review in the National Science Foundation decision process on grant awards and declinations. The Board intends the peer review process to aid the effective evaluation of proposals with the fairest possible treatment of each individual proposal and the broadest possible participation of qualified scientists and other appropriate persons. The Board intends that the review process be conducted with as much openness and information to proposers as possible consistent with the effective administration of the decision process. To these ends the National Science Board RESOLVED that:

1. The Foundation will publish annually a list of all reviewers used by each division and office.

2. Program officers should seek broadly representative participation of qualified individuals as reviewers.

3. Verbatim copies of reviews requested by the Foundation after January 1, 1976, not including the identity of the reviewer, will be made available to the principal investigator/project director upon request. The question of including the identity of the reviewer will be considered further by the National Science Board.

4. The Foundation, upon request, will inform the principal investigator/project director of the reasons for its decision on the proposal.

All reviews requested prior to January 1, 1976, will continue to be governed by earlier policies, since those reviews will have been solicited with a commitment on the part of the Foundation to the confidentiality established by that earlier policy.

The National Science Board believes this new policy will serve to improve the information exchange with the scientific community and allow it to understand better the reasons behind Foundation decisions.

March 30, 1977

APPENDIX D

POLICY REGARDING PEER REVIEW ENDORSED BY THE NATIONAL SCIENCE BOARD AT ITS 188TH MEETING ON MARCH 17-18, 1977

Responsibility for all award decisions rests with the National Science Board or other Foundation official(s) to whom such authority has been formally delegated. NSF program officers have the responsibility to select those proposals recommended for funding. In fulfilling these responsibilities, peer review is one of the most important sources of information and advice about proposal quality. The policy regarding peer review described here is intended to make the award decision process as fair, effective, open, and efficient as possible, recognizing that in some cases there may be conflicts among these objectives. It includes earlier decisions made by the Board on this subject and provides additional guidance, particularly in documenting and reporting on the peer review process and its use.

I. It is the policy of the National Science Foundation that the evaluation of all formal proposals for NSF funding includes external peer review with the following exceptions:

A. Proposals submitted in response to formal solicitations that are governed by the Federal Procurement Regulations.

B. Proposals to provide goods or services normally obtained through purchase orders or requisitions.

C. Other proposals for which peer review has been waived by the Director or his designee. A report on the use of this category of exception must be included in the Director's periodic report to the Board on the award decision process. Some classes of proposals may be excepted categorically, such as travel grants, committed renewals, etc.

D. Proposals which are withdrawn prior to decision.

II. Peer review generally takes the form of ad hoc or mail reviews; reviews by an assembled panel of peers; or a combination of the two. Each program shall select one primary method for peer review which will represent the minimum review received by proposals in that program. This primary method of peer review can be supplemented with additional reviews, site visits, etc., as needed for individual proposals or activities.

After approval by the Director or his designee, the primary method of peer review in each program, including the evaluation criteria reviewers are requested to consider in reviewing proposals, shall be suitably announced.

III. The peer review process is intended to aid in the effective evaluation of proposals and to assist in assuring that each proposal receives full and fair consideration. Selection of reviewers shall be made in accordance with criteria established to accomplish this objective. Factors to be considered in the selection of reviewers include an appropriate representation of relevant skills, viewpoints, and backgrounds needed to evaluate each proposal. To the extent practical, reviewers should be selected to obtain a wide representation of reviewers in terms of geographic distribution, type of institution represented, race and sex of reviewers, etc.

IV. Principal investigators shall be informed by the Foundation of the availability upon request of: (A) verbatim, unsigned copies of all peer reviews; (B) the criteria established for the review; and (C) a summary of the Foundation's reasons for its decision on the proposal.

V. In no case is a review to be associated with an individual panel member, a reviewer (panel or ad hoc), or subgroup of an entire panel, except as required by law. Names of ad hoc reviewers are confidential and are not to be released except as required by law or as provided in VI. below.

VI. The Director shall provide the Board no less than annually a report on the Foundation's use of peer review. This report shall include:

A. A published list, by Division, of all reviewers used during the preceding year.

B. Information on the waiver of peer review for proposals under Section I.C.

C. Statistical analyses of the use of peer review.

D. Recommendations for change or further consideration of the Foundation's policies on peer review.

E. Such other information as the Director may feel appropriate.

APPENDIX E

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Peer Review and the Support of Science

A statistical analysis of the evaluative procedures on which the National Science Foundation bases its funding decisions provides no evidence to substantiate recent public criticisms

by Stephen Cole, Leonard Rubin and Jonathan R. Cole

For more than 25 years the National Science Foundation has played a major role in the expenditure of public money for the support of science in the U.S. Currently the NSF accounts for about 20 percent of the funds distributed by the Federal Government for basic scientific research and more than 30 percent of the Federal funds allocated for such research at universities. The NSF awards its grants on the basis of a decision-making process commonly known as peer review. The term is derived from the fact that the Government officials responsible for deciding which investigators receive grants rely on the evaluations of other investigators in the same discipline.

In recent years the peer-review system has been attacked for a variety of reasons by certain members of both the scientific community and the Congress. Hearings on the alleged inequities of the peer-review system were held two years ago by a subcommittee of the House Committee on Science and Technology.

In an effort to assess the validity of the public criticisms of the peer-review system raised in the Congressional hearings and elsewhere we have been engaged for more than a year in a sociological study of the operation of the peer-review system at the NSF. This study, which is being conducted for the National Academy of Sciences, is supported by grants from the NSF; we have nonetheless had complete autonomy from the NSF in conducting our research. Our results to date have yielded little evidence in support of the main criticisms that have been made of the peer-review system. On the contrary, we have tentatively concluded that the NSF peer-review system is in general an equitable arrangement that distributes the limited funds available for basic research primarily on the basis of the perceived quality of the applicant's proposal. In particular, we find that the NSF does not discriminate systematically against noneminent scientists in the ways that some critics have charged. This is not to say, of course, that there are not errors in individual cases.

How does the NSF peer-review system work? To begin with, a scientist who wants to obtain NSF funds prepares a written proposal describing his past research, his qualifications and the new research he intends to do if he receives funds from the NSF. This proposal is usually submitted to the NSF through the scientist's institution, in most cases a university.

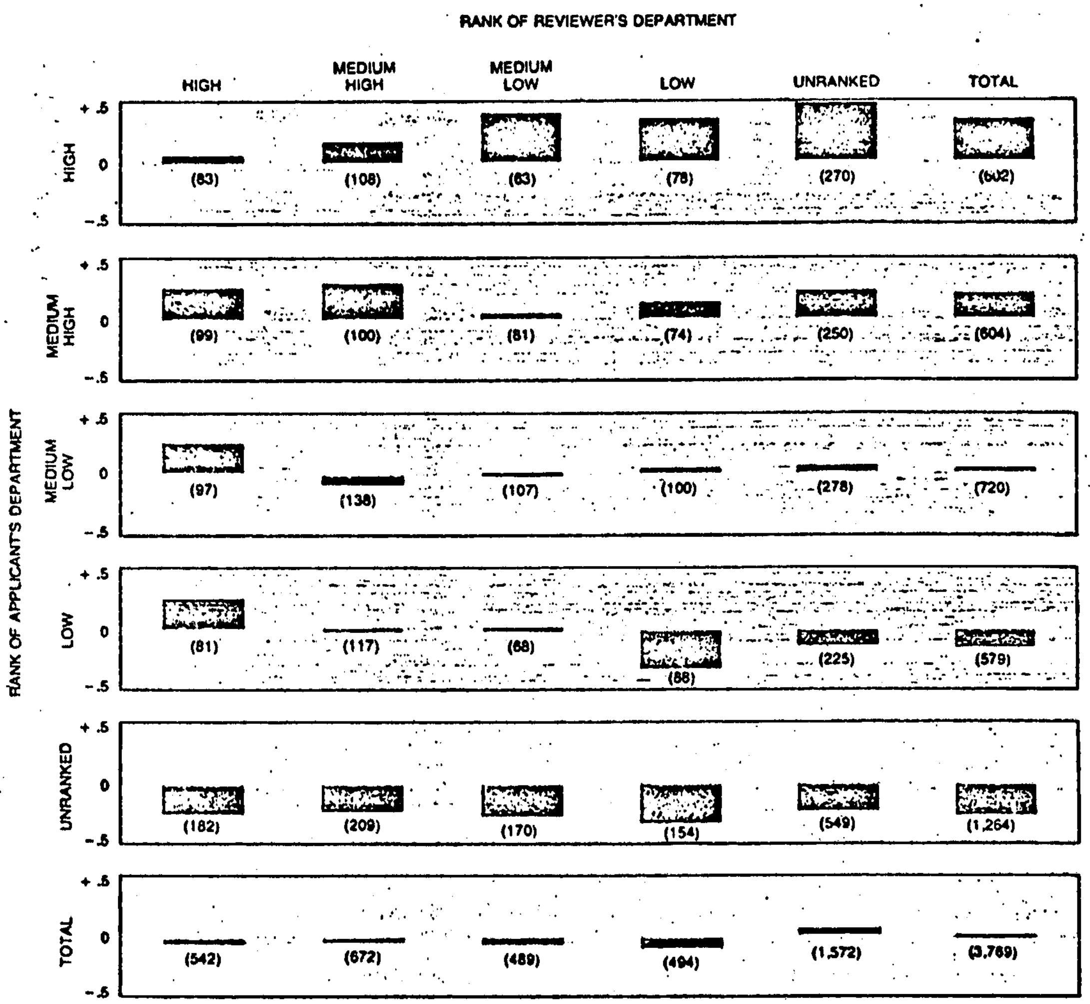
The staff of the NSF is divided into approximately 80 program areas corresponding to the various scientific disciplines and subdisciplines. (The chemistry section, for example, is divided into eight different programs.) When a research proposal comes to the NSF, it is assigned to the appropriate program and is thereafter handled by an employee of the NSF called the program director. On receiving a proposal the program director generally looks it over to determine its specific subject area. He then selects a number of reviewers who are sent the proposal by mail. The reviewers are asked to rate the proposal as being excellent, very good, good, fair or poor and in support of their rating to present written comments evaluating the proposal. In some programs an independent evaluation of the proposal i also made by a panel of scientists wh meet with the program director thre times a year in Washington.

The NSF explicitly states to its re viewers the criteria that should be ap plied in evaluating the proposals. Th main criteria are (1) the significance o the scientific investigation described i the proposal, (2) the ability of the appli cant to carry out the proposed researc and (3) the capacity of the applicant' institution to support the type of re search in question. Where all these fac tors are roughly equal, another set c criteria, including the geographic loc tion of the applicant's institution, ma be considered. Heavy emphasis i placed on the quality of the work de scribed in the proposal and on the pa research performance of the applicant

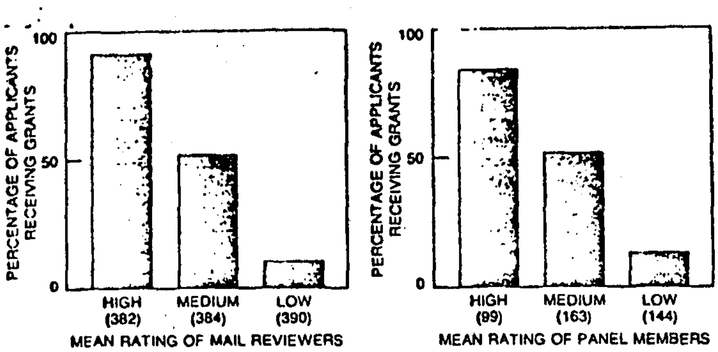
The most fundamental criticis made of the NSF peer-review system that it leads to inequitable decision Critics charge that scientists who a most capable of advancing science a sometimes denied grants and that scie tists who are doing less significant wo are given grants. Former Representati John B. Conlan of Arizona, for exan ple, asserted at the Congressional hea ings that peer review is essentially a elitist system run primarily for the ben fit of a clique of eminent "old boys." H said: "I know from studying materi provided to me by the NSF that this is 'old boy's system' where program ma agers rely on trusted friends in the ac demic community to review their pr posals. These friends recommend the friends as reviewers.... It is an ince fuuds 'buddy system' that frequently stifles new ideas and scientific breakthroughs, while carving up the multimillion-dollar Federal research and-education pie in a monopoly game of grantsmanship."

Critics in and out of Congress maintain that the main organizational condition that gives rise to this unfair distribution of support is the extraordinary power in the hands of the program directors to decide who should get funds. The program director is alleged to be at the center of the old-boy network in which reviewers favorably evaluate the proposals of their friends, eminent scientists favorably review the proposals of other eminent scientists and funds are denied to scientists who are not part of the exclusive old-boy system.

Further abuse is said to be possible because the reviews received by the program director are only advisory, leaving him free to ignore them, and because the program director can predetermine the outcome by selecting a biased group of reviewers. The critics argue that knowledgeable program directors deliberately select reviewers who will be either hard or easy on a particular proposal. Even if



STATISTICAL ANALYSIS of 3,769 peer-review ratings given by various mail reviewers to 1,200 applicants for basic-research grants from the National Science Foundation in the fiscal year 1975 was aimed at testing the "old boy" hypothesis, which holds that the proposals of eminent scientists are apt to be rated more favorably by eminent reviewers than by other reviewers. The ratings in the 10 different program areas studied were first converted into standard scores in the following manner: Within each field the mean rating was set at zero, and the rating received by an applicant was then expressed in terms of the corresponding number of standard deviations above or below the mean rating. A high number means a comparatively favorable rating, and vice versa. Both the applicants and the reviewers were separately classified according to the prestige of their current academic department, as determined in an independent survey. Thus the entry in the upper left-hand corner of the table signifies that there were 83 reviews by reviewers in high-ranked departments of proposals submitted by applicants from high-ranked departments; on the average these reviews yielded ratings that were .05 of a standard deviation above the mean. Since it appears that proposals from applicants in high-ranked departments are actually rated lower by reviewers from high-ranked departments than by reviewers from lower-ranked departments, in this sample at least the data offer no support for the old-boy hypothesis. The analysis does show that applicants from high-ranked departments are slightly more likely to receive favorable ratings than are those from unranked departments, but there is no evidence that this outcome is the result of inequitable treatment.



NSF PROGRAM DIRECTORS appear to rely heavily on the evaluations of the peer reviewers in deciding whether or not a research proposal is to be funded. As the chart at left shows, among the 382 applicants who received comparatively high ratings from the mail reveiwers 92 percent were awarded grants, whereas among the 390 receiving low mean ratings only 10 percent received grants. Similarly, as the chart at right shows, among those proposals that received comparatively high ratings from an independent panel of peer reviewers 84 percent were funded, whereas among those that received low panel ratings only 12 percent were funded. Evidently peer-review ratings are the most important determinant of the program director's decision.

the program director feels compelled by the reviews to support a proposal he dislikes, he can effectively stifle the research by reducing the size of the budget. The program director can supposedly do so because there are no effective checks on his power either inside or outside the NSF. In short, there is no appeals system to challenge the decisions made by the program director.

Critics assert further that the NSF cloaks its activities in secrecy in order to protect the old-boy system, refusing to allow Congressmen or others to see verbatim reviews or to learn the names of the reviewers of particular proposals. This protective shield of confidentiality enables the old-boy system to function unchecked and prevents effective oversight of the NSF by Congress. The ultimate consequence is that the peer-review system actually stifles innovative research, since the eminent scientists who serve as reviewers are likely to reject ideas that differ from their own.

In our study of the peer-review system we decided to limit ourselves at first to an examination of how peer review works in just those NSF programs responsible for the funding of basic research. We have not studied peer review in the NSF's applied-research programs or in its educational programs. Furthermore, we chose a sample of only 10 basic-research programs for detailed study: algebra, anthropology, biochemistry, chemical dynamics, ecology, economics, fluid dynamics, geophysics, meteorology and solid-state physics. Because our intensive analysis included only about an eighth of the NSF's basic-research programs our results may not be generalizable for the entire organization. We are currently conducting follow-up studies of other programs.

Our investigation has combined both qualitative and quantitative sociological techniques. We began by conducting 70 in-depth interviews with scientists involved at all levels of the peer-review system, including program directors, former program directors, mail reviewers, review-panel members and supervisory-level NSF officials. We also scrutinized more than 250 specific research proposals, read all of the peer-review comments on those proposals and examined all of the correspondence between the applicant and the program director. In some cases in which our analysis of the applications raised specific questions about how the peer-review system worked in that particular situation we went back and reinterviewed program directors with the files in hand.

In addition, we conducted a quantitative analysis of 1,200 applicants to the NSF in the fiscal year 1975. (Roughly half of the applicants were ultimately awarded grants.) The purpose of the quantitative study was to identify those characteristics that were correlated with the receipt of a grant from the NSF. Were Representative Conlan and the other critics of peer review correct in their assertion that eminent scientists have a great advantage in the competition for funds and that less eminent scientists, particularly younger ones, are at a serious disadvantage? We shall try to answer this question by summarizing below some of the results obtained so far in our study.

One of the main charges of the critics is that the NSF program director can predetermine the outcome of the peer-review process by sending a proposal to scientists who he knows in advance are biased either in favor of the proposal or against it. We shall call this view the old-boy hypothesis. Presumably the proposals of eminent scientists who are members of the old-boy network are sent to other eminent scientists who give their eminent colleague a favorable evaluation. In return, of course, the reviewers expect reciprocity when their proposals are sent to other members of the old-boy club. Equally important, the proposals of less eminent scientists, who are not part of the network, are sent to scientists who will give them lower evaluations than they deserve. Although we have no direct evidence that the program directors either do or do not select reviewers with a certain outcome in mind, we can see if the outcomes are consistent with the old-boy hypothesis. Are the proposals of eminent scientists actually rated more favorably by eminent reviewers than by other reviewers?

To test this hypothesis we classified both the applicants and the reviewers according to the prestige of their current academic department, as determined by a survey conducted in 1969 by the American Council on Education. The ratings given to the applicants by the reviewers in the 10 programs we studied were standardized separately before being combined into one large table [*see illustration on preceding page*]. For example, there were a total of 83 cases in which an applicant from a high-ranked department had his proposal reviewed by someone who was also from a high-ranked department. The number associated with this particular applicant-reviewer pair (+.05) indicates the average rating (in standardized units) given by high-ranked reviewers to proposals from high-ranked applicants. The higher the number, the higher the rating.

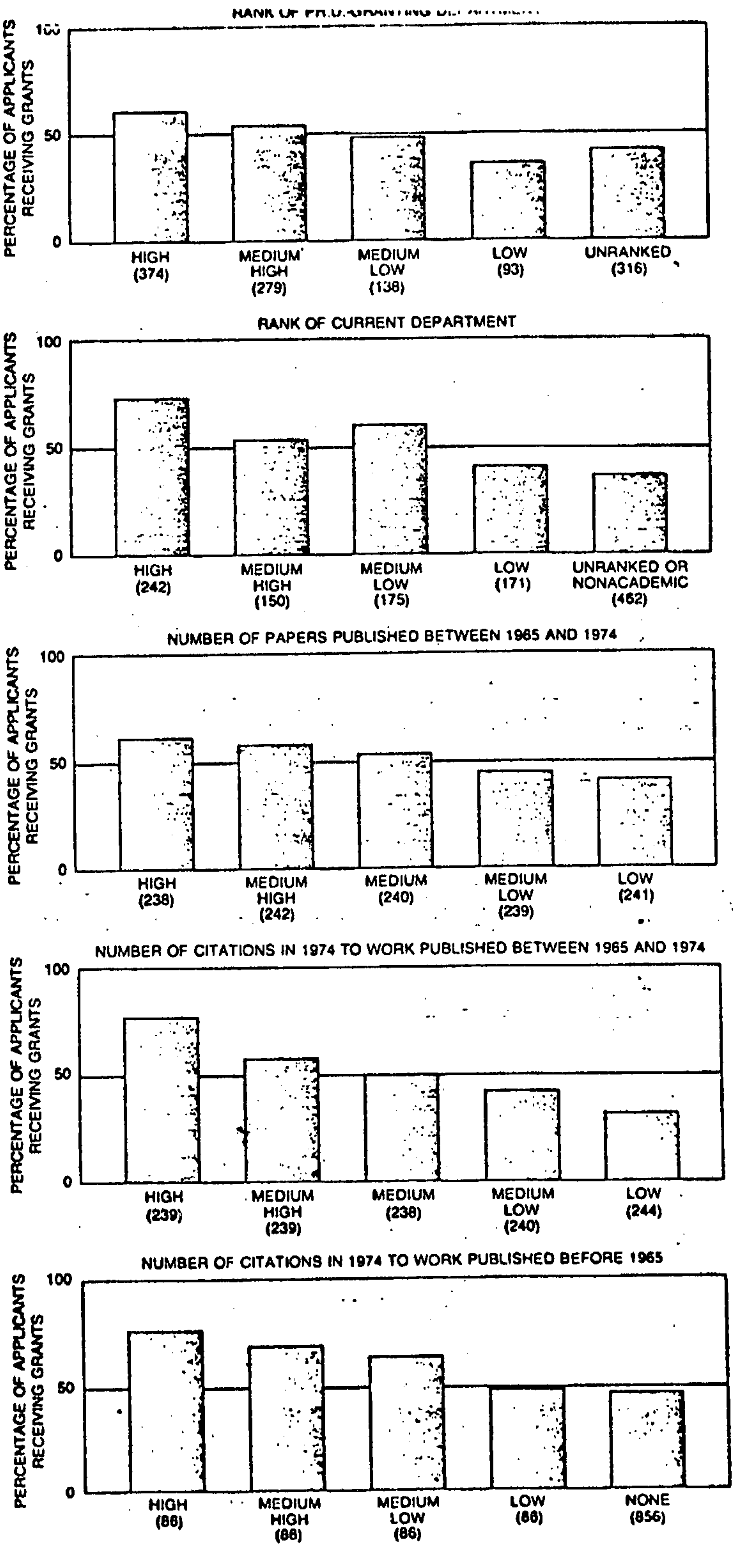
In general we found that applicants from high-ranked departments received slightly better reviews of their proposals than applicants from medium-ranked and low-ranked departments. Furthermore, it appeared that high-ranked reviewers tend to be slightly more lenient with proposals than low-ranked reviewers are. These results, in and of themselves, cannot be interpreted as offering support for the old-boy hypothesis. For example, the fact that eminent scientists tend to get higher ratings could simply be a result of the higher quality of their proposals or of the belief on the part of the reviewers that the eminent scientists are in fact better able to carry out the proposed research.

In order to explore the matter more deeply we next conducted a statistical analysis of variance that compared the observed mean rating for each applicant-reviewer pair with the expected mean rating, assuming no bias. The results of this analysis indicated that in general reviewers from high-ranked departments were not disproportionately favoring proposals from applicants in similarly high-ranked departments. We conducted this analysis separately for each of the 10 programs. In only one program were reviewers at high-ranked departments detectably more lenient toward the proposals of their colleagues at similarly high-ranked departments.

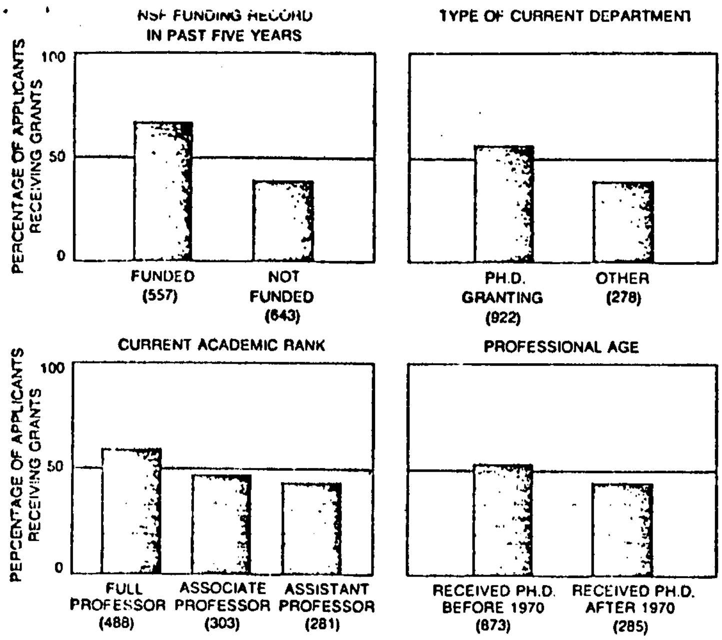
Another statistical analysis of variance tested the reviewers' bias in terms of geographic location and of the relative eminence of the reviewer and the applicant. It showed no significant tendency for scientists in one part of the country to favor proposals from colleagues in their own region or for eminent scientists to favor the proposals of eminent scientists over the proposals of less eminent scientists. Thus even if it were true that the program directors at the NSF were attempting to manipulate the outcome of the peer-review process by their selection of reviewers (and our qualitative findings indicate that it is unlikely), the quantitative data suggest that they have not been successful.

One reason it is difficult to test the validity of the old-boy hypothesis is the absence of conceptual clarity in the charge. What is referred to by the old-boy label? There are at least three possibilities. The term could refer to investigators with a common view of their field who will only appraise favorably work that is done by people with similar views. It could refer to networks of friendships: scientists who know one another, who "grew up" together or attended the same schools and who tend to fraternize and also to favor one another's proposals. It could refer to social position: scientists at a given level of eminence might tend to favor the proposals of others who are similarly situated in the hierarchy of science, even if they have no personal contact with them. Critics of the peer-review system never specify clearly which form of old-boyism is undermining the peer-review system. The data reported here allow us to examine the assertion that persons of similar rank, similar intellectual background and similar repute favor one another's proposals, but we do not have in hand data for examining forms of old-boyism that may be connected with friendship patterns.

How do the characteristics of the applicants affect the peer-review ratings they receive? Critics of the peer-review system say that regardless of the quality of proposals eminent scientists enjoy an advantage over those who are



CHARACTERISTICS of successful applicants for NSF grants in 1975 are summarized in these bar charts. Among the characteristics represented here are rank of Ph.D.-granting department (*top*), rank of current department (*second from top*), number of scientific papers published between 1965 and 1974 (*middle*), number of citations to work published between 1965 and 1974 (*second from bottom*) and to work published before 1965 (*bottom*).



OTHER CHARACTERISTICS of successful applicants for grants in 1975 are represented in these charts. Characteristics include past five years' funding record (*top left*), type of academic department (*top right*), academic rank (*bottom left*) and professional age (*bottom right*).

not eminent. In the final analysis, these critics contend, the peer-review system results primarily in eminent scientists at high-ranked departments having an unfair advantage in grant approval over less eminent scientists at lower-ranked departments. To test this "rich get richer" hypothesis we combined the applicants from all 10 programs into one large standardized sample. The 1,200 applicants in the sample were characterized by nine variables that established their status in the social system of science. Each of these characteristics was then tested separately to see if it provided evidence in support of the rich-get-richer hypothesis.

For example, we characterized the applicants according to the graduate departments from which they obtained their doctoral degree to see if scientists that come from prestigious Ph.D.-granting departments tend to get higher ratings than those who come from less prestigious departments. The applicants were also classified according to their current academic departments in order to test the assertion that applicants in high-ranked departments have an undeserved advantage over applicants in low-ranked departments. We classified the applicants according to their current academic rank in order to see if assistant professors are any less likely to receive grants than associate professors or full professors. In addition we classified all the applicants according to their professional age, their published scientific works, the number of citations of their published works and whether or not they had received NSF funds in the past.

The rich-get-richer hypothesis would suggest the existence of strong correlations between all of these variables and the ratings the applicants received on their proposals. There are, indeed, reasons other than old-boyism for this expectation. For one thing scientists who in the past had done research that other scientists had valued highly could reasonably be expected to write proposals that would be more likely to be rated highly. Moreover, since the NSF explicitly instructs reviewers to regard past performance as one of the major criteria in determining a rating, reviewers could be expected to give higher ratings to scientists with a superior "track record."

The data, however, provide little support for the rich-get-richer hypothesis. Our results show only weak or moderate correlations between each of the nine "social stratification" variables and the ratings received on proposals. The most highly correlated variable was the number of citations in the 1975 *Science Citation Index* of work published between 1965 and 1974. Even this rough measure of the significance of recently published work is not correlated very strongly with the ratings, explaining only 6 percent of the variance in the ratings. The correlations between the other variables and the ratings are all surprisingly low, explaining only an additional 5 percent of the variance in the ratings. In the end 89 percent of the observed variance in the ratings is left unexplained by the nine variables.

These results ran so counter to our expectations that at first we suspected they might have been caused by some methodological error. A thorough review of our correlation and regression procedures, however, left the results intact. In fact, the validity of our findings has been corroborated by a recent study conducted by members of the NSF's own chemistry section. Their independent analysis yielded results that were virtually identical with our own. It is difficult to avoid the conclusion that there is no substantial correlation between peer-review ratings received by applicants for NSF grants and statistical indicators of their professional status or past scientific performance. Scientists whose published work is frequently cited were only slightly more likely to receive favorable ratings than scientists with only a few citations or none.

It still appeared possible, however, that the weak correlations we observed could have resulted from a lack of agreement among the reviewers. For example, if an applicant with a large number of citations of his work received very favorable ratings from some reviewers and very unfavorable ones from others, that could account for a weak or nonexistent correlation between citations and ratings. How much agreement was there among the various reviewers of a given research proposal?

To answer this question we first determined the mean standard deviation of the reviewers' ratings, a quantity that can be taken as an approximation of the degree of agreement in a given field. This number varied from a low level of .31 in algebra to a high level of .69 in ecology and meteorology. (A low mean standard deviation corresponds to a high degree of consensus, and vice versa.) This approach could itself be flawed, however, if one were to fail to take into account the mean rating of the reviewers in each field. Clearly if there is a general tendency in a field to restrict the range of evaluations to either high or low scores, there would be less chance for variations in the ratings. We therefore relied on a statistic called the coefficient of variation, which is simply the mean peer-review rating divided by the mean standard deviation. In general we found that there was a good deal of agreement among the mail reviewers in all 10 fields and little systematic variation among the fields. The coefficient of variation ranged from a low of .13 in economics to a high of .30 in ecology.

To test further the notion that the weak correlations we observed resulted from a lack of agreement among the reviewers, we examined the correlations between the mean rating received by a proposal and several characteristics of the applicant. If the weak correlations had resulted from a lack of agreement among the reviewers, the associations between mean ratings and individual characteristics would be substantially higher, since mean scores are almost invariably more strongly correlated with any given variable than are individual scores. When the mean rating was used as the dependent variable in a statistical regression analysis, we obtained results similar to those obtained in our original analysis. The highest correlation was found between citations of recent work and the mean rating, followed by the correlation between past funding history and the mean rating. Although this method of analysis had the effect of increasing the amount of variance explained by the characteristics of the applicants from 11 percent to 16 percent, the great bulk of the observed variance in the ratings remained unexplained. The new analysis supported the conclusion that the weak correlations observed were not a result of a lack of agreement among reviewers.

In short, these data suggest that the mail reviewers are not strongly influenced by the professional status of an applicant in evaluating a proposal. On the contrary, they appear to be much more likely to be influenced by their perception of the quality of the research proposed. One crucial question remained: How is the program director's funding decision related to the reviewers' ratings on the one hand and to the characteristics of the applicants on the other?

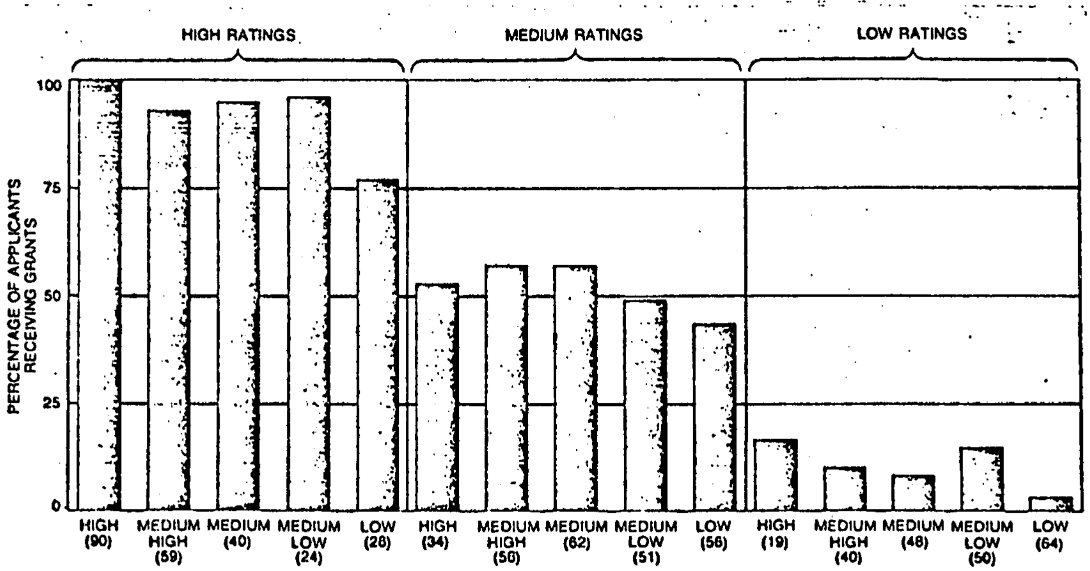
Critics of the peer-review system contend in effect that the decisions of the NSF program directors depend more on who you are than on what you propose to do. So far our data have tended to refute this version of the old-boy hypothesis. Before this refutation can be established conclusively, however, we must establish that the peer-review ratings are the single most important determinant of the program director's funding decision and that the characteristics of the applicants have little independent effect on the outcome.

The NSF states clearly that the reviews by either the mail reviewers or the panel members are advisory and the program director has the final responsibility for deciding whether or not a proposal is to be funded. Our data show that the program directors in fact rely very heavily on the evaluations of the peer reviewers. For example, among those applicants who received comparatively high mean ratings from the mail reviewers 92 percent were awarded grants, whereas among those receiving low mean ratings only 10 percent got grants. Among the group who received mean ratings in the middle ranges about half were awarded grants. Similarly, among those applicants who received comparatively high panel ratings 84 percent were funded, and among those who received low panel ratings only 12 percent were funded [*see illustration on page 36*].

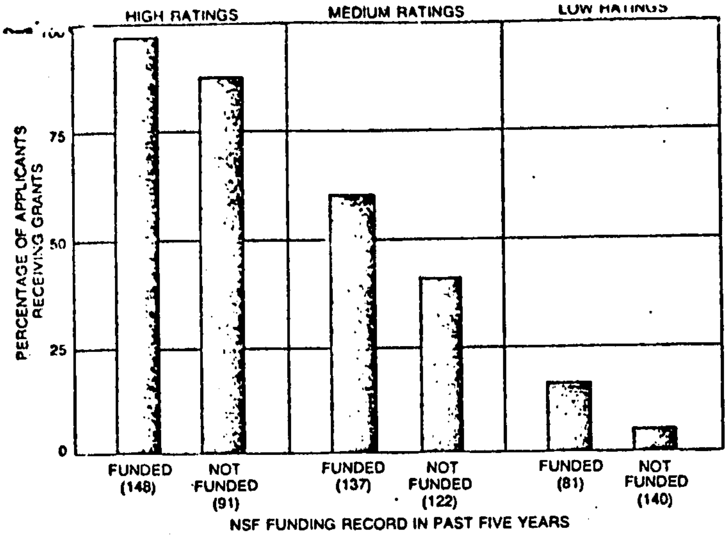
What types of scientists were successful in receiving grants from the NSF in 1975? Of those applicants who obtained their degrees from the highest-ranked graduate departments 62 percent were awarded grants, compared to 38 percent of those who were graduated from the lowest-ranked departments. Similarly, 74 percent of the applicants currently employed in the highest-ranked departments were funded, compared with 38 percent currently in either unranked departments or nonacademic institutions.

Recent NSF funding history and frequency of citations of recent work both had a moderate influence on the probability of receiving a grant. Among applicants receiving the most citations to recently published work roughly three-quarters were awarded NSF grants; among those receiving the least citations of recent work less than a third received grants. The number of papers published and the number of citations of work published before 1965 were less strongly associated with the receipt of a grant. Other attributes of the applicants, such as their professional age or their academic rank, had a minor effect on the probability of receiving a grant.

The effect of professional age on the probability of receiving an NSF grant is



INDEPENDENT EFFECTS of a scientist's past achievements on the probability of receiving an NSF grant are represented in this chart and the one on the next page. The applicants were divided into three groups: those who received comparatively high mean ratings from mail reviewers, those who received medium mean ratings and those who received low mean ratings. Within each category the probability that particular scientists—in this case those with different numbers of citations of their recent work—would receive grants was then calculated. The results show that scientists whose work is frequently cited have a slight competitive advantage in the competition for funds.



SIMILAR ACCUMULATIVE ADVANTAGE is indicated, among those scientists whose proposals received medium or low peer-review ratings, for applicants who had been funded by the NSF in the past five years. Again, a good record appears to produce a slight advantage.

particularly noteworthy. When we began our study many scientists indicated that they believed it was more difficult for younger scientists to obtain NSF funds. Our interviews with program directors, on the other hand, revealed that they perceived just the opposite. Because there is a commitment on the part of the NSF to help young, talented scientists get started, several program directors said that in the case of roughly equal peer reviews they would prefer to fund younger applicants. As it happens, the perceptions of both the applicants and the program directors are mistaken. The data we have gathered indicate that professional age has almost no effect on either the peer-review ratings or the final funding decision.

The overall pattern of our data suggests that scientists with an established track record, many scientific publications, a high frequency of citations, a record of having received grants from the NSF and ties to prestigious academic departments have a higher probability of receiving NSF grants than other applicants do. Nevertheless, the granting process is actually quite open, and there is nothing approximating a scientific caste system. Even among the most frequently cited scientists who apply for support an appreciable number do not receive grants, and among the group with the fewest citations to their work a significant number do receive grants. There is no evidence that scientists who have received grants in the past are guaranteed continued support, or that those without a past funding record have no chance of obtaining current NSF funding. Indeed, given the heavy emphasis the NSF places on past performance as one of the two most important criteria in evaluating research proposals, it is somewhat surprising that measures of past scientific performance do not show a stronger influence on the probability of receiving a grant.

It should incidentally be noted that the data presented here allow us to answer two distinct questions. The first is: How well do the social characteristics of scientists and their previous record predict peer-review ratings and the probability of funding in general, that is, when we examine the entire sample of applicants? The second is: Are there substantially different probabilities of receiving high ratings or a favorable decision for the most eminent applicants compared with the least eminent applicants, that is, when we compare relatively small subsets of the sample? The answers can be different depending on which of these two questions we ask.

For the sample as a whole status differences are not good predictors of ratings. Consider a concrete example of what we mean by focusing again on the relation between the rank of an applicant's current department and the final funding decision. First recall that 55 percent of all 1,200 applicants received NSF grants; if one had to predict whether an individual applicant had received a grant, to predict in every case that he had received one would make one right on 55 percent of the applicants and wrong on 45 percent. The question is: How does knowledge of the rank of an applicant's department increase the ability to predict whether he received a grant? To estimate this we examine each of the five classifications of departmental rank. In the two bottom categories, where a majority did not obtain support, we would guess that all applicants did not receive grants; in the other three categories, where a majority received support, we would do better to guess that all received support. That would result in correct predictions in 63 percent of the cases. When we subtract from this total the proportion (55 percent) that we would have guessed correctly without any information about the individual's departmental affiliation, we get an estimate of the increase in predictability that results from knowledge of rank of department: in this case an increase of 8 percent, which is not an extraordinary increase in predictability.

Suppose, on the other hand, we want to know whether scientists in the highest-ranked departments have a better chance of receiving NSF support than those in unranked departments or in a nonacademic setting. If we compare the percentage difference between these extreme subgroups, we find a substantial 36-point difference. In other words, some percentage differences do appear large in the extremes, but that does not mean the characteristic is a good predictor of a decision for the entire sample. Of the variance that can be accounted for in funding decisions, the peer-review rating is by far the best predictor.

The well-documented social process referred to by sociologists of science as "accumulative advantage" would lead one to expect that eminent scientists have a better-than-average chance in the competition for NSF funds. Accumulative advantage in this context means that a scientist who has been rewarded at one stage in his career has an enhanced probability of being rewarded at a later stage, regardless of the quality of his scientific work in the interim. The concept explains in part the increasing inequality in rewards that is observed as an age cohort of scientists moves through time.

According to the concept of accumulative advantage, the initial social status of a scientist influences the probability of his obtaining a variety of forms of recognition, including the esteem of his colleagues, an association with centers of excellence in the academic world and the resources and facilities necessary for productive scientific work. For example, young scientists who are trained in the best university science departments, and particularly those who have been apprenticed to leading scientists, have a better chance than less well-placed students of equal ability to secure first jobs at prestigious institutions. Once established in these positions they have a better chance than their peers to obtain support for their research. With greater support they have an enhanced opportunity for making significant scientific discoveries and publishing the results. And

...ill greater chances for future success. To the extent that this process works to the advantage of scientists who are initially well placed in the social system of science it also works to the disadvantage of their peers who are not so fortunate.

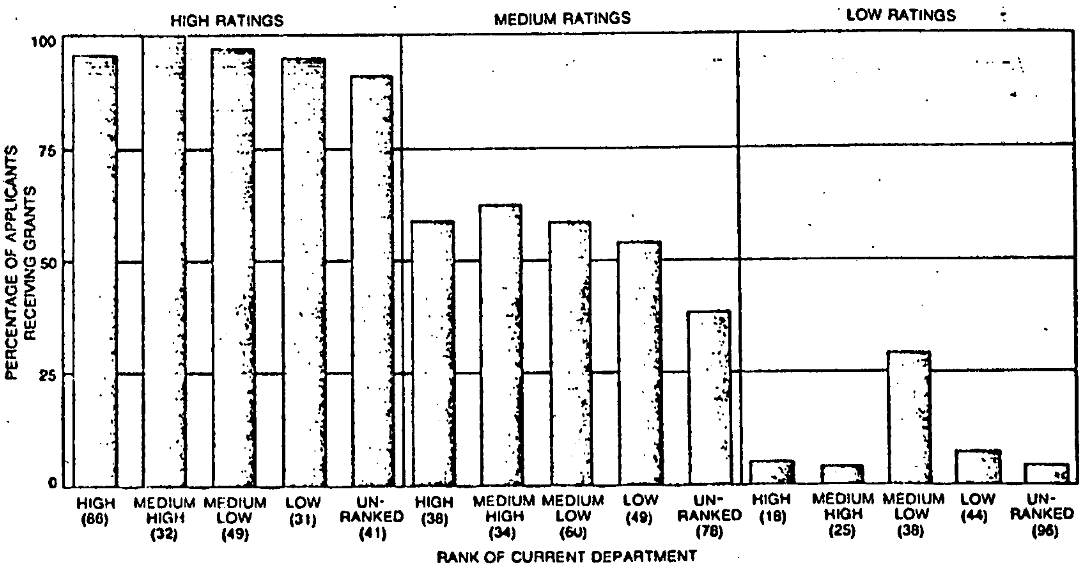
By taking the mean peer-review rating received by an NSF research proposal as a rough measure of the quality of the proposal we attempted to determine the independent effect of a scientist's past achievements on his receiving a grant. We first divided the applicants into three groups: those who received comparatively high mean ratings, those who received medium mean ratings and those who received low mean ratings. Within each category we calculated the probability that scientists who had had different numbers of citations of their recent work would receive grants. We then considered only the group of proposals that received the highest peer-review ratings. Of this group 100 percent of the quintile with the highest number of citations were awarded NSF grants. In the lowest quintile 77 percent received grants. This finding leads to two conclusions: (1) the mean peer-review rating is a far more important determinant of whether a scientist receives a grant than is the number of citations of his recent work, and (2) within each category of mean ratings the number of citations of recent work has only a slight influence on the probability of approval.

We next considered the cases of those scientists whose proposals received low ratings. A substantial majority of all the proposals in this category were declined, but the number of citations made proposals that received low ratings 16 percent of the scientists with the most citations received grants, compared with 3 percent of those who received the fewest citations.

The foregoing data offer some limited support for the concept of accumulative advantage. Scientists whose recent work has been frequently cited have a measurable advantage in the competition for current funds; this advantage is, however, very slight. The process of accumulative advantage is somewhat more evident among those scientists whose research proposals received medium peer-review ratings but who had been funded frequently by the NSF in the past five years. Among scientists whose proposals received medium ratings, for example, 61 percent of those who had been funded within the past five years were awarded a current grant, whereas only 41 percent of those who had not received funds from the NSF in the past five years were awarded a current grant. Clearly a good funding record gives rise to a slight competitive advantage.

We also examined the independent effect of an applicant's current academic department on the probability of his being awarded an NSF grant. Here the story was somewhat different. The rank of a scientist's current department apparently has almost no effect on the probability of his receiving a grant independent of the peer-review ratings received by the applicant's proposal. Of the scientists in the highest-ranked departments whose proposals received comparatively low ratings 6 percent were from that found among applicants in lower-ranked departments. In the competition for current funds, therefore, a scientist's past performance as measured by citations of his work and his recent NSF funding record does lead to a very slight accumulative advantage, but his academic affiliation does not appear to give him any advantage.

The results of our study of the operation of the peer-review system in the basic-research programs of the NSF are consistent thus far with other recent findings in the sociology of science, which suggest that the scientific enterprise is an exceedingly equitable, although highly stratified, social institution in which the individuals who produce the work that is most favorably evaluated by their colleagues receive the lion's share of the rewards. Further study of the equity of research-fund distribution will address two basic problems not yet considered. In the first phase of our study we relied on the peer-review ratings elicited by the NSF program directors as an indicator of quality and found those ratings were strongly related to the actual funding decision; now we are submitting proposals to independent review panels in order to obtain independent appraisals of their quality. Finally, having learned that peer-review ratings are strong predictors of funding decisions, we are interested in whether or not they also are good predictors of future scientific performance, and so we are studying how the ratings and recent research performance compare as predictors of future research performance.



NO INDEPENDENT EFFECT was detectable in this similar statistical analysis, which measured the influence of an applicant's current academic department on the probability of being awarded an NSF basic-research grant. Apparently current academic affiliation does not give an applicant any competitive advantage independent of the peer-review ratings that were received by his research proposal.