Evaluation of NSF's Program of Grants and Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)

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Committee to Evaluate the NSF's Vertically Integrated Grants for Research and Education (VIGRE) Program

Evaluation of NSF's Program of Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)

Committee to Evaluate the NSF's Vertically Integrated Grants for Research and Education (VIGRE) Program

Board on Mathematical Sciences and Their Applications
Division on Engineering and Physical Sciences

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Preface

The National Science Foundation (NSF) requested that the National Research Council's (NRC's) Board on Mathematical Sciences and Their Applications assess NSF's program, Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE). The NRC established a study committee with the following charge:

1. Review the goals of the VIGRE program and evaluate how well the program is designed to address those goals;
2. Evaluate past and current practices at NSF for steering and assessing the VIGRE program;
3. Draw tentative conclusions about the program's achievements based on the data collected to date;
4. Evaluate NSF's plans for future data-driven assessments and identify data collection priorities that will, over time, build understanding of how well the program is attaining its goals; and
5. Offer recommendations for improvements to the program and NSF's ongoing monitoring of it.

Through four meetings over the course of nearly 2 years, the Committee to Evaluate the NSF's Vertically Integrated Grants for Research and Education (VIGRE) Program collected and analyzed a broad range of inputs to develop this consensus report.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We wish to thank the following individuals for their review of this report:

James A. Carlson, Clay Mathematics Institute,
Richard T. Durrett, Cornell University,

Michael E. Fisher, University of Maryland,
Irene M. Gamba, University of Texas at Austin,
Roger E. Howe, Yale University,
Leon M. Keer, Northwestern University,
Sallie Keller-McNulty, Rice University, and
Thomas M. Liggett, University of California at Los Angeles.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Ronald G. Douglas, Texas A&M University, College Station, and by John C. Bailar, University of Chicago. Appointed by the NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

The committee thanks the members of the National Research Council staff who provided extensive input during the project. Thanks are also extended to all presenters who participated in the committee's meetings for sharing their thoughts and experiences regarding the VIGRE program. The committee would also like to thank all those who responded to its requests for information, including mathematics, applied mathematics, and statistics department chairs, and the experts who conducted site visits. James Maxwell of the American Mathematical Society (AMS) graciously provided AMS data and assisted the committee in contacting department chairs. Henry Warchall of the National Science Foundation answered many questions posed by the committee and provided key data.

William E. Kirwan, *Chair*
Committee to Evaluate the NSF's Vertically Integrated
Grants for Research and Education (VIGRE) Program

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Summary

In 1998, the Division of Mathematical Sciences (DMS) at the National Science Foundation (NSF) launched a program of Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE).[1] These were "grants to institutions with PhD-granting departments in the mathematical sciences to carry out high-quality education programs, at all levels, that are vertically integrated with the research activities of these departments."[2,3] The goals of the program as initially enunciated were as follows: "(1) to prepare undergraduate students, graduate students, and postdoctoral fellows for a broad range of opportunities available to individuals with training in the mathematical sciences; and (2) to encourage departments in the mathematical sciences to consider a spectrum of education activities and their integration with research."[4] To date, more than 50 departments at 40 institutions have received VIGRE awards.

At NSF's request, in 2007 the National Research Council (NRC) appointed the Committee to Evaluate the NSF's Vertically Integrated Grants for Research and Education (VIGRE) Program to conduct an assessment of the VIGRE program, examining its goals, design, monitoring, and achievements and making recommendations for improvement. (The study charge is given in the Preface.) In order to carry out its charge, the committee relied on the following varied sources of information:

[1] The title of NSF's program was originally Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE). Subsequently, in NSF literature and elsewhere, it has been referred to as Grants for Vertical Integration of Research and Education (VIGRE), or just by the acronym VIGRE.

[2] From the first program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," NSF 97-155, available at http://www.nsf.gov/pubs/1997/nsf97155/nsf97155.htm. Accessed June 12, 2009.

[3] Except where explicitly noted, this report uses the terms "mathematics" and "mathematical sciences" interchangeably. They both include pure mathematics, applied mathematics, and statistics.

[4] See NSF 97-155.

- NSF data:[5]
  —The requests for proposals (RFPs);
  —Data contained in proposals submitted by departments in the mathematical sciences;
  —Reports from NSF site visits to the departments that submitted proposals;
  —Results of NSF proposal review panels;
  —Annual reports submitted by awardees;
  —Reports from NSF 3rd-year site visits to awardees, which provide input into decisions on whether or not to continue grants into the 4th and 5th years;
  —Final reports submitted by awardees;
- Enrollment data and information on degrees awarded, which are collected by the American Mathematical Society;
- Information collected by the Department of Education's National Center for Education Statistics through its Integrated Postsecondary Education Data System (IPEDS);
- Information collected by the committee:
  —The information from a conference call conducted with members of VIGRE site-visit teams;
  —Presentations at full committee meetings; and
- A survey conducted by the committee of all PhD-granting mathematics, applied mathematics, and statistics departments in the United States.

Chapter 1 defines the committee's interpretation of its charge, its sources of information, and the scope and approach of its evaluation. Chapter 2 documents the wide range of concerns that contributed to the creation of the VIGRE program, as reflected in a series of high-level reports published between 1994 and 1998. These reports provide a context for understanding and evaluating the VIGRE program. Chapter 3 describes the VIGRE award process and reviews the progression of VIGRE goals from the inception of the program until the present, indicating that although the core goals have remained consistent over time, the program's emphasis has changed, as have goals outside the core.

In Chapter 4, the committee reviews NSF's administration of the VIGRE program, and in Chapter 5 the committee uses information generated from its data sources and its own expertise to review the achievements of the program. In Chapter 6, on the basis of its review of the VIGRE program and its accomplishments, the committee develops nine recommendations, which it presents below in this Summary and which are discussed more fully in Chapter 6.

Recommendations 1 and 2 respond to the committee's first charge, to review the goals of VIGRE, and to its third charge, to draw conclusions about the program's achievements. The committee finds that, although some clarification is needed, the goals of the program are worthwhile and the VIGRE program is an appropriate way to foster those goals. Impressive examples show that VIGRE has had a meaningful impact on the educational programs of departments, leading to the kind of systemic change called for when the program was conceived. With the changes described in this report, VIGRE will serve a valuable purpose that is consistent with its original design.

Recommendation 8 is in response to the second and fourth charges, to evaluate current practices for steering and assessing VIGRE and to develop plans for future data-driven assessments and collection.

[5] The committee regrets that the committee itself was not allowed access to some NSF source documents, such as proposals submitted to the VIGRE program and reviews of departments with VIGRE grants. Conflicting requirements exist between the NSF, whose policy is that these documents not be made public, and the NRC, which is required by law to make public most documents received by a committee in the course of a study. Although access was allowed to NRC staff, who reviewed and summarized some of these documents and provided some statistical analysis, direct access by committee members would have aided the committee in formulating conclusions and recommendations.

The committee found that at VIGRE's planning stage insufficient thought had been given to data requirements necessary for evaluation, and it recommends the selection of a small number of benchmarks that can be compared across individual VIGRE projects and over time. Finally, Recommendations 3, 4, 5, 6, 7, and 9 all respond to the committee's fifth charge, to suggest improvements to VIGRE.

Recommendation 1: Continue the National Science Foundation's program of Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE) but with critical policy and programmatic changes identified in the eight recommendations below.

The committee found considerable confusion among potential applicants to VIGRE about the goals and expectations of the VIGRE program. The committee believes that applicants would benefit from increased clarity in the linking of VIGRE program goals with national goals for mathematics and in the criteria for success in both initial and renewal proposals. The committee could find no specific reference in any VIGRE RFP to the scientific quality of proposed VIGRE projects as a criterion for selecting VIGRE awardees. This is a serious omission that needs to be corrected.

Recommendation 2: Clarify the goals of the VIGRE program and emphasize scientific quality in making awards.

The committee found that to call for the simultaneous occurrence of vertical integration from undergraduate education to postdoctoral research, department-wide change across all subdisciplines, and simultaneous and significant change in a department's undergraduate, graduate, and postdoctoral programs is a worthy aspiration for the VIGRE program. It is also a daunting prospect and should not be seen as the only path to achieving the goals of the program. Within the broad goals established for the VIGRE program, providing greater flexibility and scope for local initiative in meeting the goals, similar to the approach taken in other NSF workforce programs, would encourage a broader range of institutions to apply for and participate in the VIGRE program.

Recommendation 3: While retaining the VIGRE program's distinctive focus on projects that span the entire spectrum of educational levels from the undergraduate through the postdoctoral associate levels, allow greater flexibility in proposal design by encouraging VIGRE projects that address some, but not necessarily all, of the goals of the VIGRE program.

The committee views the sustainability of individual VIGRE projects as a serious problem. If a department uses its VIGRE grant and its own energy to develop successful programs that enrich the education of its students, how will those programs be continued after the VIGRE grant has expired? In order to enhance sustainability, the committee suggests a new financial structure for individual grants consisting of an initial 5-year award, followed by a noncompetitive 5-year renewal if the grant is succeeding and if the institution makes a commitment to continue the successful portions of its VIGRE project at the expiration of the grant.

Recommendation 4: To ensure the sustainability of an institution's successful VIGRE-initiated reforms, establish longer-term original awards and renewal awards, and require and enforce institutional support for grantees in the out-years of awards.

Developing proposals for VIGRE projects requires a large amount of faculty and administrative time. According to NSF statistics, the declining number of proposals to VIGRE in recent years suggests that the magnitude of the effort to develop proposals is not cost-effective for some departments. In order to decrease the effort required by careful proposal writing and submission, not all of which will be funded, the committee recommends an initial preproposal step.

Recommendation 5: Institute a preproposal step into the VIGRE application process.

The committee believes that a program designed to increase departmental interaction, communication, and cooperation is ill-served when a significant proportion of the graduate student and postdoctoral population, namely, foreign nationals, is excluded.

Recommendation 6: Allow international students and postdoctoral fellows to receive financial support from VIGRE projects.

In a nonacademic setting, there is a need for well-prepared master's- or doctorate-level professionals who can use sophisticated mathematics such as financial mathematics, biostatistics, and a range of areas at interfaces with computational sciences. In Recommendation 7, the committee recommends that the VIGRE program's scope be expanded to allow support for such efforts.

Recommendation 7: Expand the scope of the VIGRE program to include students preparing to apply advanced mathematics in nonacademic settings.

The committee found that the VIGRE program was established with no preparation for subsequent program analysis. Planning for specific analyses and for data collection should go hand in hand. There should be continuity of data requests across the duration of an award, if not across the duration of the entire VIGRE program. The committee believes that the requirement for self-evaluation by the awardees should be strengthened in the VIGRE program's request for proposals. Grantees should be required to conduct process and outcome evaluation linked both to the goals of the VIGRE program and to proposed activities. NSF should develop a consistent evaluation strategy, and grantees should develop appropriate inputs for that strategy.

Recommendation 8: Create a rigorous assessment process with a small number of carefully chosen benchmarks for which data can be collected and compared across VIGRE projects on an annual basis.

The committee believes that successful strategies to achieve VIGRE goals should be disseminated to all mathematics departments, not just VIGRE awardees. This dissemination should be a component of the VIGRE program, and the committee has suggested several means, such as the maintenance of a VIGRE Web site by all awardees, to accomplish this.

Recommendation 9: Develop systematic and highly visible strategies for the dissemination of successful VIGRE projects.

Improving the quality of education in mathematics, as in other sciences, involves many issues. This committee is constrained to address only those issues implied by its charge, quoted in the preface to this report; and this constraint, at times, requires interpretation by the committee. Some issues that the committee regarded as beyond its charge are the following:

- The mechanics of proposal preparation and submission;
- The justification of previous reports and of NSF's conclusions used to initiate and formulate the VIGRE program;
- The process used by NSF to allocate funds among its directorates and programs;
- Salaries paid by universities to faculty, postdoctorals, and graduate students; and
- The priority given by NSF to this report and to the committee's recommendations.

1

Introduction

In 1998, the Division of Mathematical Sciences (DMS) at the National Science Foundation (NSF) launched a program of Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE).[1] As stated in the first program solicitation, these were "grants to institutions with PhD-granting departments in the mathematical sciences to carry out high quality educational programs, at all levels, that are vertically integrated with the research activities of these departments." The goals of the program as initially enunciated were "(1) to prepare undergraduate students, graduate students and postdoctoral fellows for a broad range of opportunities available to individuals with training in the mathematical sciences; and (2) to encourage departments in the mathematical sciences to consider a spectrum of education activities and their integration with research."[2] This key notion of vertical integration was further explained:

> The intent of the VIGRE program is to support the development of a community of researchers and scholars in which there is interaction among all the members. This would not only provide meaningful educational experiences for undergraduate and graduate students, but also encourage continuing professional development at the postdoctoral level and beyond. These experiences should take place in an environment in which research and education fit together naturally and reinforce each other and in which interaction takes place among all participants. This is called *vertical integration* and refers to programs in which research and education are coupled and in which undergraduates, graduate students, postdoctoral fellows, and faculty are mutually supportive.[3]

[1] The title of NSF's program was originally Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE). Subsequently, in NSF literature and elsewhere, it has been referred to as Grants for Vertical Integration of Research and Education (VIGRE), or just by the acronym VIGRE.

[2] From the first program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," NSF 97-155, available at http://www.nsf.gov/pubs/1997/nsf97155/nsf97155.htm. Accessed June 12, 2009.

[3] Ibid.

COMMITTEE'S CHARGE

In 2007, at the request of the National Science Foundation, the National Research Council (NRC) appointed an ad hoc committee to conduct an assessment of NSF's program Grants for Vertical Integration of Research and Education in the Mathematical Sciences (see Appendix A for biographies of the committee members). The committee was given the following tasks:

1. Review the goals of the VIGRE program and evaluate how well the program is designed to address those goals;
2. Evaluate past and current practices at NSF for steering and assessing the VIGRE program;
3. Draw tentative conclusions about the program's achievements based on the data collected to date;
4. Evaluate NSF's plans for future data-driven assessments and identify data collection priorities that will, over time, build understanding of how well the program is attaining its goals; and
5. Offer recommendations for improvements to the program and NSF's ongoing monitoring of it.

EVALUATION OF THE SCOPE AND APPROACH

The NRC's Committee to Evaluate the NSF's Vertically Integrated Grants for Research and Education (VIGRE) Program held its first meeting in June 2007. To carry out its charge, the committee began by asking what components of the VIGRE program could be evaluated. Program evaluation is beneficial in assessing the processes or outcomes of a program to determine whether improvements can be made. Evaluations are sometimes planned during the creation of a program. They may also be designed during the program or even retrospectively after the program has ended. The latter types of evaluation may be more difficult to conduct if the assessment's data needs were not planned for in advance. Finally, evaluations can be longitudinal (for example, comparing an outcome such as the number of students pursuing a mathematics major before, during, or after a program's lifetime) or cross-sectional (for example, comparing two departments, where one had a particular program—such as an undergraduate research experience—and the other department did not).

To organize an answer to the questions involved in evaluation, the committee sought to describe the VIGRE program, as captured in Figure 1-1 in the diagram that the committee developed. As that figure illustrates in the topmost boxes, the state of the mathematical sciences as well as other factors (e.g., NSF-wide goals, NSF budget) motivate the VIGRE program; and each year DMS releases a call for proposals from PhD-granting departments in the mathematical sciences in the United States. Departments in applied mathematics, mathematics, and statistics may submit proposals. The proposals are then subjected to a review process at NSF, the end result of which is that some proposals are funded (becoming the "VIGRE awardees"). The awardees carry out the plans developed in their proposals over the first 3 years of the award, submitting annual reports of their progress. In the 3rd year, NSF conducts site visits to determine whether each individual award should be continued for 2 more years. If continuation is approved, the departments proceed with their programs and submit additional annual reports and a final report.

The diagram in Figure 1-1 shows several feedback mechanisms. Recall that the VIGRE program has evolved over time, and most of the processes shown in the diagram can be thought of as occurring annually. The actions of awardees are supposed to have a positive impact on the mathematical sciences and, to the extent that they do, they might alter DMS's goals for the program. Awardees' actions might also directly affect DMS's goals: in response to submissions, DMS could change the submission process; in response to the programs that individual departments are proposing to carry out, DMS could change the goals of the VIGRE program.

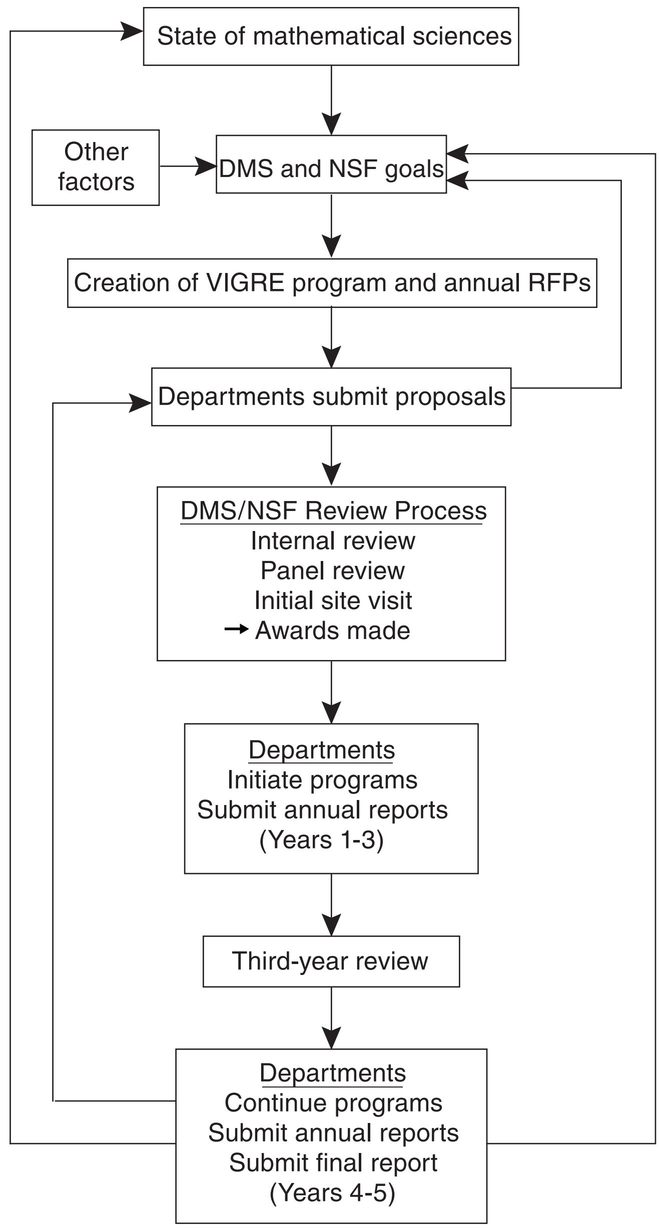

FIGURE 1-1 Conceptual model of the Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE) program. NOTE: DMS, Division of Mathematical Sciences of the National Science Foundation (NSF); RFP, request for proposals.

Figure 1-1 suggests aspects of the program that could be subject to evaluation, including the following:

- The appropriateness of the goals in the request for proposals (RFPs);
- The information that is requested from departments in submitting of proposals;
- The quality of the proposals;
- The departments that do and do not apply;
- NSF's review process, including decision making and information gathering;
- The actions that departments have taken;
- The quality of departmental reporting;
- The outcomes of departments' actions; and
- The overall accomplishments of the program.

The committee determined to focus its assessment on three aspects of the VIGRE program: (1) the program's goals as they have evolved over time, (2) data collection by NSF for purposes of its review process and of NSF's assessment of the progra, and (3) the achievements of the program.

In thinking about the success of VIGRE—both for the VIGRE awardees and, aggregated, for the entire VIGRE program—the committee identified several potential indicators of achievement that could be studied in this evaluation, as noted in Table 1-1. While this table lists only positive achievements, it is also possible that opposite effects could be observed, and those would be important indicators as well.

With respect to the entry for "time to degree" in Table 1-1, there is a conflict between the reduction in time to degree and the reduction in teaching requirements for graduate students encouraged by VIGRE. The committee believes that a careful balance between the two needs to be achieved because teaching as a graduate student not only provides experience necessary for possible academic appointment but is a valuable learning tool for the graduate student.

SOURCES OF INFORMATION

The committee sought out sources of data that could be used to examine the VIGRE program. However, it was aware of certain problems that it would face in conducting its assessment. First, it is difficult to determine causality in an evaluation. For instance, if a goal of the VIGRE program was to interest more U.S. citizens in mathematical sciences and in obtaining advanced degrees, and if over the time of the program (1998 to the present) more U.S. citizens have received doctorates in the mathematical sciences, one cannot be certain whether this is due to the VIGRE program or to some other factors—for example, perhaps the employment outlook in the mathematical sciences has brightened since earlier years of the program and so job prospects have attracted more U.S. citizens into mathematics, or the employment outlook has dimmed, encouraging students to postpone getting a job and instead pursuing further education. Second, indicators of success are often difficult to measure, and progress toward some of the program goals might not be observed until more time has passed. Finally, for a variety of reasons, many of the data required for the evaluations have never been collected.

The committee was fortunate to have multiple sources of information in carrying out its work. These included information collected by NSF, information collected by other organizations, and information collected on behalf of the committee. Each of these categories is described in more detail below.

TABLE 1-1 Potential Indicators of VIGRE Achievement

Possible Indicator	Hypothesized Effect (either at VIGRE program after award or compared with non-VIGRE awardees)
Undergraduate majors	The number of undergraduate majors in the mathematical sciences has increased.
Graduate enrollment	The number of U.S. graduate students rises more at departments awarded VIGRE grants than at other departments.
PhDs	The percentage of U.S. PhDs rises more at departments awarded VIGRE grants than at other departments.
Postdoctorals	Departments awarded VIGRE grants attract more postdoctoral researchers than do other departments.
Placement of U.S. undergraduates	Students who have participated in VIGRE make more use of their training in their first positions compared to students who have not participated in VIGRE.
	VIGRE departments offer students a broader range of career opportunities than other departments do.
	Among those who express an interest in an academic career, students who have participated in VIGRE are more likely to go to graduate school than are students not participating in VIGRE.
Placement of U.S. graduate students	Students who have participated in VIGRE are more likely to graduate because of culture, mentoring, and other advantages, and more are successfully recruited for relevant positions than are those who have not participated in VIGRE.
Placement of U.S. postdoctorals	Postdoctorals who have participated in VIGRE are more likely to succeed as researchers than those who have not.
Undergraduate research experience	More undergraduates at VIGRE departments have research experience at their university than do those at departments not awarded VIGRE grants.
Interdisciplinarity	Faculty at VIGRE departments collaborate more in teaching or research with faculty in other departments than do faculty at non-VIGRE departments.
	VIGRE students take more upper-level courses outside their department and/or non-mathematics majors take more mathematical science courses than students not participating in VIGRE.
Mentoring	Students participating in VIGRE get more mentoring (measured perhaps by number of contacts or time spent) than do those not participating.
Productivity	Graduate students produce more at VIGRE departments; postdoctorals produce more at VIGRE departments; VIGRE departments are overall more productive than non-VIGRE departments.

continued

TABLE 1-1 Continued

Possible Indicator	Hypothesized Effect (either at VIGRE program after award or compared with non-VIGRE awardees)
Integration	Courses at VIGRE departments better integrate research and education (e.g., seminars open to graduate students) than do courses at non-VIGRE departments.
	Undergraduates, graduate students, postdoctorals, and faculty at VIGRE departments spend more time working with one another than do those at non-VIGRE departments.
Curriculum	More course content on communication is offered at VIGRE departments than at non-VIGRE departments.
Outreach	VIGRE departments collaborate with other departments and with K-12 more than non-VIGRE departments do.
Professional development	Students participating in VIGRE learn more skills (e.g., communication, team building, problem solving, grant writing) than non-VIGRE students do.
Summer programs	VIGRE departments offer more summer programs, or offer them to a broader number and type of students, than non-VIGRE departments do.
Internships and apprenticeships	VIGRE departments offer more such opportunities, offer them to a broader range of students, or offer a broader range of such opportunities than do non-VIGRE departments.
Time to degree	VIGRE departments have a lower average time to degree because graduate students have better support, get better advising, mentoring, and so on, than do non-VIGRE departments.
Supportive culture	VIGRE departments experience a shift in cultural norms (for instance, from little departmental concern about the progress of individual students to faculty responsibility and assistance).
Student ownership	Students in VIGRE departments feel more a part of the community represented by the department and of the larger overall community of mathematicians than do those in non-VIGRE departments.
Diversity	VIGRE departments have broader recruitment, recruit more actively, and see increases in their number of women and/or underrepresented minorities as compared with non-VIGRE departments.
Retention rates	VIGRE departments have higher retention rates, especially for women and minorities, than do non-VIGRE departments.

NOTE: VIGRE, Grants for Vertical Integration of Research and Education.

NSF Sources of Information

NSF data consist of two main categories: data collected as a result of the VIGRE program and data collected by NSF for other purposes (e.g., quantitative data from NSF surveys). As described below, among the NSF data related to the program, and roughly in the order of the VIGRE process outlined in Figure 1-1, are data that come from the following: the RFPs, proposals submitted by mathematical sciences departments, reports of NSF site visits to departments that have submitted proposals, results of NSF proposal review panels, annual reports submitted by awardees, reports of NSF 3rd-year site visits to awardees to determine eligibility for continuation of the program into the 4th and 5th year, and final reports submitted by awardees.

Requests for Proposals

The first RFP for the VIGRE program was issued in 1997, and one has been released annually through 2008. The solicitations evolved until 2005, after which the same request was used. No proposals were considered in 2009 because this NRC review was in progress when departments would normally have been developing their proposals.

Information Provided by Departments in Their Proposals

From the beginning of the VIGRE program, departments submitting proposals were required to include the following data on trainees: (1) a list of PhD recipients during the previous 5 years, along with each individual's citizenship status, baccalaureate institution, time to degree, post-PhD placement, and thesis adviser; (2) the names of postdoctoral associates (including holders of named instructorships and 2- or 3-year terminal assistant professors) during the previous 5 years, their PhD institutions, postdoctoral mentors, and post-appointment placements; and (3) the dollar amount of funding by federal agencies for research experiences for undergraduates, for graduate students, and for postdoctoral associates in each of the previous 5 years. Departments that were applying for a second (renewal) VIGRE award were required to submit data covering 10 years.

Since the 2005 solicitation, additional data also have been requested as shown in Box 1-1. These data were to be supplied for each of the previous 5 academic years, and for each of the previous 10 academic years if the applying department had already held a VIGRE grant.

Initial Site-Visit Reports

The initial pre-award site-visit reports from the past few years seem to contain more information than did earlier such reports. Beginning in 2004, but more consistently since 2005, NSF posed 10 general questions to departments prior to site visits, and the responses help to inform the site-visit reports. Those questions are listed in Box 4-1 in Chapter 4 of this report. In addition, at its discretion, each site-visit team asks specific questions.

Proposal Review Panels

NSF hosts panels of experts to review the VIGRE proposals each year. Reviewers comment on the proposals, and the comments are collected and summarized.

BOX 1-1
Data Now Requested with Proposals to the National Science Foundation's Program of Grants for Vertical Integration of Research and Education (VIGRE)

- Undergraduate student population
  —Total university undergraduate enrollment
  —Total number of mathematical science undergraduate majors
  —Total number of mathematical science female undergraduate majors
  —Total number of mathematical science minority undergraduate majors
- BS/BA degrees awarded
  —Total number of university BS/BA degrees
  —Total number of BS/BA mathematical science degrees
  —Number of BA/BS mathematical science degrees to women
  —Number of BA/BS mathematical science degrees to minorities
- Graduate student population
  —Total number of mathematical science graduate students
  —Number of female mathematical science graduate students
  —Number of minority mathematical science graduate students
  —Number of U.S.-citizen mathematical science graduate students
- Internal university support (non-teaching) for mathematical science graduate students
  —Total dollar amount for mathematical science graduate students
  —Total dollar amount for female mathematical science graduate students
  —Total dollar amount for minority mathematical science graduate students
  —Total dollar amount for U.S.-citizen mathematical science graduate students
- PhD degrees awarded
  —Total number of mathematical science PhDs granted
  —Number of mathematical science PhDs granted to women
  —Number of mathematical science PhDs granted to minorities
  —Number of mathematical science PhDs granted to U.S.-citizens

Annual Reports

Annual progress reports are to be submitted to NSF by each VIGRE awardee, although some awardees have missed some filing requirements. Each awardee is also required to file a final report. (Final reports tend to summarize the annual reports.) Annual reports are supposed to include the following information:

- Names of project participants;
- Names of organizational partners and other collaborators or contacts;
- Lists of activities and findings (including research and education activities, findings, training and development, and outreach activities);
- Lists of journal publications, books or other one-time publications, Web/Internet sites, and other specific products; and
- Lists of contributions within the discipline, to other disciplines, to human resource development, to resources for research and education, and beyond science and engineering.

- Mathematical sciences postdoctoral researchers
  —Total number of postdoctoral fellows supported by department
  —Number of female postdoctoral fellows supported by department
  —Number of minority postdoctoral fellows supported by department
  —Number of U.S.-citizen postdoctoral fellows supported by department
- VIGRE-supported individuals (if a renewal proposal)
  —Total number of undergraduates supported by VIGRE
  —Number of female undergraduates supported by VIGRE
  —Number of minority undergraduates supported by VIGRE
  —Total number of graduate students supported by VIGRE
  —Number of female graduate students supported by VIGRE
  —Number of minority graduate students supported by VIGRE
  —Total number of PhDs awarded to VIGRE students
  —Number of PhDs awarded to female VIGRE students
  —Number of PhDs awarded to minority VIGRE students
  —Total number of postdoctoral fellows supported by VIGRE
  —Number of female postdoctoral fellows supported by VIGRE
  —Number of minority postdoctoral fellows supported by VIGRE
- Disbursement of VIGRE funds
  —Total VIGRE funds spent for support of undergraduates
  —Total VIGRE funds spent for support of graduate students
  —Total VIGRE funds spent for support of postdoctoral fellows

SOURCE: National Science Foundation, 2005, Enhancing the Mathematical Sciences Workforce in the 21st Century (EMSW21) Program Solicitation, NSF 05-595, Arlington, Va.

As noted in Chapter 3 of this report, the VIGRE program was quite specific in its early years as to the quantitative data to be included in annual reports, but that policy appears to have been relaxed somewhat since 2000.

Third-Year Site-Visit Reports

In contrast to the initial site-visit reports, the 3rd-year site-visit reports are quite uniform and detailed, presenting well-reasoned recommendations. For the most part they are organized by the following topics:

- Introduction,
- General observations,
- Graduate programs,
- Undergraduate programs,

- Postdoctoral programs,
- Outreach,
- Life after VIGRE, and
- Recommendation to NSF.

The 3rd-year reports are in part based on a self-assessment in response to direction from NSF asking awardees to furnish the following information:

- Departmental responses to the nine items listed in their VIGRE award letter:
  - —How well has the integration of research and education been achieved at all levels?
  - —How is the program broadening education at all levels?
  - —How has the program improved the instruction skills and communication skills of students and postdoctorals?
  - —What has been the effect of the mentoring programs that have been developed?
  - —How has the program promoted recruitment into the mathematical sciences?
  - —How has the interaction of several levels of students and faculty been enhanced?
  - —What is the program doing to affect the time to degree?
  - —Has there been effective dissemination to the mathematical sciences community of the results of this activity?
  - —Can you identify other changes that the grant has made possible and that may not have occurred without it?
- A list of the previous institution and placement institution for each recipient of a VIGRE stipend during the project,
- A list of the faculty who participated in the VIGRE project and their roles,
- A breakdown, covering the period from 5 years preceding the VIGRE award, of the numbers of trainees involved in the department's activities,
- Accurate estimates of funds remaining and funds that will be spent in each budget category of the award,
- Any other pertinent information that the department would like to site-visit team to see.

Beginning in 2005, NSF circulated a spreadsheet to be filled in with the information requested in the departmental responses above.

NSF Surveys

A second category of NSF data consists of quantitative data that NSF collects by means of surveys. These data can be used to provide context or background for trends among VIGRE awardees and other PhD-granting mathematical sciences departments. Three surveys are particularly useful in this regard: the Survey of Earned Doctorates (SED), the Survey of Doctoral Recipients (SDR), and the Survey of Graduate Students and Postdoctorates in Science and Engineering (GSS).

According to the NSF Web site, the SED began in 1957-1958 to collect data continuously on the number and characteristics of individuals receiving research doctoral degrees from all accredited U.S. institutions. The results of this annual survey are used to assess characteristics and trends in doctorate education and degrees. Data are now available through 2006 disaggregated by gender, race/ethnicity, and citizenship. However, the online version uses a more limited set of fields, for example "Mathematics and Statistics," than the full SED field list. Also, the online version is aggregated by institution, not by department/program. The survey does record departmental information, but does not make it public. Data are available online at NSF's WebCASPAR database, which provides access to statistical data resources for science and engineering (S&E) at U.S. academic institutions.[4]

The SDR gathers information from individuals who have obtained a doctoral degree in a science, engineering, or health field (SEH). The SDR, which is conducted every 2 years, is a longitudinal survey that follows recipients of research doctorates from U.S. institutions until they reach age 76. This group is of special interest to many decision makers because it represents some of the most educated individuals in the U.S. workforce. The SDR results are used by employers in the education, industry, and government sectors to understand and to predict trends in employment opportunities and salaries in SEH fields for graduates with doctoral degrees. The results are also used to evaluate the effectiveness of equal opportunity efforts. Coverage began in 1973. There was no 2005 survey, but there was a 2006 survey instead. Data are available online at WebCASPAR.[5]

The GSS provides data on the number and characteristics of students in graduate S&E and health-related fields enrolled in U.S. institutions. NSF uses the results of this annual survey to assess trends in financial support patterns and shifts in graduate enrollment and postdoctoral appointments. The GSS collects data from all U.S. institutions that offer graduate programs in any field of science or engineering and/or in specific health-related fields of interest to the National Institutes of Health (NIH). This survey collects data items at the academic department level, including counts of full-time graduate students by source and mechanism of support, by total, and by gender; number of part-time graduate students by gender; and citizenship and racial/ethnic background of all graduate students, including first-time students. In addition, the survey requests count data on postdoctorates by source of support, gender, and citizenship, with separate data on those holding first-professional doctorates in the health fields; and summary information on other doctorate nonfaculty research personnel. Coverage is academic year 1966 to academic year 2005. Data are available online at WebCASPAR.[6]

Other Sources of Information

Data similar to those obtained in the NSF surveys for the mathematical sciences are collected by the American Mathematical Society (AMS) in its annual surveys. AMS collects data on the total undergraduate and graduate course enrollments in the fall of each academic year, as reported by departments through surveys conducted each year from fall 1991 through fall 2006. For the years 1991 through 1999, the survey asked departments to report the prior year's numbers plus the current year's numbers. Having the 2 years of data will permit one to deal with nonresponse in cases where a department responds in year N but not in year $N - 1$. There are some issues with the data:

1. There are years in which some departments did not reply, sometimes for several years in a row. The number seems to shrink a bit over the years: in 1991 more than 40 departments did not respond; in the mid-2000s, the figure is in the range of 10 to 15.
2. In addition, a department is sometimes dropped from the survey and at other times a department

[4] See NSF, "Survey of Earned Doctorates," available at http://www.nsf.gov/statistics/showsrvy.cfm?srvy_CatID=2&srvy_seri=1. Accessed June 15, 2009.

[5] See NSF, "Survey of Earned Doctorates," available at http://www.nsf.gov/statistics/showsrvy.cfm?srvy_CatID=3&srvy_seri=15. Accessed June 15, 2009.

[6] See NSF, "Survey of Earned Doctorates," available at http://www.nsf.gov/statistics/showsrvy.cfm?srvy_CatID=2&srvy_seri=12. Accessed June 15, 2009.

is added. For the mathematics departments, this occurs only in Group III.[7] There are also changes as to which statistics, biostatistics, and applied mathematics departments are included.

3. In some cases, departments returned a form but the specific data either were missing or judged not usable.
4. Some departments may not have undergraduate programs (i.e., the department reports graduate enrollment only).

AMS also collects data on the number of doctorates in the mathematical sciences. Data focus on the number of new doctorates by gender, race/ethnicity, and citizenship, organized by academic calendar year, by institution, and by department. Coverage is from academic year 1991 to academic year 2005. There are a number of technical issues (e.g., values changing for race/ethnicity categories in the 1990s), and there are some indications of inaccuracies.

A second source of information is provided by the Department of Education's National Center for Education Statistics through its Integrated Postsecondary Education Data System (IPEDS) Peer Analysis System. IPEDS allows users to compare a postsecondary institution to a group of peer institutions, all of which are user-selected. Data of relevance include degree data, enrollment data, and data on enrollment of mathematics majors. Degree data include information on level of degree, gender, and race/ethnicity. Enrollment data are fall enrollment or 12-month enrollment data, and enrollment data on mathematics majors are available by gender, race, attendance status, and level of student. Degree data go back to 1986. General enrollment data go back at least to 1990. Data on enrollment of mathematics majors were collected every 2 years from 1996 through 2006.

Information Collected by the Committee

The study committee sent an e-mail request for information to VIGRE awardees and to other departments of applied mathematics, mathematics, and statistics. The objective of this request was to collect additional information on the following:

- Initial and renewal applications to the VIGRE program,
- Experiences of VIGRE awardees, and
- Basic trends in the departments.

Working with AMS, the committee sent an e-mail to chairs of all PhD-granting departments of applied mathematics, biostatistics, mathematics, and statistics, asking them to submit information on their departments' experiences. The committee requested information from a total of 288 departments. To facilitate the data collection, a Web site was created to store the information received; the e-mail to the chairs contained a link to this Web site. The initial request was sent in November 2007. Three e-mail follow-ups were sent, the final one in early February 2008. Of 50 VIGRE awardees (departments) that were surveyed, 40 returned the committee's questionnaire. Of 238 non-awardee departments that received the e-mail, 114 responded. See Appendix C for the questionnaires sent to departments.

On February 29, 2008, three committee members conducted an hour-long conference call with seven professors who had in previous years served on site-visit teams, either at the time of an initial proposal

[7] According to the AMS (http://www.ams.org/employment/groups_des.html; accessed August 6, 2009), Group III contains U.S. mathematics departments reporting a doctoral program that received a ranking of less than 2.0 in the 1995 National Research Council volume *Research Doctorate Programs in the United States: Continuity and Change* (NRC, 1995) or were not included in the NRC rankings.

or at the time of the 3-year renewal. Questions included how the professors had conducted their evaluations, what criteria they had used to evaluate the sites, and what guidance the NSF staff had provided. Additionally, the committee sent an e-mail to all non-NSF people who had ever served on a VIGRE site-visit team. That e-mail asked for the recipients' thoughts about the most helpful and least helpful parts of the site visit in terms of evaluating a proposal or awardee, and for any suggestions for improvements in the site-visit process. One follow-up reminder was sent. About 10 reviewers responded.

During several meetings, the entire committee met with various NSF staff members as well as with faculty from selected mathematical sciences departments who were involved in VIGRE activities at their institutions. The NSF staff included former DMS directors Donald Lewis and William Rundell and current director Peter March. The committee also heard presentations from NSF program officer Henry A. Warchall and from the following representatives of departments with current or former VIGRE grants: Peter May (University of Chicago); Alan Tucker (State University of New York, Stony Brook); Calvin Moore (University of California, Berkeley, Mathematics Department); Deborah Nolan (University of California, Berkeley, Statistics Department); Robert Greene (University of California, Los Angeles); and Jesús de Loera (University of California, Davis). Professors Greene and de Loera were each accompanied by undergraduate and graduate students, who presented their impressions of the VIGRE program's effect on their department. Appendix E contains a list of presentations.

Some committee members also conducted individual telephone and e-mail interviews with selected faculty from various mathematical sciences departments around the country to learn about the interviewees' experiences with the VIGRE program. The interviewees included William Goldman (University of Maryland), Barry Simon (California Institute of Technology), David Jerison (Massachusetts Institute of Technology), Rick Durrett (Cornell University), George Papanicolaou (Stanford University), and Peter Jones (Yale University). The committee was unable to interview Philippe Tondeur, a former director of NSF/DMS.

Finally, the committee conducted a literature review related to the VIGRE program. *Increasing the Quantity and Quality of the Mathematical Sciences Workforce Through Vertical Integration and Cultural Change* (Cozzens, 2008) provides many instances of innovative teaching and research within departments supported by this program. Other commentaries that the committee found useful were an early article by Rick Durrett entitled "VIGRE Turns Three," in the *Notices of the AMS* (Durrett, 2002); and the report of the American Mathematical Society, the American Statistics Association, the Mathematical Association of America, and the Society for Industrial and Applied Mathematics 2002 workshop on VIGRE.[8]

The committee regrets that the committee itself was not allowed access to some NSF source documents, such as proposals to the VIGRE program and reviews of departments with VIGRE grants. Conflicting requirements exist between NSF, whose policy is that these documents not be made public, and the NRC, which is required by law to make public most documents received by a committee in the course of a study. Although access was allowed to NRC staff, who reviewed and summarized some of these documents and provided some statistical analysis, direct access by committee members would have aided the committee in formulating conclusions and recommendations.

OUTLINE OF THE REPORT

In this introductory chapter, the committee defined its interpretation of its charge and described its sources of information and the scope and approach of its evaluation. In Chapter 2 the committee examines the case for the VIGRE program, detailing the state of higher education in the mathematical sciences,

[8] Available at http://www.ams.org/amsmtgs/VIGRE-report.pdf. Accessed August 5, 2009.

as seen by NSF, in the years leading up to the establishment of the program and focusing in particular on several key reports summarizing the state of the field. Chapter 3 describes the VIGRE program, and Chapter 4 discusses the administration, monitoring, and assessment of the program to date. Chapter 5 presents the committee's assessment of the VIGRE program through its evaluation of successes and some outcomes at individual departments. Finally, Chapter 6 presents the committee's conclusions and recommendations.

The report also contains six appendixes:

- Appendix A presents the biographies of members of the Committee to Evaluate the NSF's Vertically Integrated Grants for Research and Education (VIGRE) Program,
- Appendix B presents tables used to characterize the state of education in the mathematical sciences from 1980 through 1998,
- Appendix C contains the questionnaires sent by the committee to all U.S. PhD-granting institutions in the mathematical sciences,
- Appendix D presents tables and charts needed to describe the changes in the mathematical sciences since 1998,
- Appendix E is a list of presentations at committee meetings, and
- Appendix F defines the acronyms used in this report.

Except where explicitly noted, this report uses the terms "mathematics" and "mathematical sciences" interchangeably. Both include pure mathematics, applied mathematics, and statistics.

2

Background of the VIGRE Program

In the 1980s and 1990s, there was concern within the mathematical sciences community that postsecondary education in the mathematical sciences was in trouble. A series of challenges was identified in several important national reports, many of which provided the intellectual framework for the National Science Foundation's (NSF's) Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE) program. Prominent among these reports were the following:

- *Renewing U.S. Mathematics: Critical Resources for the Future,* also known as the David Report after the chair of the committee, former Presidential Science Advisor Edward David (NRC, 1984);
- Its successor report, prepared by a committee also chaired by Edward David (and hence sometimes referred to as David II), *Renewing U.S. Mathematics: A Plan for the 1990s* (NRC, 1990);
- *Educating Mathematical Scientists: Doctoral Study and the Postdoctoral Experience in the United States,* also known as the Douglas Report after committee chair Ronald Douglas (NRC, 1992);
- A study, *Graduate Education and Postdoctoral Training in the Mathematical and Physical Sciences,* by a panel convened in June 1995 by the Mathematics and Physical Sciences Directorate of the National Science Foundation (NSF, 1996); and
- The report of an international panel convened by NSF, *Report of the Senior Assessment Panel for the International Assessment of the U.S. Mathematical Sciences,* also known as the Odom Report after panel chair General William Odom, former head of the National Security Agency (NSF, 1998).

Together, these reports painted a picture for the mathematical sciences that focused on three major challenges: inadequate funding, insufficient numbers of students interested in mathematics, and shortcomings in the shape and direction of postsecondary mathematics education. This chapter reviews the state of education in the mathematical sciences in the 1980s and 1990s, as perceived by NSF, in order to understand the deficiencies that VIGRE was intended to ameliorate.

FUNDING FOR MATHEMATICAL SCIENCES IN THE 1980s AND 1990s

Federal support in the mathematical sciences is provided largely by NSF, and to a lesser extent by the Department of Defense (DOD) through the Office of Naval Research (ONR), the Army Research Office (ARO), and the Air Force Office of Scientific Research (AFOSR). Additionally, some funding is provided by the Department of Energy (DOE), the National Security Agency, and the National Institutes of Health (NIH), and minor amounts come from other federal agencies. In the 1990s, funding from NIH rose to match that provided by DOE. As the Odom Report noted and as is illustrated in Table 2-1: "The NSF provides the majority of support for mathematical research in U.S. universities and institutions" (NSF, 1998, p. 38).

The reports mentioned above raised three concerns about funding for the mathematical sciences: (1) federal funding was perceived as inadequate to sustain and grow the field, (2) funding was too heavily dependent on NSF, and (3) the modes of support and the targets of funding were imbalanced, with too much emphasis on investigators and not enough on graduate students and postdoctoral researchers, and with graduate support focused heavily on research assistantships with little allocated to fellowships and traineeships that would help professional development in other ways.[1]

The David Report, which presented a "state of the field" in the early 1980s, cogently made the case for a higher level of funding for the mathematical sciences. In drawing its conclusions, the report focused on federal support for mathematical research in universities, federal support for students, and the budgets of federal agencies. Overall, the report found the following:

- Federal support for the mathematical sciences research enterprise stood in 1982 at less than two-thirds its 1968 level (in constant dollars);
- the principal reduction occurred during the period 1968-73;
- it was followed by nearly a decade of zero real growth in support;
- these budgetary events occurred during the peak in growth of the field—growth in the range and depth of uses of mathematics, with a concomitant doubling of the number of mathematical scientists productively engaged in research (NRC, 1984, p. 36).

The follow-up to the David Report, released in 1990, indicated that there had been some improvement in the funding situation. David II noted: "NSF support of mathematical sciences research nearly doubled (almost 50% real growth compared to 29% for total NSF R&D) over the six years from FY 1983 to FY 1989" (NRC, 1990, p. 22). Likewise, "The Department of Energy (DOE) doubled its support for the mathematical sciences over the period from FY 1984 to FY 1988" (ibid., p. 26). The picture at DOD was more complex: although support had increased, much of it was "because two new mathematical sciences research programs were created, one at the Defense Advanced Research Projects Agency (DARPA) and the other at the National Security Agency (NSA)" (ibid., p. 24). While noting this progress, David II also pointed out that the increases were far from meeting the goals laid out in the David Report. The Odom Report noted that "students of these [mathematical sciences] programs are provided substantially less federal funding than are students of the other sciences" (NSF, 1998, p. 31). Figure 2-1 shows that total academic research and development (R&D) expenditures at universities in mathematics and statistics had been rising over the 1980s and 1990s, although the percentage coming from federal sources had been declining.

[1] The National Science Foundation defines the terms as follows: A *fellowship* is any competitive award (often from a national competition) made to a student that requires no work of the recipient. A *traineeship* is an educational award given to a student selected by the institution. An *assistantship* should be classified as research or teaching, depending on the assigned duties.

TABLE 2-1 Federal Obligations to U.S. Universities and Colleges for Research in Mathematical Sciences, 1980-1998 (in thousands of current dollars)

Year	USDA	DOD	DOE	DHHS—NIH	DHHS—Other	NASA	NSF	Total	Percentage NSF
1980	282	16,121	2,921	3,671	0	1,344	24,686	49,025	50
1981	1,492	20,991	3,350	3,975	0	862	28,815	59,485	48
1982	1,107	24,362	3,163	4,079	0	937	30,630	64,278	48
1983	1,051	27,493	3,972	4,074	0	834	34,869	72,293	48
1984	1,032	30,181	3,393	5,251	0	416	38,133	78,406	49
1985	973	32,239	11,384	3,733	0	833	47,816	96,978	49
1986	833	35,066	12,812	4,615	0	761	51,079	105,166	49
1987	704	32,526	17,051	4,520	0	953	55,784	111,538	50
1988	615	33,152	15,958	5,759	0	1,115	61,199	117,798	52
1989	497	32,165	13,727	4,666	0	998	63,155	115,208	55
1990	353	36,551	17,155	5,642	0	989	68,501	129,191	53
1991	867	25,829	16,280	6,477	0	623	71,834	121,910	59
1992	678	39,961	15,122	5,299	467	873	88,045	150,445	59
1993	632	39,716	7,575	6,473	456	684	80,351	135,887	59
1994	466	48,030	9,070	7,433	353	689	74,997	141,038	53
1995	567	35,190	0	19,984	128	917	76,368	133,154	57
1996	297	35,019	0	24,290	7	641	75,716	135,970	56
1997	203	20,263	7,297	9,320	381	841	79,862	118,167	68
1998	610	29,183	7,280	9,993	308	816	84,326	132,516	64

NOTE: Acronyms are defined in Appendix F.
SOURCE: National Science Foundation, "Survey of Federal Funds for Research and Development," accessed via WebCASPAR, http://webcaspar.nsf.gov.

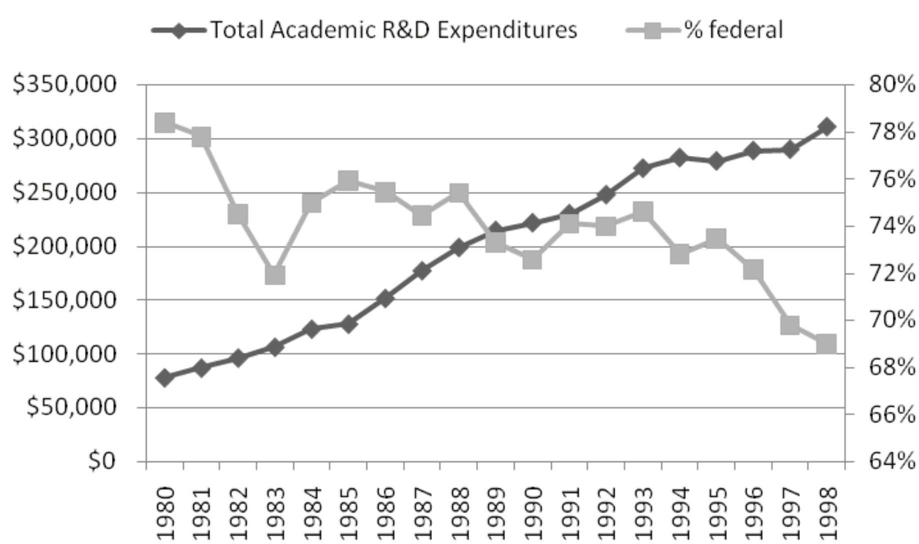

FIGURE 2-1 Total academic research and development (R&D) expenditures and percentage of the federally financed R&D expenditures in mathematics and statistics in the United States, 1980-1998. SOURCE: National Science Foundation, "Survey of Federal Funds for Research and Development," accessed via WebCASPAR, http://webcaspar.nsf.gov.

The second concern raised by the four important national studies cited was the concentration of funding. The Odom Report suggested that NSF had a high level of responsibility for the stewardship of the mathematical sciences (NSF, 1998, p. 38). This is clear from Table 2-1, which shows support for the mathematical sciences from several federal agencies. The David Report put it somewhat differently, suggesting that NSF might inadvertently have had too much control over policies that should be made by, or with, the broader research community. NSF's proportion of federal support for graduate students rose from 30 percent in 1980 to about 37 percent in 1998, with most of this occurring between 1984 and 1985, and irregularly otherwise (see Figure D-1 in Appendix D, "The Mathematical Sciences Since 1998," in this report).

The third point of concern was that federal funding in the mathematical sciences was imbalanced in major ways that hindered the support for and development of young people. As Figure 2-2 shows, most graduate students were supported by nonfederal sources of funding (about 70 percent), followed by self-support (about 20 percent). Federal sources only supported about 10 percent of full-time graduate students in mathematics and statistics during the 1980s and 1990s, and that support was relatively flat as a proportion of total support (although the number of graduate students changed over this time, as noted in Table B-4 in Appendix B, "The Mathematical Sciences in the 1980s and 1990s," in this report).

The Odom Report noted: "Despite the excellence of the U.S. graduate programs in the mathematical sciences, the students of these programs are provided substantially less federal funding than are students of the other sciences. They depend almost entirely on teaching assistants stipends and on their own resources" (NSF, 1998, p. 31). As Figure 2-3 shows, most students who received support relied on teaching assistantships (TAs) or other mechanisms of support. These mechanisms tend to lengthen the time to degree.

In terms of support mechanisms, federal sources rarely funded full-time graduate students through teaching assistantships—99 percent or more of TAs were funded by nonfederal sources such as state

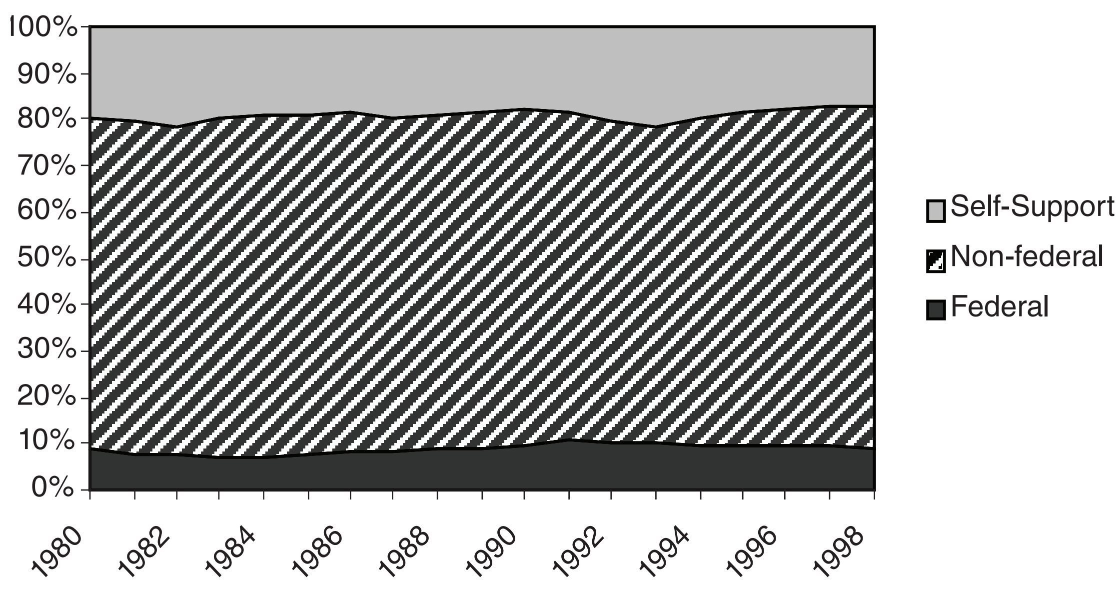

FIGURE 2-2 Sources of support to full-time graduate students in mathematics and statistics in the United States, 1980-1998. SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://webcaspar.nsf.gov.

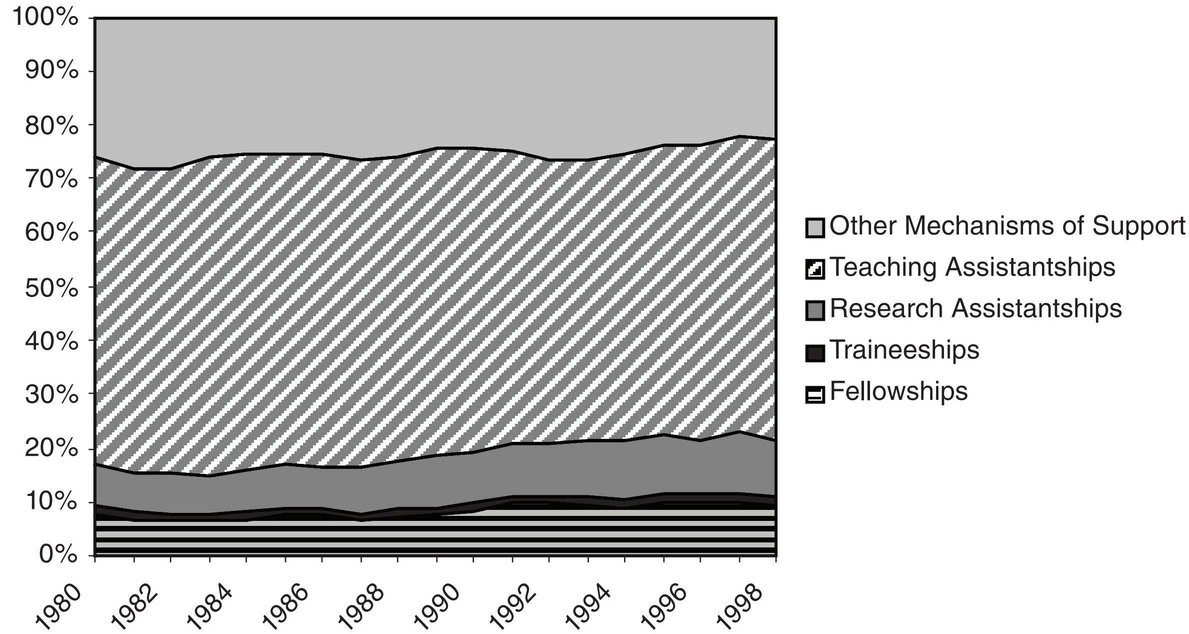

FIGURE 2-3 Mechanisms of support for full-time graduate students in mathematics and statistics in the United States, 1980-1998. SOURCE: National Science Foundation-National Institutes of Health, “Survey of Graduate Students and Postdoctorates in S&E,” accessed via WebCASPAR, http://webcaspar.nsf.gov.

university funds. On the other hand, about half of research assistantships were funded through federal sources, as indicated in Table 2-2.

The NSF (1996) report noted that the funding approach had helped to create an imbalanced focus on research.

> Since the main criterion for judging grant applications has traditionally been the quality of the research to be performed, along with the success of past research, this is necessarily where the attention of grant applicants must be focused. Not only does this affect the principal investigators, who may believe they are expected to give lower priority to other aspects of the education of their students in order to keep the funding pipeline open, but it affects graduate and postdoctoral students themselves, who perform most of the labor involved in such research and who are often effectively discouraged from spending time on other educational pursuits not directly involved in their advisor’s research project. [Moreover,] [t]he current funding mechanism (where graduate students are supported primarily by Research Assistantships) also has the effect of allowing a lengthening of the time to obtain a Ph.D. Successful researchers are understandably unwilling to lose graduate students when they have finally become highly productive, and these students may, in turn, prefer the protected, known world of the university over a usually unknown “outside” world. (NSF, 1996, pp. xi, xii)

Table 2-3 shows, for instance, that NSF had used research assistantships most often in supporting graduate students.

Postdoctoral researchers and investigators also faced funding issues in the 1980s and 1990s. According to the Odom Report:

TABLE 2-2 Percentage of Each Mechanism of Support for Full-Time Graduate Students in Mathematics and Statistics in the United States That Comes from Federal Sources, 1980-1998

Year	Fellowships	Research Assistantships	Teaching Assistantships	Traineeships	Other Mechanisms of Support
1980	17	54	0	15	10
1981	12	45	1	13	11
1982	12	45	0	14	10
1983	17	44	0	18	9
1984	13	47	0	6	8
1985	14	48	0	8	10
1986	14	52	0	13	10
1987	17	57	0	10	8
1988	18	54	0	5	10
1989	25	51	0	18	7
1990	35	46	1	29	7
1991	37	47	0	36	7
1992	32	49	0	43	6
1993	29	51	1	32	6
1994	25	48	1	28	7
1995	23	45	1	32	7
1996	22	47	1	34	7
1997	19	45	1	27	8
1998	20	45	1	33	7

SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://websacpar.nsf.gov.

> Lack of financial support thwarts the careers of many young mathematical scientists. Not only is there a lack of sufficient postdoctoral fellowships for new doctorates in the mathematical sciences, but few young researchers are successful in obtaining research grants. With only 35% of academic research mathematical scientists receiving such grants, it is exceedingly difficult for young researchers to pursue careers in research. This lack of support, especially when compared with support for young researchers in the physical, biological, and engineering sciences, discourages young mathematicians, many of whom have left academia for Wall Street and other nonacademic fields. This loss of young researchers has the potential to undermine future U.S. strength in the mathematical sciences (NSF, 1998, p. 28).

As Table 2-4 illustrates, during the 1980s and 1990s about two-thirds of postdoctorates were supported by federal sources, which mainly provide research funds.

Figure 2-4, on the other hand, shows little progress in federal support for academic mathematics doctorate holders through 1999. The proposal success rate—one of several criteria used by NSF to determine adequacy of support—was in the same range as for other fields within NSF's Mathematics and Physical Sciences Directorate (MPS).

These trends led the 1995 NSF workshop to recommend changing the mix of funding:

> Currently, the bulk of graduate student support provided by the Foundation is in the form of awards to individual investigators, who use these funds in part to support graduate students. Many participants agreed that this often has had the unintended consequence of limiting the areas in which students take courses and acquire experience. The Workshop recommended that MPS experiment with means to increase gradu-

TABLE 2-3 Mechanisms of Support by the National Science Foundation for Full-Time Graduate Students in Mathematics and Statistics in the United States, 1980-1998

	Percentage of Support Provided by:					
Year	Fellowships	Traineeships	Research Assistantships	Teaching Assistantships	Other Mechanisms of Support	Number of Students Supported
1980	37	2	57	2	2	262
1981	27	4	67	1	1	227
1982	24	4	69	0	2	228
1983	36	4	59	0	1	223
1984	27	0	69	0	3	279
1985	26	2	69	0	2	321
1986	26	0	71	1	2	357
1987	24	0	73	1	2	436
1988	25	0	73	0	2	463
1989	27	0	71	1	1	475
1990	28	0	68	3	0	491
1991	31	0	67	1	1	452
1992	26	0	71	2	0	457
1993	24	1	71	4	0	470
1994	25	4	67	3	0	518
1995	27	4	61	6	2	474
1996	29	5	59	6	1	435
1997	25	5	66	3	1	386
1998	23	6	68	1	2	384

SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://webcaspar.nsf.gov.

ally the fraction of graduate students supported on fellowships and traineeships. Further, it recommended that NSF should encourage members of the MPS community in academia to propose new institutional, "thematic" funding mechanisms for graduate student training and support that would involve collective responsibility for groups of students. Funds could be awarded to entire departments, to combinations of departments, or to theme-oriented entities that would allocate resources to students themselves. This would have the effect of allowing departments, or other groups, to take greater ownership of the overall quality of graduate education. The criteria for making awards would have to guarantee that special, new efforts would be made to achieve the desired educational improvements. In addition, NSF could reward and encourage such "collective proposals" that exhibit success in the recruitment and retention of students from underrepresented groups, including women, minorities, and, where applicable, domestic students (NSF, 1996, pp. xiv-xv).

Overall the funding situation in the 1980s and 1990s was characterized by the following:

- Rising funding overall, but federal funding declining as a share of total funding (from Figure 2-1);
- Funding for the mathematical sciences being increasingly dependent on NSF (from Table 2-1);
- Graduate students relying primarily on teaching assistantships and other support mechanisms (from Table 2-3); and

TABLE 2-4 Number of Postdoctorates Supported in Mathematics and Statistics in the United States, 1980-1998, by Mechanism of Support

	Federal					
Year	Fellowships	Traineeships	Research Grants	Nonfederal	Total	Percentage Federal
1980	23	3	31	105	162	35
1981	20	3	41	49	113	57
1982	22	4	20	148	194	24
1983	27	3	53	87	170	49
1984	46	3	83	71	203	65
1985	35	6	79	106	226	53
1986	39	5	70	87	201	57
1987	42	6	81	100	229	56
1988	44	5	139	96	284	66
1989	38	4	99	84	225	63
1990	41	1	116	91	249	63
1991	27	3	113	63	206	69
1992	23	6	114	58	201	71
1993	34	8	124	58	224	74
1994	37	7	113	82	239	66
1995	39	5	130	88	262	66
1996	54	4	164	104	326	68
1997	49	2	146	111	308	64
1998	41	2	136	100	279	64

SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://webcaspar.nsf.gov.

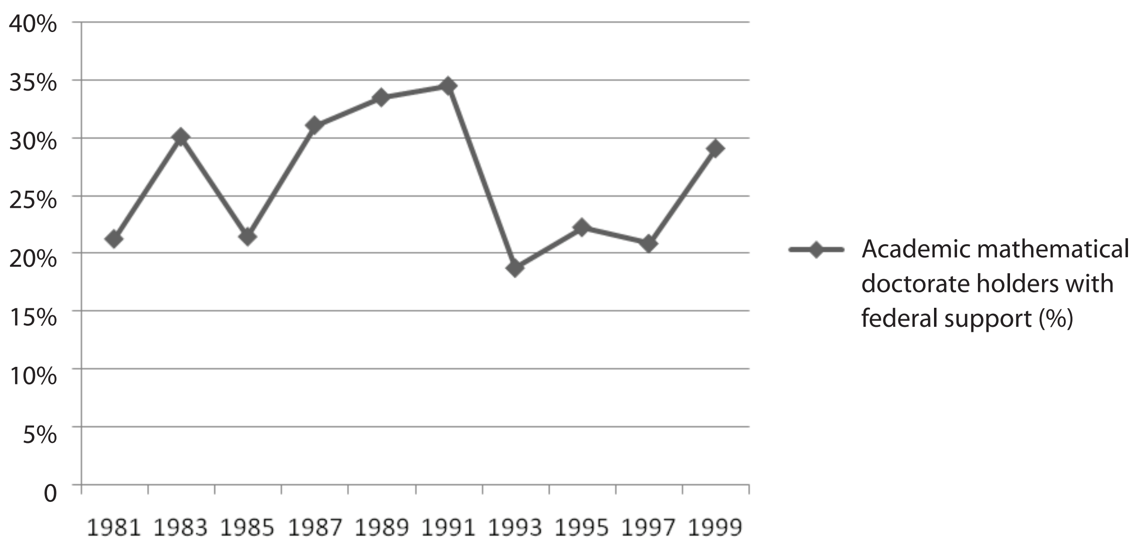

FIGURE 2-4 Percentage of academic doctorate holders in mathematics in the United States with federal support, 1981-1999. NOTE: Data from 1985, 1993, 1995, and 1997 are not comparable to the other years and understate the degree of federal support because a survey question asked whether work performed during the week of April 15 was supported by the government. In other years, this question pertained to work conducted over the course of a year. SOURCE: Adapted from National Science Board (NSB, 2004), Appendix Tables 5-26 and 5-32.

- Federal graduate student support being overly concentrated in the form of research assistantships rather than in a broader array of professional development mechanisms (from Odom Report [NSF, 1998] extract, above).

STUDENTS IN THE MATHEMATICAL SCIENCES

During the 1980s and 1990s, the mathematical sciences community (as evidenced, for instance, by the David Reports [NRC, 1984, 1990] and the Odom Report [NSF, 1998], was concerned about four major issues with respect to students: (1) the number of students receiving degrees, (2) the lack of racial and gender diversity among the mathematics graduate student body, (3) the declining fraction of U.S. citizens receiving advanced degrees in mathematics, and (4) the lack of sufficient postdoctoral fellowships for new doctorates. As Figure 2-5 shows, during the period from 1980 through 1998, graduate enrollments in mathematics and statistics peaked in the early 1990s and then began to decline through 1998.

While the numbers of graduate students had been changing over time, so too had the demographic characteristics of students in the mathematical sciences. Much has been written about the rising number of foreign students in mathematics higher education as in the sciences and engineering more generally, as well as about the challenges facing the mathematical sciences in attracting, retaining, and advancing a more diverse group of students and scholars. In looking at this group of full-time students, Figure 2-6 shows three demographic trends over the period 1980-1998:

- The percentage of U.S. citizens and permanent residents among full-time graduate students in mathematics and statistics remained level or declined,
- The percentage of female full-time graduate students in mathematics and statistics rose, and
- The percentage of underrepresented minorities among full-time graduate students in mathematics and statistics rose somewhat, but only by a few percent.

Figure 2-7 shows that the number of bachelor's degrees awarded in the mathematical sciences from 1980 through 1998 rose and then declined. The apparent flatness in the number of master's and doctor's degrees is an artifact of the graph. In fact they increased by about 30 percent and 50 percent respectively during the period shown.

Focusing just on doctorates over the same period, Figure 2-8 shows the following:

- The percentage of doctorates awarded to U.S. citizens and permanent residents declined,
- The percentage of doctorates awarded to women doubled, and
- The percentage of doctorates awarded to underrepresented minorities rose by a small amount.

Table 2-5 provides information about the postdoctoral plans of new doctorates between 1982 and 1998. The number of mathematics doctorates with definite plans to move into a postdoctoral appointment had grown somewhat, comparing the early 1980s to the 1990s. At the end of the 1990s, about one in three new doctorate recipients had such commitments.

As Figure 2-9 shows, the number of postdoctorals grew from 1980 to 1988 but then dipped and rose, ending up in 1998 at about where it was for 1988.

The envisioned role of postdoctoral fellowships in completing the training of new PhDs is well stated in the Douglas Report: "The number of postdoctoral fellowships in the mathematical sciences should be greatly increased so that such positions can be viewed as a logical next step after completion

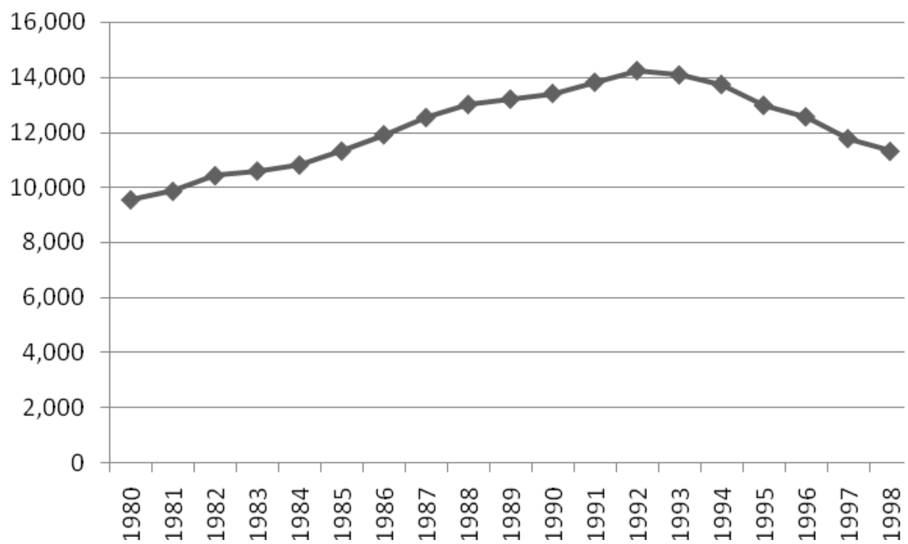

FIGURE 2-5 Full-time graduate students in mathematics and statistics at doctorate-granting institutions in the United States, 1980-1998. SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://webcaspar.nsf.gov.

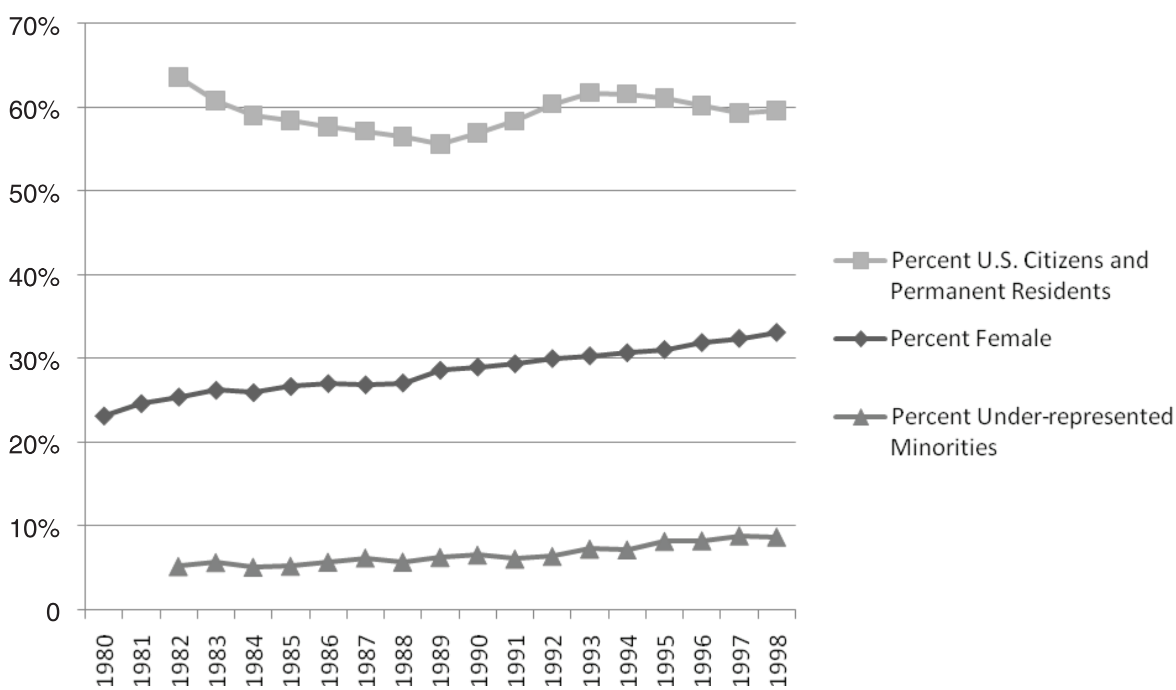

FIGURE 2-6 Percentage of full-time graduate students in mathematics and statistics in the United States who are U.S. citizens and permanent residents, underrepresented minorities, or female, 1980-1998. NOTE: Citizenship and gender are known. "Underrepresented minorities" includes blacks, non-Hispanics; American Indians or Alaska Natives; and Hispanics. Race/ethnicity data include other/unknown in the denominator. Race/ethnicity is only known for U.S. citizens and permanent residents. SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://webcaspar.nsf.gov.

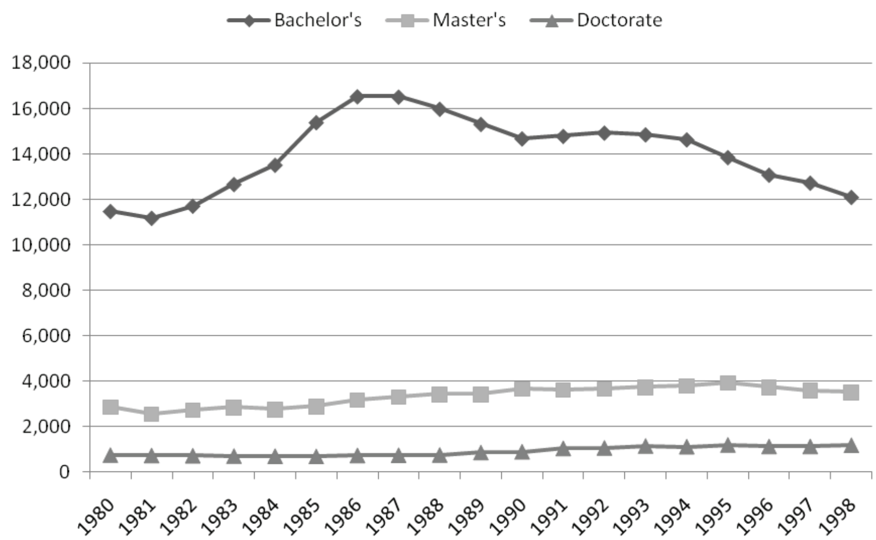

FIGURE 2-7 Number of degrees awarded in the mathematical sciences in the United States, 1980-1998, by degree level. SOURCE: Adapted from NSF, Division of Science Resources Statistics (2008), Table 35.

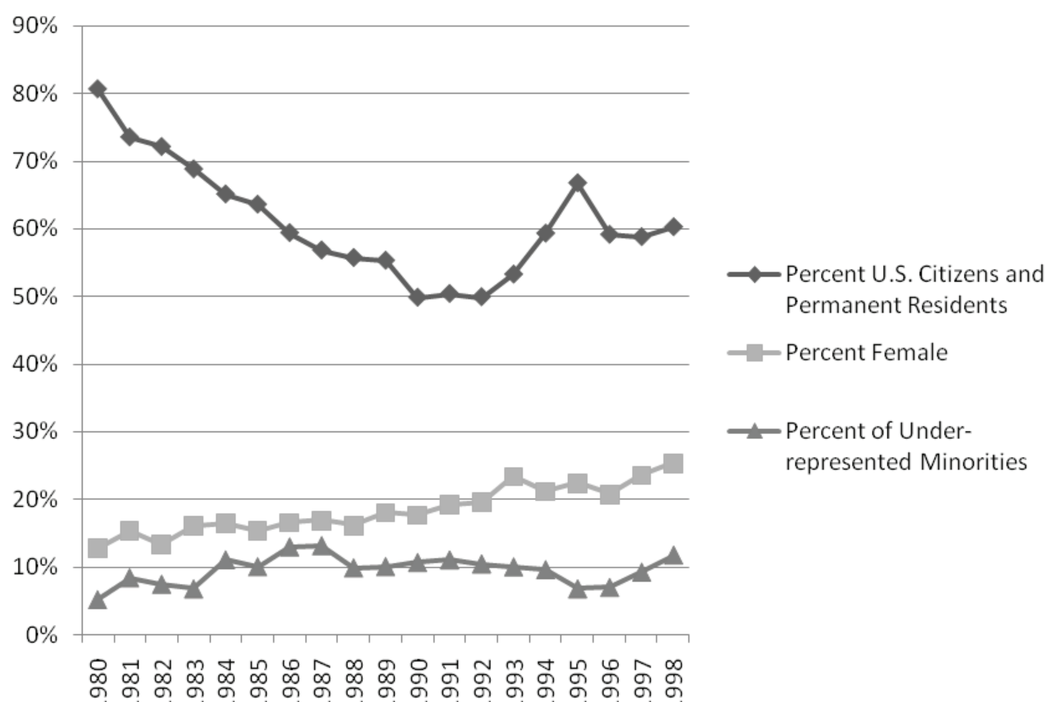

FIGURE 2-8 Percentage of mathematics and statistics doctorates awarded in the United States, by gender, race, and citizenship, 1980-1998. NOTE: The percentage of females is the number of females divided by the number of (females plus males). In some cases gender was unknown. The same is true for citizenship. “Underrepresented minorities” includes blacks, non-Hispanics; American Indians or Alaska Natives; and Hispanics. The percentage of underrepresented minorities is divided by total doctorates, which include some people for whom race/ethnicity is “other/unknown.” SOURCE: National Science Foundation, “Survey of Earned Doctorates/Doctorate Records File,” accessed via WebCASPAR, http://webcaspar.nsf.gov.

TABLE 2-5 New Doctorate Recipients with Definite Commitments to Postdoctoral Study or Research, by Broad Field of Doctorate: 1982, 1993-1998

Field of Doctorate	1982	1993	1994	1995	1996	1997	1998
	Number						
All fields, total recipients with commitments	21,429	24,480	24,946	24,980	26,073	25,533	26,643
Total planning postdoctoral study	4,238	7,060	7,275	7,380	7,667	7,092	7,580
Science and engineering, total	3,918	6,568	6,708	6,774	7,103	6,551	6,909
Mathematics	80	167	168	196	217	199	206
	Percent						
Total planning postdoctoral study	19.8	28.8	29.2	29.5	29.4	27.8	28.5
Science and engineering, total	31.7	43.7	43.7	44.3	43.4	40.4	40.9
Mathematics	15.8	27.1	27.5	29.9	33.7	30.5	28.9

NOTE: Year designates the 12-month period ending on June 30 of the calendar year cited.
SOURCE: Adapted from Hill et al. (2004), Table 1.

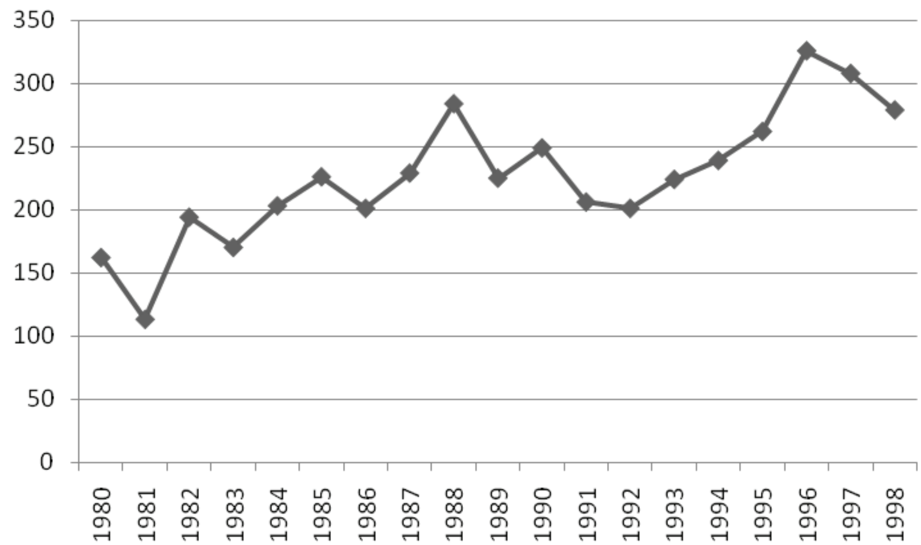

FIGURE 2-9 Number of postdoctorates in mathematics and statistics at doctorate-granting institutions in the United States, 1980-1998. SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://webcaspar.nsf.gov.

of the doctorate for the good student, not as a highly competitive prize for a select few" (NRC, 1992, p. 3). In contrast to labor-intensive laboratory sciences in which many research projects require a team of people with differing levels of research experience, there is not a lot of reliance on postdoctorates in the mathematical sciences. Therefore, postdoctoral appointments have never been a common element of career training. In statistics, where there has long been a strong demand for new PhDs in industry, there is scant interest in postdoctoral appointments. And in mathematics, with its tradition of solitary research, it is not always obvious how to parcel out tasks from a research project to people at different levels of experience. But many in the field recognize the value of a postdoctoral appointment as an opportunity to build research expertise and to develop a track record without the competing demands felt by a junior faculty member. Some see the value of such fellowships as allowing a broadening of training, with "applied, interdisciplinary, or pedagogical components" (NRC, 1992). The 1980s and early 1990s were also a time during which it was difficult to attain a tenure-track faculty appointment, and a number of new PhDs had to make do with "research professorships" or "visiting professorships."

The David II Report (NRC, 1990) went farther in emphasizing educational issues by entitling a section of its recommendations "Improve the Mathematical Sciences Career Path." Recognizing, as did the David Report (NRC, 1984), that "the rate at which young people enter the mathematical sciences remains inadequate to renew the field" (NRC, 1990, p. 5), the report made several specific recommendations. Beyond the need for more funding, it advocated that 10 percent of the new funding should "support coherent programs that directly encourage young people to enter and remain in mathematical science careers. Recruitment of women and minorities into the mathematical sciences is a high priority" (ibid., p. 1). The NSF and other federal agencies "should solicit research proposals for programs that will improve the career path. Such proposals may combine research opportunities for students, postdoctorals and young faculty with increased support for senior researchers who can act as mentors" (ibid., p. 7). Another recommendation was for a change in the reward structure of academic departments, which "should give increased recognition to faculty who act as mentors for students and junior colleagues, who contribute to education, and who interact with collaborators from other disciplines" (ibid., p. 7).

REDEFINING MATHEMATICAL SCIENCES PROGRAMS

Four key issues were discussed in the Douglas (NRC, 1992) and Odom (NSF, 1998) Reports: (1) the need for increased breadth of training for students, including greater emphasis on interdisciplinarity, applied mathematics, and off-campus experiences (e.g., internships); (2) providing a better balance of education and research; (3) decreasing time to degree for students; and (4) creating positive learning environments.

Concerning the first issue, breadth of skills and knowledge, the 1995 workshop on graduate education and postdoctoral training noted: "The skills and knowledge acquired by new Ph.D.'s are too narrowly focused, and are not adequately applicable to the diverse business and industry environments in which most Ph.D. scientists actually work" (NSF, 1996, p. x).

The Odom Report, in addition to recommendations about funding, devoted much of its emphasis to the changing nature of the discipline and the implications of those changes for training mathematicians. Its recommendations to NSF addressed the second issue, improving the balance of education and research: "[E]ncourage activities that connect mathematics to other areas of science, technology, business, finance and government, strengthen the connections between 'pure' and 'applied' mathematics, broaden the exposure of professional and student mathematicians to problems in other fields, and maintain and strengthen abstract mathematics" (NSF, 1998, p. 43). In particular, NSF should "encourage activities aimed at broadening undergraduate and graduate curricula, with the objective of widening the range of curricular choices, raising the attractiveness of mathematical careers to students, and increasing the vocational flexibility of future mathematicians" (ibid., p. 45).

As noted above, time to degree is negatively impacted by the reliance of many students on teaching assistantships and self-support; it could be offset by increasing the number who instead are supported by fellowships. This issue arose because time to degree was growing during the 1980s and 1990s and was raised as a concern in the various reports noted above. As NSF noted in 1997: "In the last decade, the time to degree for a Ph.D. in the Mathematical Sciences has significantly increased from four to

TABLE 2-6 Median Years from Bachelor's Degree to Doctoral Degree in Mathematics in the United States, 1980-1998

Year	Years Elapsed (median years)	Years Enrolled (median years)
1980	7.0	6.0
1981	7.0	6.0
1982	7.1	6.0
1983	7.3	6.3
1984	8.0	6.2
1985	8.0	6.4
1986	7.3	6.1
1987	8.0	6.5
1988	8.1	6.4
1989	8.0	6.3
1990	8.0	6.7
1991	8.3	6.7
1992	8.9	7.0
1993	8.6	7.0
1994	8.9	6.9
1995	8.6	6.9
1996	8.3	6.8
1997	8.7	7.0
1998	8.0	6.8

SOURCE: Adapted from NSF, Division of Science Resources Statistics (2004), Appendix Table 2-29.

seven years. This partially reflects that entering students, especially native-born students, are less well prepared than before. But also involved is the heavy dependence by the Mathematical Sciences graduate students and postdoctorates on time consuming teaching assignments for financial support" (NSF, 1997). Table 2-6 shows the median years elapsed from bachelor's to doctoral degree in mathematics during the 1980s and 1990s. The data in this table are inconsistent with NSF's quoted observations. The committee was unable to determine how NSF arrived at this conclusion and has no additional data to draw other conclusions; however, these observations by NSF played a role in VIGRE's original design.

The fourth issue common to the Douglas (NRC, 1992) and Odom (NSF, 1998) reports had to do with the culture of mathematics departments. The Douglas Report (NRC, 1992) studied a number of departments in an attempt to find out what makes for successful graduate and postdoctoral programs in mathematics. It found that there was considerable variation in explaining such success, and the report broadly classified these variations as the standard model, the subdisciplinary model, the interdisciplinary model, the problem-based model, and the college-teachers model. Within this varied landscape, the report distilled three common characteristics of all the successful programs that it encountered: a focused, realistic mission; a positive learning environment; and relevant professional development. The report highlighted the importance of active recruitment, especially for recruiting women and underrepresented minorities. A detailed description is given of what it means to have a positive learning environment; and communication and cooperation, effective advising, and early research experience are emphasized. It was also emphasized that "a positive learning environment is important to all doctoral students but is crucial for women and underrepresented minorities" (NRC, 1992, p. 3). The report stressed: "Clustering faculty, postdoctoral associates and doctoral students together in research areas is a major factor in creating a positive learning environment" (ibid., p. 3). The importance of broadening the training of doctoral and postdoctoral students was underscored, as was the importance of teaching and communication skills.

3

The VIGRE Program

This chapter describes the original structure and evolution of the Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE) program leading to the committee conclusions and recommendations found in Chapter 6. All of the major challenges for the mathematical sciences recounted in Chapter 2 were heard by the National Science Foundation (NSF). In September 1997 Donald Lewis, then director of the Division of Mathematical Sciences (DMS) at NSF, wrote a "Dear Colleague" letter to the mathematical sciences community introducing and justifying the VIGRE program. The letter presented the background that follows.[1]

Both the David Report (NRC, 1984) and the Douglas Report (NRC, 1992) recommended that DMS at NSF increase support for graduate students and postdoctoral trainees in the mathematical sciences. In addition, these reports recommended that more DMS trainee funding should be done through departmental infrastructure grants than through individual research grants and that this training should be broader and accomplished in less time than it was taking. In 1994 DMS started the Group Infrastructure Grant (GIG) program to provide infrastructure support for departments in the mathematical sciences. The proposals received focused primarily on funding for graduate students and postdoctoral support and on innovative ways to improve graduate programs.

During the previous decade several other factors had come into play. The average time to degree for PhDs in the mathematical sciences had risen from 4 to 7 years,[2] doctoral programs had become more narrowly focused on producing academicians (and students were less well prepared for careers in industry), and the number of U.S. graduate students had fallen dramatically. Concerns had also been voiced indicating that the quality of U.S.-trained undergraduates was decreasing and that problems in kindergarten through grade 12 (K-12) education required a reexamination of the education of K-12

[1] "Dear Colleague" letter, September 10, 1997, from Donald Lewis, Director, Division of Mathematical Sciences, National Science Foundation, to the mathematical sciences community (hereafter cited as "Dear Colleague" letter, September 10, 1997). Available at http://www.nsf.gov/pubs/1997/nsf97170/nsf97170.htm. Accessed July 6, 2009.

[2] This is different from the data reported in Table 2-6 in Chapter 2 of the present report. The discrepancy may reflect a different definition of median time to degree.

teachers. During this period, NSF Director Neal Lane was promoting the concept of integration of research and education.

Given these facts, DMS, with the advice of a DMS Special Emphasis Panel (SEP),[3] decided to replace the GIG program with the Grants for Vertical Integration of Research and Education in the Mathematical Sciences—VIGRE—program. The report of the SEP stated that this program could "achieve a change in the culture in a department" (NSF, 1997) and that

- The funding should enable departments to carry out innovative educational programs at all levels that were not possible with their current resources;
- The duration of awards should be 3 to 5 years (a 5-year period was recommended) and, if possible, should be renewable; and
- Every proposal must include components on undergraduate, graduate, and postdoctoral education and programs to increase the participation of underrepresented groups.

The SEP report (NSF, 1977) went on to recommend that VIGRE proposals should include components addressing the improvement of research, mentoring, and communication skills at all trainee levels and that an integration of faculty and students into a "community of scholars" be achieved. Moreover, it suggested that the average time to PhD degree should be reduced to 5 years, that undergraduates should be exposed to a breadth of mathematical sciences and problem solving, that graduate students should receive supervision in teaching and seminar presentation, and that postdoctoral training should be flexible and should include the possibility of interdisciplinary research. The SEP also suggested that optional outreach programs—such as collaboration with industry and the Department of Energy's national laboratories, K-12 teacher enhancement, and the development of K-12 instructional material—should be viewed positively.

As detailed in the letter from Donald Lewis, the SEP was provided, at the request of its chair, with "a draft description of a program named VIGRE . . . as a means of focusing the panel's discussions."[4] The SEP report opens by saying, "The panel strongly endorsed the concept of vertical integration; that is, constructing undergraduate, graduate and postdoctoral programs to be mutually supportive." Overall, "the funding provided by these grants should enable departments to carry out innovative educational programs at all levels not possible through present departmental resources. The panel sees this as a program that can achieve a change of culture in a department, one that results in broadening opportunities for undergraduate and graduate students both through innovative curriculum development and research experiences" (NSF, 1997).

The SEP report recommended that the VIGRE program have undergraduate, graduate, postdoctoral, and optional curriculum development and outreach components tied together by vertical integration and supported by active recruitment of women and underrepresented minorities. The objectives for the undergraduate component were "preparing mathematical science majors for a wider variety of career opportunities, improving communication skills of mathematics students, and increasing the number of students who major in the mathematical sciences" (ibid.). For the graduate traineeships foreseen in the program, they would "provide a mechanism for broadening graduate education, shortening the average

[3] The SEP was chaired by Morton Lowengrub, then at Indiana University. The other members were Mary Ellen Bock (Purdue University), John Garnett (University of California at Los Angeles), Tom Gerig (North Carolina State University), Philip Hanlon (University of Michigan), Raymond Johnson (University of Maryland), Nancy Kopell (Boston University), Calvin Moore (University of California at Berkeley), Tinsley Oden (University of Texas, Austin), Peter Sarnak (Princeton University), and Shmuel Winograd (IBM).

[4] "Dear Colleague" letter, September 10, 1997.

time to doctoral degree, improving communication skills and improving opportunities for employment" (ibid.). The program for postdoctoral fellows "should be designed to produce professionals ready to begin an academic career. At the conclusion of the postdoctoral program, fellows should have developed an independent research program, developed teaching skills at various program levels, and begun to develop a broad perspective of their field" (ibid.). While the emphasis was on postdoctoral fellows who would become academicians, "industrial experience involving practical problem solving or interdisciplinary research involving the integration of other disciplines into the fellows' research may provide invaluable experience for an academic career" (ibid.). The optional curriculum development component should "mesh with the overall research and educational goals of the project and could include efforts of junior members of the project team" and might involve "areas that are not part of the traditional curriculum, as in interdisciplinary subjects" (ibid.). The optional outreach component would involve "outreach to industry, national laboratories, other academic areas and K-12 education. . . . We encourage creative new models of collaborations with industry, national laboratory and academic partners" (ibid.).

EVOLVING GOALS OF THE VIGRE PROGRAM

This section examines the goals of the VIGRE program as elucidated in NSF's requests for proposals (RFPs). The goals have evolved over the lifetime of the program, although with consistent themes. The original RFP in 1998 stated the following:

> The goals of the Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE) program are: (1) to prepare undergraduate students, graduate students and postdoctoral fellows for a broad range of opportunities available to individuals with training in the mathematical sciences; and (2) to encourage departments in the mathematical sciences to consider a spectrum of education activities and their integration with research.[5]

In 1999, the following focus was added to the second goal: " . . . with particular attention to the interaction of scholars across boundaries of academic age and departmental standing."[6] In 2000, the phrase "consider a spectrum of" in the second goal was replaced with the more emphatic "to initiate or improve."[7] This all culminated in the 2001 RFP:

> The goals of VIGRE are: (1) to prepare undergraduate students, graduate students, and postdoctoral fellows for the broad range of opportunities available to individuals with training in the mathematical sciences; and (2) to encourage departments in the mathematical sciences to initiate or improve education activities that lend themselves to integration with research, especially activities that promote the interaction of scholars across boundaries of academic age and departmental standing.[8]

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[5] From the first program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," NSF 97-155, available at http://www.nsf.gov/pubs/1997/nsf97155/nsf97155.htm. Accessed June 12, 2009.

[6] From the program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," available at http://www.nsf.gov/pubs/1999/nsf9916/nsf9916.pdf. Accessed June 29, 2009.

[7] From the program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," available at http://www.nsf.gov/pubs/2000/nsf0040/nsf0040.pdf. Accessed June 29, 2009.

[8] From the program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," NSF 01-104, available at http://www.nsf.gov/pubs/2001/nsf01104/nsf01104.pdf. Accessed June 29, 2009.

In 2002, the goals were restated as follows:

> The long-range goal of the VIGRE program is to increase the number of well-prepared U.S. citizens, nationals, and permanent residents who pursue careers in the mathematical sciences. A successful VIGRE project must:
> 1. integrate research with educational activities;
> 2. enhance interaction among undergraduates, graduate students, postdoctoral associates, and faculty members;
> 3. broaden the educational experiences of its students and postdoctoral associates to prepare them for a wide range of career opportunities; and
> 4. motivate more students to pursue an education in the mathematical sciences. With these goals in mind, each VIGRE proposal must present a coherent plan for the integration of:
>   - a graduate traineeship program,
>   - an undergraduate research experience program, and
>   - a postdoctoral program.[9]

In 2003, the VIGRE program was subsumed within the larger grant competition, Enhancing the Mathematical Sciences Workforce in the 21st Century (EMSW21), the goals of which were described as follows in the 2003 RFP:

> The long-range goal of the EMSW21 program is to increase the number of U.S. citizens, nationals, and permanent residents who are well-prepared in the mathematical sciences and who pursue careers in the mathematical sciences and in other NSF-supported disciplines. EMSW21 builds on the VIGRE program and now includes a broadened VIGRE activity, an additional component for Research Training Groups (RTG) in the Mathematical Sciences and an additional component for Mentoring through Critical Transition Points (MCTP) in the Mathematical Sciences.[10]

The EMSW21 activity included the VIGRE program, for projects "that involve the entire department and span the entire spectrum of educational levels from undergraduates through postdoctoral associates; Research Training Groups (RTG) [which] support the training activities of a group of faculty who have a common research interest; [and] Mentoring through Critical Transition Points (MCTP) [which] involves a larger group of faculty but focuses on specified stages in the professional development of the trainees."[11]

While the 2004 solicitation for the EMSW21 program included the same goals, the 2005 solicitation was altered to highlight the departmental nature of the award and the vertical integration:

> The long-range goal of the EMSW21 program is to increase the number of well-prepared U.S. citizens, nationals, and permanent residents who pursue careers in the mathematical sciences and in other NSF-supported disciplines, while broadening trainees' background and perspective. A significant part of this goal is to directly increase the proportion and the absolute number of U.S. students at the EMSW21 sites who pursue graduate studies and complete advanced degrees in the mathematical sciences. A related goal of EMSW21 is based on the fact that the direct impact of EMSW21 funds cannot yield a substantial proportional increase in national workforce production; the funds are simply not of the order

[9] From the program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," NSF 02-120, available at http://www.nsf.gov/pubs/2002/nsf02120/nsf02120.pdf. Accessed June 29, 2009.
[10] From the program solicitation: "Enhancing the Mathematical Sciences Workforce in the 21st Century (EMSW21)," NSF 03-575, available at http://www.nsf.gov/pubs/2003/nsf03575/nsf03575.pdf. Accessed June 29, 2009.
[11] Ibid.

> of magnitude to create such an infrastructure. Therefore, indirect impacts, in which EMSW21 can serve as a catalyst beyond the directly-supported students in its home departments and beyond the institutions receiving EMSW21 funds, are crucial as well. Practices and cultural changes that support direct and indirect impacts of this nature will be key strengths in an EMSW21 proposal. Such aspects include, but are not limited to, ideas for attracting strong U.S. students to careers in the mathematical sciences and seeing them through to completion of their studies, and/or evidence of success in doing so; and effective dissemination of best practices that can serve as a national model.[12]

This committee concurs that these current goals of the EMSW21 program are important ones. The ideas of integrating research and education, increasing interaction among different levels of students and scholars, broadening the educational experiences of students with an eye toward increasing career opportunities, and motivating students to pursue an education in the mathematical sciences are all worthwhile objectives.

The committee notes that while the goal of increasing the number of U.S. citizens and permanent residents is important, it believes that the VIGRE program should be broadened to include all students, including international students, studying in the mathematical sciences. It recognizes, however, that a decision to broaden the program in this way might be outside NSF's control. Separating students according to whether they participate in the VIGRE program or not—to the extent that this is practical in a department—risks creating a tension that can reduce collegiality and interaction. Additionally, some international students will choose to remain in the United States, and their participation in the VIGRE program might encourage that choice.

KEY COMPONENTS OF THE VIGRE PROGRAM

Each VIGRE RFP has contained a lengthy description of what is expected of the individual departments and of funded projects. A summary of the RFPs' important passages and changes over the years are presented here. The 1998 RFP clearly sets out the notion at the heart of the program: vertical integration, which "refers to programs in which research and education are coupled and in which undergraduates, graduate students, postdoctoral fellows, and faculty are mutually supportive." According to that RFP:

> Every VIGRE proposal should have as its core a coherent plan for the vertical integration of:
> - a graduate traineeship program
> - a postdoctoral fellowship program
> - undergraduate and graduate curriculum review.[13]

Undergraduates were expected to have research experiences, which the RFP noted could take many forms, and which also "should include exposure to the many opportunities for careers in the mathematical sciences and the development of communication skills."[14]

The graduate traineeships, according to the 1998 RFP, "are intended as a mechanism for: broadening graduate education; shortening the average time-to-degree for the doctorate; improving communication skills; and expanding career opportunities."[15] This is a very useful statement because it establishes four

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[12] From the program solicitation: "Enhancing the Mathematical Sciences Workforce in the 21st Century (EMSW21)," NSF 05-595, available at http://www.nsf.gov/pubs/2005/nsf05595/nsf05595.pdf. Accessed June 29, 2009.

[13] From the program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," NSF 97-155, available at http://www.nsf.gov/pubs/1197/nsf97155/nsf97155.htm. Accessed June 12, 2009.

[14] Ibid.

[15] Ibid.

indicators of success for the program. Furthermore, "Departments are expected to utilize the traineeships to improve the quality, not the size, of the graduate program. In particular, the traineeships are not meant to increase the size of the graduate program by enabling departments to hire additional teaching assistants, nor are they meant to replace current university funding of fellowships or scholarships."[16] In theory it should be possible to test at least whether or not this use of traineeships was violated, although it is more difficult to measure whether the quality of the graduate program improved. Finally, the 1998 RFP noted that, "For postdoctoral fellows, the goal of the program is to produce professionals ready to begin an academic career. . . . At the conclusion of the postdoctoral program, fellows should have developed an independent research program, teaching skills at various levels, a broader perspective of their field, and a comprehension of the responsibilities of the profession."[17] Again, these are indicators that could be tested in theory.

VIGRE proposals were also intended to include an undergraduate and graduate curriculum review for which DMS set out the following goals:

> The curriculum should prepare the students for a broader range of careers than has been the case in recent times and [for] the probable need to change careers over one's working life. It should also emphasize discovery learning, especially in the undergraduate program, involve graduate students in research earlier, and develop analytic and communications skills. The preparation of future K-12 teachers in the mathematical sciences is an important responsibility of mathematical sciences departments and might require the design of appropriate curriculum and courses.[18]

Finally, DMS strongly suggested that VIGRE proposals include either or both of two other components: curriculum/instructional materials development and/or outreach.

The 1999 RFP is important for laying out the justification behind vertical integration:

> The intent of the VIGRE program is to promote the development of a diverse community of researchers and scholars whose members interact on an appreciably wider scale than is now commonly observed, breaking through long-standing barriers that have served to compartmentalize the scholarly activities of undergraduates, graduate students, postdoctoral fellows, junior faculty, and senior faculty. A community characterized by the kind of vertical integration just indicated would not only provide a setting conducive to more meaningful educational experiences for undergraduate and graduate students alike, but also be a stimulus to continuing professional development at the postdoctoral level and beyond.[19]

That RFP also clarified that the undergraduate and graduate curriculum review should occur and should be underway, if not completed, by the time of the proposal submission. The curriculum goals favored by DMS are similar to those described in the 1998 RFP, although a few more elements were added in 1999:

> Recent trends within the mathematical sciences professions strongly suggest that a forward-looking curriculum should prepare students for a broader range of mathematically oriented careers than has traditionally been contemplated and for the probable need to change careers over the course of one's working life. It should also emphasize inquiry-based learning, especially in the undergraduate program;

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[16] Ibid.
[17] Ibid.
[18] Ibid.
[19] From the program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," NSF 99-16, available at http://www.nsf.gov/pubs/1999/nsf9916/nsf9916.pdf. Accessed June 29, 2009.

> involve graduate students in research earlier than is typical in current practice; and develop analytic, computational, and communication skills. Exposure to other disciplines in which mathematics plays a significant role would be a highly desirable element in such a curriculum. The preparation of future K-12 mathematics teachers has become another important responsibility of many mathematical sciences departments, yet the curriculum appropriate to this mission is often not in place.[20]

As in the 1998 RFP, the main program components in 1999 were graduate traineeships, undergraduate research experience, and postdoctoral fellowships. In the 1999 RFP, the graduate traineeships are noted as the "centerpiece" of the program, and the length of the postdoctoral fellowship was shortened from 36 months to 31 months. The two optional components were maintained.

The RFPs for 2000 through 2002 were similar in form to the 1999 RFP. One substantive change was that, beginning in 2002, the purpose of the postdoctoral fellowships changed: teaching skills were taken out and the ability to mentor was added. In 2003, as VIGRE was subsumed into the larger EMSW21 competition, the overview description changed:

> The focus of this [VIGRE] component is enhancing the educational experience of all students and postdoctoral associates in a department (or departments). Broad faculty commitment and a team approach to enhancing learning are necessary. A principal element of VIGRE activity is increasing the interaction among undergraduates, graduate students, postdoctoral associates, and faculty members, whether pairwise or collectively. Integrating research and education for graduate students and postdoctoral associates, involving undergraduates in substantial learning by discovery, and developing a team approach are keys to successful VIGRE projects. These goals can be accomplished in many ways and proposers should develop creative approaches that suit their circumstances.
>
> The enhancement of educational experiences of all students should stem from an understanding of current patterns of student participation in the life of the department(s). All VIGRE proposals are required to include the outcome of a curriculum review and at least five years of data on past performance in attracting and retaining well-qualified U.S. citizens, nationals, and permanent residents as graduate students and postdoctoral associates in the mathematical sciences, including women and those from underrepresented groups. Those departments who have had previous VIGRE awards should present data through the period of the award. Departments can use this information to describe its capacity to host a VIGRE project that will create a significant improvement in the educational experiences of their students and postdoctoral associates. These data may also inform recruitment and retention plans and mechanisms for assessment of the project.
>
> In conjunction with NSF's goal of a globally-oriented science and engineering workforce, possibilities for international interaction are now included among VIGRE options. VIGRE student and postdoctoral associates and their mentors may participate in international research and education collaborative activities, including activities in other countries that are integrated into and benefit the overall VIGRE program at the institution. When incorporating this option in the program, organizers will need to give careful attention to the practical aspects of sending U.S. students abroad, including logistical arrangements, language and cultural issues, and administrative requirements and how effective mentoring will take place in the foreign host institution.[21]

Generally, the three main components of graduate traineeships, undergraduate research experience, and postdoctoral fellowships remained the same, although the postdoctoral fellowship reverted from 31 months to 36 months in length. The 2004 and 2005 RFPs were similar to the 2003 RFP.

[20] Ibid.

[21] From the program solicitation: "Enhancing the Mathematical Sciences Workforce in the 21st Century (EMSW21)," NSF 05-595, available at http://www.nsf.gov/pubs/2005/nsf05595/nsf05595.pdf. Accessed June 29, 2009.

An important conclusion of the committee is that the notion of verticality as suggested by the VIGRE RFPs and as conceptualized by NSF is too all-encompassing and therefore too restrictive. By pushing for integration everywhere, it focuses attention on one portion of a spectrum of engagement and encouragement when more-targeted integration may also bring benefits. This topic is explored further in Chapter 6.

STRUCTURE OF THE VIGRE PROGRAM

The structure of the VIGRE program was set up to reflect the recommendations of the DMS's Special Emphasis Panel (NSF, 1997). For instance, as noted in the 1998 RFP, proposals were to be for 5-year projects with budgets of up to $500,000 per year. Additionally, $100,000 per year could be requested for curriculum development and $100,000 per year could be requested for an outreach component. Initial awards would contain 3 years of funding, with an additional 2 years of funding possible on the successful completion of a noncompetitive review.

Departments were to conduct undergraduate and graduate program reviews, emphasize discovery learning in the undergraduate curriculum, plan for improving the participation of women and underrepresented groups, find ways to involve graduate students in research earlier in their careers, and develop the teaching skills of graduate and postdoctoral trainees. Departments were meant to increase the number of undergraduates majoring in the mathematical sciences; they were also to use graduate traineeships to increase the quality of student training, but increasing the number of graduate students was not an explicit goal. The VIGRE program for postdoctoral fellows was aimed at producing professionals ready to begin academic careers. Ten awards were expected in each of the first 2 years of the VIGRE program.

As noted above, the 1999 RFP made more explicit that the VIGRE program's goals included "increas[ing] the number of U.S. citizens, nationals, and permanent residents who receive training for and subsequently pursue careers in the mathematical sciences [and that] the centerpiece of each VIGRE proposal should be a program of graduate traineeships for PhD students."[22] That RFP also said explicitly that "VIGRE is not intended to provide support for Master's degree programs."[23] The funding formula for VIGRE grants was also changed in that year. It stated that awards could be up to $1 million per year, although the expectation was to fund proposals at less than $500,000 per year. Supplements could be considered, but the $100,000 figure was dropped.

In the 2000 RFP, some details were expanded on, particularly the required departmental curriculum review. In 2002 the statement that departmental VIGRE programs should "motivate more students to pursue an education in the mathematical sciences"[24] was included. The discussion of the optional programs also changed, with the RFP now stating: "It should be stressed that a department is expected to provide its own resources to cover costs for normal changes in its curriculum and upgrades in the standard infra-structural elements required for its instructional mission. The optional activities envisioned for a VIGRE proposal should involve significant changes, exhibit substantial originality, be highly portable, and be made nationally available."[25]

In 2003 the DMS workforce program changed substantially with the introduction of the Research Training Groups in the Mathematical Sciences (RTGs) and Mentoring through Critical Transition Points

[22] From the program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," NSF 99-16, available at http://www.nsf.gov/pubs/1999/nsf9916/nsf9916.pdf. Accessed June 29, 2009.

[23] Ibid.

[24] From the program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," NSF 02-120, available at http://www.nsf.gov/pubs/2002/nsf02120/nsf02120.pdf. Accessed June 29, 2009.

[25] Ibid.

(MCTP) programs. These programs allowed for greater flexibility in the way that cultural changes within departments could be accomplished. The VIGRE program also changed; the proposals now had to include institutional commitments in two ways. Among the nine points describing a successful VIGRE proposal were (1) to "have an institutional commitment to furthering the plans and goals of the VIGRE project" and (2) "to have a post VIGRE plan."[26] It should be noted that the DMS funds targeted at workforce programs increased from $12 million to $18.5 million with the introduction of the new programs, but that the amount proposed to be spent on VIGRE grants decreased to $10 million.

Following the introduction of the RTG and MCTP programs, the structure of the VIGRE grants has remained unchanged.

GRANT DURATION

In 1997, the SEP report recommended that "[t]he duration of an award should be three to five years and if possible the award should be renewable" (NSF, 1997). In fact, the award was granted for 5 years, conditional on a 3rd-year assessment, and several VIGRE awardees have received a second award.

On the basis of its broad experience in research and education endeavors and from observing the rates of progress in the departments that have held VIGRE grants, the committee concludes that 5 years is not enough time for a department to accomplish the goals set out by DMS for the VIGRE program. It is not clear to the committee that a department can successfully put in place a range of initiatives that will be self-maintaining in the time currently allotted by a grant. Changing the culture of a department takes time. It appears to take about 1 year for a VIGRE program to get underway at an institution, so VIGRE awardees have about 4 years to work with students. And, as is noted below, sustaining the programmatic components of VIGRE has proven difficult for departments. If departments cannot maintain the initiatives undertaken during their VIGRE grant beyond the life of the program, then 5-year grants mean that departments might be limited to directly influencing just four yearly classes of students, which does not provide enough momentum for change.

AWARDEES TO DATE

To date, 53 VIGRE awards have been made (see Table 3-1). Some awards involve one department at an institution and others involve multiple departments (e.g., the University of Washington award involves three departments). Some institutions have received more than one award: most often these involve a renewal (e.g., North Carolina State University's award) or different departments at the same institution receiving different awards (e.g., University of California at Berkeley). In all, 51 unique departments have received one or two awards at 40 different institutions. The committee examined data from 50 departments at 39 institutions. Louisiana State University's award began after the committee had begun the project, as indicated in Table 3-1.

[26] From the program solicitation: "Enhancing the Mathematical Sciences Workforce in the 21st Century (EMSW21)," NSF 03-575, available at http://www.nsf.gov/pubs/2003/nsf03575/nsf03575.pdf. Accessed June 29, 2009.

TABLE 3-1 VIGRE Awardees, 1999-2012, by Institution, Department, and Academic Grant Years

Institution	Department	May 1999-May 2000	May 2000-May 2001	May 2001-May 2002	May 2002-May-2003	May 2003-May 2004	May 2004-May 2005	May 2005-May 2006	May 2006-May 2007	May 2007-May 2008	May 2008-May 2009	May 2009-May 2010	May 2010-May 2011	May 2011-May 2012
Brown University	Mathematics		1st	2nd	3rd	4th	5th							
Carnegie Mellon University	Statistics					1st	2nd	3rd	4th	5th				
Carnegie Mellon University	Mathematical Sciences, Statistics	1st	2nd	3rd										
Columbia University	Mathematics	1st	2nd	3rd	4th	5th								
Cornell University	Mathematics		1st	2nd	3rd	4th	5th							
Duke University	Mathematics		1st	2nd	3rd	4th	5th							
Georgia Tech	Mathematics				1st	2nd	3rd	4th	5th					
Harvard University	Mathematics	1st	2nd	3rd	4th	5th								
Indiana University	Mathematics			1st	2nd	3rd	4th	5th						
Iowa State University	Statistics			1st	2nd	3rd	4th	5th						
New York University	Mathematics		1st	2nd	3rd	4th	5th							
North Carolina State University	Statistics	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th			
Ohio State University	Mathematics				1st	2nd	3rd	4th	5th					
Pennsylvania State University	Mathematics	1st	2nd	3rd	4th	5th								
Princeton University	Mathematics	1st	2nd	3rd	4th	5th								
Purdue University	Mathematics, Statistics		1st	2nd	3rd	4th	5th							
Rensselaer Polytechnic Institute	Mathematics		1st	2nd	3rd	4th	5th							
Rice University	Mathematics, Statistics, Applied Mathematics					1st	2nd	3rd	4th	5th				
Rutgers University	Mathematics	1st	2nd	3rd										
Stanford University	Statistics							1st	2nd	3rd	4th	5th		
State University of New York at Stony Brook	Mathematics, Applied Mathematics and Statistics		1st	2nd	3rd									
Texas A&M University	Mathematics		1st	2nd	3rd	4th	5th							
Tulane University	Mathematics					1st	2nd	3rd	4th	5th				
University of Arizona	Mathematics	1st	2nd	3rd	4th	5th			1st	2nd	3rd	4th	5th	
University of California at Berkeley	Mathematics	1st	2nd	3rd										

University of California at Berkeley	Statistics				1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
University of California at Davis	Mathematics				1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
University of California at Los Angeles	Mathematics		1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th		
University of Chicago	Mathematics		1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th		
University of Colorado	Applied Mathematics	1st	2nd	3rd	4th	5th								
University of Georgia	Mathematics			1st	2nd	3rd	4th	5th						
University of Illinois at Chicago	Mathematics, Statistics, Computer Science		1st	2nd	3rd									
University of Illinois at Urbana-Champaign	Mathematics		1st	2nd	3rd	4th	5th							
University of Iowa	Mathematics								1st	2nd	3rd	4th	5th	
University of Maryland	Mathematics					1st	2nd	3rd	4th	5th				
University of Michigan	Mathematics	1st	2nd	3rd	4th	5th								
University of Texas	Mathematics			1st	2nd	3rd	4th	5th						
University of Utah	Mathematics			1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	
University of Washington	Mathematics, Applied Mathematics, Statistics	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th			
University of Wisconsin	Mathematics	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th			
Yale University	Mathematics		1st	2nd	3rd									

NOTE: Louisiana State University's award is not shown because it was made after this study began.
SOURCE: National Science Foundation.

4

Administering, Monitoring, and Assessing the Program

This chapter evaluates the Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE) proposal process. Beginning with the program's 1998 request for proposals (RFP), there were two noteworthy requirements: proposals should include a program evaluation component, and they should contain a data appendix:

> Performance assessment. Each proposal should describe a performance evaluation plan that includes goals, objectives, indicators, and specific measurements for assessing the progress toward the achievement of the goals. This plan will form the basis of the required annual progress reports as well as an in depth review to be conducted by NSF during the third year. Examples of indicators that may be useful are shortening time-to-degree, broadening career opportunities, assessment of the postdoctoral fellows' and graduate trainees' performance, impact of the research experience on the career plans of undergraduates, placement of graduate students and postdoctoral fellows upon completion of the program, and the participation of women and members of underrepresented groups.
>
> Each proposal should include an appendix (Appendix 1) indicating (a) the number of baccalaureate degrees in the mathematical sciences in the past five years, (b) the number of full-time graduate students for each of the previous five years, (c) the PhD recipients during the past five years, their placements, and thesis advisors, (d) the names of postdoctoral fellows (e.g. holders of named instructorships) during the past five years and their mentors and placements, (e) the dollar amount of non-teaching support of graduate students supplied by the university for each of the previous five years, and (f) the anticipated size of the graduate program should this award be received. This information will provide baseline data to be used in subsequent performance assessments.[1]

According to the 1999 RFP, the requested data appendix was to include a new element, the amount of funding by federal agencies for graduate students and for postdoctorates in each of the previous 5 years. The 2000 and 2001 RFPs retained this language.

[1] From the first program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," NSF 97-155, available at http://www.nsf.gov/pubs/1197/nsf97155/nsf97155.htm. Accessed June 12, 2009.

In 2002, a number of changes to the solicitation language were adopted. First, the indicators suggested for the performance assessment were dropped. However, the RFP called for an additional component, a "Post-VIGRE plan." The RFP noted: "The VIGRE program is intended to help stimulate and implement permanent positive changes in education and training within the mathematical sciences in the U.S. Thus it is critical that a VIGRE site adequately plan how to continue the pursuit of VIGRE goals when funding terminates."[2] In 2003, similar language was used. It was noted in the section on the data appendix that "[e]xisting VIGRE institutions should also include data for five years prior to the beginning of their existing award,"[3] so that the data history for those departments would be longer than what was required of departments not already holding a VIGRE award.

The 2004 RFP made that last point more emphatic and also added a dissemination requirement:

> Dissemination. The VIGRE program is intended to have a positive impact at the national level on the mathematical sciences community. Broad dissemination of VIGRE site activities, experiences, and insights is critical to achieve this. Each proposal must include a plan for this dissemination. It is important to disseminate both successful activities as well as information on less successful activities and mid-course corrections.[4]
>
> Results from Prior Support. Existing VIGRE departments should include a summary of what has been accomplished with a previous VIGRE award. This should include information on career paths of VIGRE-supported graduate students and postdocs.[5]

The most current proposal solicitations state these information requirements as follows:

> Performance Assessment Plan. Each proposal should describe a plan to assess the progress towards the achievement of the EMSW21 [Enhancing the Mathematical Sciences Workforce in the 21st Century] goals. This plan should describe the quantitative and qualitative information that will be used to monitor the EMSW21 activities and determine necessary mid-course corrections. The performance assessment of a VIGRE proposal will form part of the basis for the comprehensive third year review that will be conducted by NSF of the VIGRE sites.
>
> Dissemination. The EMSW21 program is intended to have a positive impact at the national level on the mathematical sciences community. Broad dissemination of EMSW21 site activities, experiences, and insights is critical to achieve this. Each proposal must include a plan for this dissemination. It is important to disseminate both successful activities as well as information on less successful activities and mid-course corrections. A minimum form of dissemination is a web page devoted to EMSW21 describing its activities. The department's web page should contain an easily seen link to its EMSW21 page.
>
> Post-EMSW21 plan. The EMSW21 program is intended to help stimulate and implement permanent positive changes in education and training within the mathematical sciences in the U.S. Thus, it is critical that an EMSW21 site adequately plan how to continue the pursuit of EMSW21 goals when funding terminates. . . .

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[2] From the program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," NSF 02-120, available at http://www.nsf.gov/pubs/2002/nsf02120/nsf02120.pdf. Accessed June 29, 2009.

[3] From the program solicitation: "Enhancing the Mathematical Sciences Workforce in the 21st Century (EMSW21)," NSF 03-575, available at http://www.nsf.gov/pubs/2003/nsf03575/nsf03575.pdf. Accessed June 29, 2009.

[4] From the program solicitation: "Enhancing the Mathematical Sciences Workforce in the 21st Century (EMSW21)," NSF 04-600, available at http://www.nsf.gov/pubs/2004/nsf04600/nsf04600.pdf. Accessed June 29, 2009.

[5] Ibid.

> Outcome of curriculum review. Describe the nature of the curriculum review and any planned or implemented changes based on it.
>
> Results from Prior Support. Existing VIGRE departments should include a summary of what has been accomplished with a previous VIGRE award. This should include information on career paths of VIGRE-supported graduate students and postdocs.
>
> Trainee Data. All EMSW21 proposals must supply the following data unless such data is irrelevant to the proposed activities: (a) a list of Ph.D. recipients during the past five years (ten years for those seeking a second VIGRE award), along with each individual's citizenship status, baccalaureate institution, time-to-degree, post-Ph.D. placement, and thesis advisor; (b) the names of postdoctoral associates (including holders of named instructorships and 2- or 3-year terminal assistant professors) during the past five years (ten years for those seeking a second VIGRE award), their Ph.D. institutions, postdoctoral mentors, and post-appointment placements; (c) the dollar amount of funding by federal agencies for REUs, for graduate students, and for postdoctoral associates in each of the past five years (ten years for those seeking a second VIGRE award).[6]

VIGRE proposals must also include the data listed in Box 1-1 of Chapter 1 in this report for each of the previous 5 academic years, or for each of the previous 10 academic years if the department is applying for a renewal grant.

The committee draws the following four conclusions:

1. *Producing a proposal for a VIGRE program grant involves a substantial amount of work.* While some departments have implemented what they consider to be positive change as a result of the application process,[7] spending the time and energy to produce a proposal is of limited value if the department does not receive an award. The requirements for preparing a VIGRE proposal are fairly onerous.
2. *The performance assessment requirement is problematic.* The Division of Mathematical Sciences (DMS) at the National Science Foundation (NSF) has never established a formal, consistent evaluation paradigm for the VIGRE program, one that could guide an analysis of how the contents and demands of the program are linked to the program's long-term goals. Besides not making those linkages explicit, NSF did not identify at least a short list of basic indicators or measures that would reflect progress toward the goals; it might even have requested baseline data for those measures. As for data collection, early in the life of the VIGRE program it was not thoroughly thought through at DMS what would be a minimal core of data needed to determine, at least in very general terms, whether or not the VIGRE program was a success. If the amount of data were small but very specific and carefully targeted, it would not impose an onerous responsibility on grant recipients. However, leaving it to the individual applicants and grantees to identify measures for assessing performance ensures that there would be no common template against which to compare outcomes and to relate those outcomes to the goals of the program.

[6] From the program solicitation: "Enhancing the Mathematical Sciences Workforce in the 21st Century (EMSW21)," NSF 05-595, available at http://www.nsf.gov/pubs/2003/nsf05595/nsf05595.pdf. Accessed June 29, 2009.

[7] For example, in its survey (see Appendix C), the committee asked departments that had applied for, but not received, VIGRE grants whether the process of applying for a VIGRE award led to any changes in the department. The response from 19 out of 45 respondents was "yes." Positive effects were, for example: "A new graduate course was initiated, inspired by discussions during the grant proposal preparation"; "Along with our process of program reviews, it motivated changes in the undergraduate curriculum—a capstone course and gateway courses—and in the graduate program, firming up required core courses"; "We launched a curriculum review and revision of our graduate program."

3. *The dissemination component of the proposals raises two concerns.* Most important is that there does not seem to be a clear plan for VIGRE awardees to share their successes with others except for NSF. Given that NSF does not have the budget to assist all mathematics, applied mathematics, and statistics departments, it would seem critical that NSF attempt to leverage its resources by using VIGRE awardees as testbeds for piloting new and innovative solutions to the problems facing higher education and solutions to the workforce issues facing the mathematical sciences and then seek ways to have other departments copy or learn from those solutions. There does not seem to be a mechanism in place to make this happen. A second concern is that information about the VIGRE awardees is essentially contained within NSF and not sufficiently public. The committee noted with frustration the lack of a central database of information on departments that had received VIGRE awards as well as the lack of Web-based information provided by some of the VIGRE awardees. It was difficult, for example, to find annual or final reports on VIGRE awardee Web sites.
4. *The sustainability of the VIGRE program at VIGRE sites is problematic.* An infusion of NSF funding cannot and was never meant to last indefinitely. When awardees take on expensive new initiatives, such as expanding the number of postdoctorals supported by the department, it is not at all clear that such efforts can last beyond the VIGRE grant. In fact, in the committee's request for information from VIGRE awardees, it became clear that a number of efforts would not remain in place "post VIGRE." In its survey, the committee asked those whose awards had ended if they planned to continue all the VIGRE-funded activities. About 40 percent said no. Following are comments from these departments:

   - "Anything that costs money for which we haven't been able to find alternate funding [will go away]: we've cancelled undergraduate stipends for participation in working groups, undergraduate stipends for participation in our summer REU-like program, new graduate traineeships (fellowships and relief-from-teaching quarters) for graduate students; and about half of our postdoctoral positions have been downgraded to high-teaching-load lectureships. One reason for these rather drastic cutbacks has been our decision to keep our commitments to current VIGRE postdocs and VIGRE graduate trainees."
   - "Obviously, our graduate and postdoctoral fellowships will not be maintained."
   - "We had to drastically decrease the number of admitted graduate students. This had a profound effect on our graduate program."[8]

This is very disconcerting, because for maximum effect, the grant money provided by the VIGRE program should serve as seed money.

PROPOSAL AND AWARD REVIEW PROCESS

The NSF review of VIGRE proposals consists of two elements: the panel review conducted by DMS prior to the award (which the committee considered to be outside the scope of its charge) and the two site visits, one prior to making an award and one during the 3rd-year review of awardees. The deliberations of the proposal review panels are observed by DMS staff, who then recommend which proposals should advance to the next stage of consideration, the pre-award site visit. A site-visit team consists of two or more DMS VIGRE program directors and one mathematical scientist from outside NSF. Site visits take

[8] Responses to the survey by the Committee to Evaluate the NSF's Vertically Integrated Grants for Research and Education (VIGRE) Program; for information see Appendix C.

place over the course of 1 day. During the site visit, the team meets with the principal investigator(s), undergraduate students, graduate students, postdoctoral fellows, faculty, and relevant administrators.

In advance of a pre-award site visit, DMS sends the department to be visited a set of basic questions to be addressed, as shown in Box 4-1. Sometime during the evolution of the VIGRE program, DMS began to include additional, site-specific questions.

BOX 4-1
Guidance from the National Science Foundation to Departments Preparing for a Pre-Award Site Visit

The following questions are quoted from the standard letter, provided by the National Science Foundation (NSF), which NSF sends to mathematical sciences departments that have submitted VIGRE grant proposals and have been recommended, after a proposal review panel's deliberations, for a pre-award site visit.

(1) Elaborate on your plans to recruit U.S. students and postdocs to careers in the mathematical sciences, including individuals who might otherwise choose other careers. Specify any special attention to be given to recruitment of people from groups underrepresented in the mathematical sciences.
(2) For each of the past ten entering cohorts . . . of graduate students in your program, provide longitudinal retention data by filling in the attached Excel spreadsheet. The matrix to be filled in is on the "Template" tab, with directions on the "Instructions" tab. If some additional clarification of the data would be useful, include a brief written statement. We are doing this because questions about retention and tracking students through graduate programs are being examined more closely, and it is best if we have such data in a consistent form. We hope that the information that you have already assembled for the proposal submission will make this task relatively straightforward.
(3) Elaborate on your plans for mentoring:
    (a) undergraduate students;
    (b) graduate students;
    (c) postdocs.
(4) Elaborate on planned activities to help graduate students and postdoctoral researchers improve their instructional and communication skills.
(5) Elaborate on plans for broadening the education of students.
(6) Provide detailed evidence of faculty plans for participation in VIGRE activities.
    (a) What percentage of the faculty has agreed to participate in the research groups?
    (b) What percentage of the faculty has agreed to participate in the VIGRE project in some mentoring capacity?
(7) Discuss your plans for dissemination of the results of the VIGRE project, in terms of national impact on best practices for training the mathematical sciences workforce.
(8) What will you be able to accomplish with a VIGRE award that would not be possible without an award?
(9) To what extent will the accomplishments be sustainable when VIGRE funding ceases?
(10) Report significant changes, if any, relevant to the VIGRE project since submission of the proposal.

During the 3rd year of a VIGRE award, the awardee is visited by NSF to determine the awardee's eligibility for continuation of the award for the 4th and 5th years. Again, awardees are requested to answer a set of questions as well as to provide data to NSF, as detailed in Chapter 1.

As indicated in Chapter 1 (see the subsection entitled "Information Collected by the Committee"), to understand the adequacy of the site visits, the committee held a conference call with seven mathematical scientists (excluding NSF staff members) who had participated in site visits; it also sent an e-mail to all non-NSF site-visit team members. That e-mail asked team members what component of the site visit they found most/least helpful for the purpose of evaluating a proposal or awardee and whether they had any suggestions for how NSF could improve the value of the site visits. Finally, National Research Council (NRC) staff working on this study looked at both pre-award site-visit reports and at the 3rd-year site-visit reports and recorded their impressions of the structure of the reports.

In talking with the reviewers from outside NSF, the committee heard the following messages:

- Site visits were well planned.
- The duration of the site visits was about right.
- NSF provided appropriate guidance to the site visitors as to how to conduct the visit, and site visitors thought that NSF program managers participated at the appropriate level during the site visits.
- Site-visit teams met with all the appropriate groups at the institution being evaluated.
  - —Some team members, however, seemed to think that they were meeting mostly with people who like the program and so missed hearing some negative comments; and
  - —Some team members commented that they would like to interact also with some people (presumably faculty or postdoctoral fellows) who are not involved in VIGRE activities, in order to calibrate their impressions of the VIGRE program.
- The information collected during site visits is appropriate to perform the review, and there is no need to collect additional information.
- Concerns expressed by site visitors included the following:
  - —There may be a burden on departments to put together data in support of a site visit. Data gathering was also a burden for the site-visit team, as they sometimes were overwhelmed by the amount of information provided. Site visitors would like to see the assembling of data necessary for an efficient evaluation more streamlined.
  - —Site visitors are not anonymous, and being the only reviewers in the NSF proposal review process who are not anonymous can be a bit awkward for them.
  - —It is assumed that the institution's dean will be a cheerleader for the proposal, so not everyone believed it to be useful for the site-visit team to meet with the dean.
  - —Some, but not all, would have preferred the team to have two non-NSF members to complement the two NSF program officers.
- Site visitors thought that NSF appropriately included input from them in the site-visit report.
- Site visitors noted that lunch with students was a particularly worthwhile component of the visit, as was talking with students and postdoctorals, comparing trends in the department, and seeing interactions among students at different levels.

The committee also asked for comments from site visitors in an e-mail request. The comments received in response should be taken as illustrative, as they represent only those who responded—that is, only a fraction of all those who participated in site visits. For those who had participated in a pre-award site visit, comments relating to the most helpful elements of the site visit included these:

- "The most important part of the proposal was the data provided: number of majors, number of PhDs and their placement, postdocs and their placement, years to degree for PhD students. During the visit, meeting the students and the postdocs was the most useful part."
- "Meetings with the faculty, postdocs, and graduate students; data on the recruitment and retention of students. All information was useful for the overview of the success or problems of the previous VIGRE award."
- "Two NSF program officers talked with me about questions regarding the VIGRE program before we went on the site visits. One stressed the importance of mentoring the postdocs and graduate students. I think we reviewed two departments together. It was important for me to be told what VIGRE means for the DMS program, i.e., what the program officers envision. Each person wants to see something else stressed, and it's important to have that discussed, say at a casual meal, before the visits."
- "Original proposal, preliminary panel evaluations, departmental responses to issues raised in the preliminary evaluation. I thought these were all essential to have and were helpful. During the site visit itself, meetings with current undergraduate students, graduate students, and postdocs were all especially helpful in understanding the reality of education and training at the institution."[9]

Comments from the e-mail respondents on the least helpful elements of the site visits included the following:

- "Speaking to various deans. You can predict what they will say."
- "The VIGRE program description at the time, online through nsf.gov, was so general that I wasn't sure what it was asking for, in terms of DMS."[10]

In terms of possible improvements to the process, it is clear that site visitors who responded to the committee's e-mail were quite positive about the experience. The major issue raised by respondents focused on the amount of work to be done in the time allotted:

- "The visits are rushed, with the need to produce a document on-site (at least a first draft). Having said this, the reality is that it is not feasible to spend more time on a visit."
- "I am not sure that it could be improved, in that the program officers had specifically asked for a certain schedule, and that schedule was pretty tight. I think it was a fair way to compare different departments by asking for the same schedule from each place."[11]

For those respondents who had been on 3rd-year site visits, the most helpful elements included the following:

- "I found the interviews with the key personnel to be quite important, as was a careful analysis of how the funds were spent. Information on the recruiting pool and the status of the trainees was useful, but in an intermediate review there is little to report. What is hardest to judge, but essential, I think, is what exceptional experiences are the trainees getting and what is being institutionalized as a result of the program. Again, this is hard to judge in a 3rd-year review. I also found the

[9] Responses to the e-mail request to site visitors from the committee.
[10] Ibid.
[11] Ibid.

interviews with the trainees to be important to understand how committed they were and what their true role was. It is easy to make things look good on paper."
- "Talking to the managers and participants in the program. Having the original proposal and communications between the program officers and PIs [principal investigators]."[12]

Only one respondent mentioned a "least-helpful" element, which seconds the notion above, that most respondents were quite satisfied with the process:

- "In general, detailed CVs and course syllabi are of limited value unless they are included to make a point. To the extent that institutional support is provided, a leveling of how things are reported would be helpful."[13]

Suggestions of respondents regarding improving the 3rd-year site process included the following:

- "The review teams need to provide some level of anonymity. I would also recommend that the site visit rules be established generally so that, for example, the PI isn't in all meetings. It would probably also be appropriate to have a pre-meeting of the site visit team where pre-specified topics are discussed prior to the site visit. Included in this could be NSF-mandated ground rules, site specific concerns and key questions that NSF wants answered."
- "Assuming the NSF staffers act as observers, the outsider participation needs to be increased and the NSF staffers need to talk less and listen more."
- "It would be worth considering the option of allowing the site visit team to send questions in areas where clarity is required to the institution prior to the visit so that any appropriate information can be accumulated."
- "Making sure that as many participants in the project as possible are available for interviews, unfettered."[14]

Finally, the NRC staff analyzed a number of site-visit reports. The pre-award site-visit reports from 1999 through 2006 were of widely varying quality. There was not much consistency of detail or topic within a year and among years, nor was there consistency of format. It appears that the structure of the report depended a great deal on the composition of the visiting committee and, in particular, on who chaired the site-visit team. Many of the reports were merely a brief, or even bulleted, version of the university's proposal—often without comment—whereas others contained very detailed evaluations. Many of the site-visit reports do not appear to contain a recommendation for action, or the recommended action is hard to interpret (for instance, "The award should be made if there are sufficient funds.").

By contrast, the 3rd-year site visits are very uniform, as noted previously. These reports are much more detailed and contain well-reasoned recommendations.

STRUCTURE OF ANNUAL AND FINAL REPORTS

The award letter that accompanies a VIGRE grant contains a requirement to provide data to the National Science Foundation. Originally, the following list of indicators was identified, and the 1998

[12] Ibid.
[13] Ibid.
[14] Ibid.

award letter added that the awardee is “free to identify additional indicators that it deems appropriate to the process”:

- The number of students taking each of the “new” graduate and undergraduate courses;
- Summary of the course evaluations;
- A list of the VIGRE participants (including both students and mentors) and the topics for that year’s research experiences for undergraduates;
- Time to PhD of any graduate student who graduated that year and was supported by VIGRE funds;
- The name and baccalaureate institution of each graduate student supported by VIGRE funds that year, the cumulative amount of funding, and the graduate’s mentor;
- A list of the postdoctoral fellows supported by VIGRE during that year, the mentor of each, and their PhD institutions;
- A list of publications emanating from the activities;
- The next position of each undergraduate, graduate student, and postdoctoral fellow supported under VIGRE and leaving the institution that year;
- A list of significant VIGRE-related presentations that year by VIGRE-supported undergraduates and graduate students;
- A description of the outreach activities; and
- The number of women and members of underrepresented groups involved in each aspect (undergraduate, graduate, postdoctoral) of the VIGRE program during that year.

However, in the middle of the VIGRE program’s history, the focus for data collection became much less prescriptive. By 2000, the award letters contained the following description of data needed in each annual report:

- “The previous institution and the placement institution for each recipient of a VIGRE stipend during the past year.”
- “A list of the faculty who participated in the VIGRE program during the past year, and their roles in the project.”

The committee notes that the information collected by NSF during the application process differs from the information collected during the reporting phase, and it is not clear how helpful some of the data in the annual reports are. Tracking student placement, for example, might not be a good indicator because the students in programs with VIGRE awards are often at top institutions, meaning that many of them would be well placed regardless of whether or not the department had a VIGRE program. Also, without knowing a student’s preferences, it is difficult to make inferences based on their subsequent placement. What might be more instructive would be to see whether students in VIGRE programs considered a range of career options broader than those considered by other students.

5

Program Achievements

CHALLENGES TO IDENTIFYING ACHIEVEMENTS

There are four challenges to evaluating the National Science Foundation's (NSF's) program Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE). The first arises from the fact that the goals of the program shifted somewhat as the program evolved from 1998 on, as noted in Chapter 3. For example, in his initial "Dear Colleague" letter, Donald Lewis, then Director of NSF's Division of Mathematical Sciences (DMS) said: "We want to emphasize again that the purpose is to increase the quality and breadth of mathematical sciences education, not the size of graduate programs."[1] However, the 1999 request for proposals (RFP) included the explicit goal of increasing the number of U.S. citizens, nationals, and permanent residents who receive training for and subsequently pursue careers in the mathematical sciences.[2] So it is not surprising that one of the most frequent claims of success the committee heard from funded programs was how much their graduate programs had grown in size. Similarly, a component of outreach was originally stated quite clearly as strictly being optional, but all the successful programs encountered by the committee had very strong outreach programs. These two instances demonstrate why clarity and consistency of goals are necessary for effective evaluation and administration.

A second evaluational challenge concerns the lack of consistent and comparable indicators of success. This challenge is twofold, consisting of both a conceptual and a data issue: there has not been a consistent list of indicators, and the data collected have not been consistent over the course of the VIGRE program.

A third challenge to evaluating the VIGRE program comes from the difficulties in comparing awardees' achievements to those of a control group. One approach is to do this chronologically and to

[1] "Dear Colleague" letter, September 10, 1997, from Donald Lewis, Director, Division of Mathematical Sciences, National Science Foundation, to the mathematical sciences community (hereafter cited as "Dear Colleague" letter, September 10, 1997). Available at http://www.nsf.gov/pubs/1997/nsf97170/nsf97170.htm. Accessed July 6, 2009.

2 From the program solicitation: "Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)," NSF 99-16, available at http://www.nsf.gov/pubs/1999/nsf9916/nsf9916.pdf. Accessed June 29, 2009.

consider the control group to be the group of awardees prior to the receipt of their VIGRE awards; that is, to have a before-and-after comparison. A second approach is spatial and compares the awardees to a group of similar departments or institutions that did not receive an award. Finally, it is possible to combine these approaches and to compare the two types of departments at two different points in time. Although data tracking numbers and progress of undergraduate students, graduate students, and post-doctoral fellows at selected VIGRE and non-VIGRE departments could have been extracted from existing reports and other sources, comparable comparison would have been challenged in three ways:

- The departments that received awards are different from those that did not. In particular, the departments funded through the VIGRE program have tended to be at top institutions as ranked according to NRC (1995). As noted in Table 5-1, 19 of the top 25 mathematics departments have received a VIGRE award. However, among those 25, 9 schools either never received a VIGRE grant (Massachusetts Institute of Technology [MIT]; Stanford University's Department of Mathematics [although Stanford's Department of Statistics received a grant]; California Institute of Technology; University of California, San Diego; University of Minnesota), or were judged by NSF to have failed in their VIGRE programs (University of California, Berkeley; Yale University;

TABLE 5-1 VIGRE Grants Received Among 25 Top-Ranked Mathematics Departments Since the Inception of the VIGRE Program in 1998

Rank	Institution	Grant
1.5	Princeton University	Yes
1.5	University of California, Berkeley	Yes
3	MIT	No
4	Harvard University	Yes
5	University of Chicago	Yes
6	Stanford University	No
7	Yale University	Yes
8	New York University	Yes
9.5	Columbia University	Yes
9.5	University of Michigan, Ann Arbor	Yes
11	California Institute of Technology	No
12	University of California, Los Angeles	Yes
13	University of Wisconsin, Madison	Yes
14	University of Minnesota	No
15	Cornell University	Yes
16	Brown University	Yes
17	University of California, San Diego	No
18	University of Maryland, College Park	Yes
19	Rutgers University, New Brunswick	Yes
20	State University of New York, Stony Brook	Yes
21	University of Illinois, Urbana-Champaign	Yes
22	University of Pennsylvania	No
23	University of Texas, Austin	Yes
24.5	Purdue University	Yes
24.5	Rice University	Yes

NOTE: Stanford University's Department of Statistics did receive a grant.
SOURCE: Ranking data from NRC (1995); VIGRE grant data from the National Science Foundation.

State University of New York, Stony Brook; Rutgers University). These top departments tend to be larger, both in terms of faculty and students; they support more research; and they might offer graduate students more opportunities for teaching or research or offer more postdoctoral positions. Finding similar departments that did not receive a VIGRE award is difficult.

- Additionally, because the VIGRE program is still relatively young, many of the awardees are still in their first 5-year grant, and so there is not much "after" history to compare with the performance of departments prior to the award. Only a few departments have 5 or more years of VIGRE experience, and none has reached the 10-year mark. Unfortunately, there was no requirement that VIGRE awardees collect data after the award ended, so few data have been accumulated about the longer-lasting effects of an award.
- Finally, awardees tried to meet basic goals in somewhat different ways. That is, all departments increased vertical integration, but they used different approaches within that general goal. Although this flexibility is a good thing, it also makes comparison difficult.

The fourth challenge to an evaluation of the VIGRE program is in determining causality—that is, proving that the VIGRE program caused particular outcomes, as opposed to these outcomes being caused by other factors that operated at the same time. Consider, for example, the fact that the number of postdoctorals in mathematical sciences departments rose substantially after the VIGRE program began. One reasonable explanation is that the VIGRE program created new postdoctoral appointments and is responsible for the increase. However, the explanation might also be that the labor market for new PhDs changed substantively (for example, less chance for new doctorates to go straight into employment might add to the appeal of the postdoctoral positions as temporary places of employment). Of course, the VIGRE program could also be one of several factors explaining recent trends in the mathematical sciences. The difficult challenge is testing for the impact of VIGRE in isolation from these other forces.

SOME EFFECTS OF VIGRE AWARDS

Given these challenges, the committee first looked at trends in the mathematical sciences post 1998. These data are presented in Appendix D. The committee thought that these data were insufficient to attribute the changes in the size and composition of the graduate student population in the mathematical sciences to VIGRE. The committee considered quantitative data provided by departments that received a VIGRE award—such data were either provided directly by departments to the committee in response to a committee request for information or were culled from data collected by NSF during the application process. The focus of comparison is on VIGRE awardees, examining the state of the departments prior to the award and during the award period.

Summary of Four Cases

Anecdotal evidence suggests that the VIGRE grants have improved the situation for mathematical science departments that receive them. Cozzens (2008), for example, gives a number of illustrative examples of success by VIGRE awardees.

A second source of information is individuals at departments that had received VIGRE grants and who spoke to the committee. Their presentations suggested that, while the VIGRE grants had produced a lot of new or improved activities at the institutions and some notable successes, there were also challenges. Four cases are briefly summarized here. As noted earlier in this chapter, the diversity of characteristics among departments makes drawing general conclusions from individual examples difficult.

University of California, Berkeley

The differing experiences of the Departments of Mathematics and Statistics at the University of California, Berkeley, illustrate very clearly the failures and successes of the VIGRE program. The Department of Mathematics, under the direction of then-chair Calvin Moore, was awarded a grant during the first year of the VIGRE program, but NSF terminated the grant in 2003 after only 3 years. Moore's presentation "Reactions to VIGRE from the Trenches"[3] records his responses to the NSF's actions. Following are some of his observations:

> NSF has . . . constructed a program that does not give sufficient recognition to the diversity of departments and institutional goals. . . . A second and related problem is that VIGRE guidelines call for changes in departmental programs, even when there is no reason for change or when some significant changes have already been made. . . . the VIGRE program . . . has become encrusted and weighed down with many specifics that go far beyond the original intent. . . .

An additional concern voiced by Moore was that the VIGRE grant was removed with no warning, and in particular with no chance to rectify the perceived shortcomings.

By contrast, the VIGRE experience at Berkeley's Department of Statistics has been far more positive. The Department of Statistics won an initial grant in 2002 and a renewal in 2007, for what will be a total of 10 years of support. The department's recent activities include research assistantships, a seminar series, and a summer statistics camp for undergraduates; traineeships, travel support, and a summer "camp" used to introduce incoming graduate students to their new environment; and fellowships for postdoctorals, as well as an ongoing VIGRE seminar.[4]

University of Chicago

The University of Chicago VIGRE program, which began in 2000 and will continue through 2010, has been particularly successful.[5] The largest VIGRE influence has been the new summer Research Experiences for Undergraduates (REU) program, which in 2008 will have 82 University of Chicago undergraduate participants mentored by 30 graduate students and taught by 9 faculty members. The undergraduates themselves will serve as counselors to approximately 100 Chicago-area high school students and 120 grade school teachers. This REU has become a central part of the mathematics undergraduate experience at Chicago, and its sustainability is an issue, as it now costs nearly $300,000 per summer. Other smaller-scale programs initiated with VIGRE funding include the following:

- The warm-up program for entering graduate students is a 2-week program preceding the start of the school year, organized and run by graduate students for the benefit of incoming graduate students;

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[3] Presented at the AMS, ASA, MAA and SIAM Workshop on Vertical Integration of Research and Education in the Mathematical Sciences, May 3-4, 2002, Reston, Virginia.

[4] This discussion is based on presentations to the committee on October 8, 2007, in Irvine, California, by Calvin Moore, professor of mathematics, University of California, Berkeley, and Deborah Nolan, co-principal investigator for the Berkeley Department of Statistics' VIGRE grant.

[5] This discussion is based on written comments provided to the committee by Peter May, principal investigator for the University of Chicago's VIGRE grant, and also on Dr. May's presentation before the committee (June 28, 2007, Washington, D.C.). The committee notes that a member of the site-visit team, during the telephone conference, said that the team had spoken of its perception that most of the faculty seemed uninvolved in the VIGRE program. Anecdotal evidence from several former Chicago graduate students interviewed by a member of the committee supported that perception.

- The directed reading program comprises graduate students mentoring undergraduates one-on-one; about 15 to 20 mentor-mentoree pairs participate per quarter;
- VIGRE course assistants are not just graders, but assistant teachers, holding independent office hours and meeting at least once a week with the graduate student teacher; some 25 undergraduates participate each year; and
- Under the Young Scholars program, about 25 undergraduates each quarter serve as counselors to about 60 Chicago-area high school students every other Saturday morning.

The VIGRE grant has also offered substantial funding of graduate students and postdoctorates, both groups gaining time off from teaching to focus on their research. The support of graduate students has helped cut the attrition rate, to the point that at most, two or three students drop out of each entering class before achieving a PhD.

University of California, Davis

The VIGRE program at the University of California, Davis, illustrates what can be done at a large state school.[6] The Davis VIGRE grant is principally built around Research Focus Groups (RFGs), each consisting of undergraduates, graduate students, postdoctorates, and a faculty member, who get together to explore a specific research area. Each year there are four such groups, which conduct special topics courses, seminars, mini-workshops, and REU projects. Postdoctorates help co-organize these groups, undergraduate students work on projects, and the faculty member receives one-course teaching relief. The department also has formal mentoring structures for graduate students, undergraduate students, and postdoctoral fellows. Communications skills are fostered by oral presentations within the RFGs, and written skills are fostered as graduate students write up expository or instructional material, postdoctorates prepare grant applications, and RFG participants help students apply for mini-grants for travel, summer support, visitor support, and so on.

The recruitment and outreach efforts of the VIGRE RFGs are remarkable. Graduate students have created and run a program for high school and young undergraduate students in the Sacramento area. Outreach to the general public is done with math festivals, which put on a show of puzzles and math games. At one such festival, a PIXAR scientist came to talk about mathematics in the movies, drawing an audience of 400 people. Students are aggressively recruited from California programs that target talented high school students and minorities and from local high schools, which include a large Hispanic population. The department-wide nature of VIGRE is crucial; the committee is convinced that the culture has changed dramatically owing to the VIGRE-funded initiatives, becoming much livelier and more open, and that the curriculum has undergone major revision. Statistics show an increase in the number of graduate students (from 58 to 119 in 8 years) and of undergraduate majors (from 294 to 385 in 6 years).

University of Maryland

The Department of Mathematics at the University of Maryland, College Park, received a VIGRE grant in 2003, after four previous applications had failed to be accepted.[7] The department has about

[6] This commentary is based on a presentation to the committee on October 8, 2007, in Irvine, California, by Jesús de Loera, professor of mathematics and principal investigator for the University of California, Davis's VIGRE grant, and several students from the University of California, Davis.

[7] This discussion is based on written comments provided to the committee by William Goldman, professor of mathematics and principal investigator for the University of Maryland's VIGRE grant.

450 undergraduate majors (many pursuing other majors as well) and about 250 graduate students. The mathematics faculty of 65 is large, but there are few postdoctorals.

The centerpiece of VIGRE at the University of Maryland, College Park, is a system of Research Interaction Teams (RITs), small, informal groups mainly composed of graduate students and often postdoctorals or undergraduate students, led by faculty members. RITs were originally augmented by a minicourse series, designed to draw undergraduate students into research. By the end of the second year of the grant, the pace seemed too intense, and some of the minicourses were replaced with panel discussions and special colloquia. The RITs, which were initiated on the basis of feedback about a rejected VIGRE proposal, continue and thrive; some semesters have seen as many as 20 active RITs. Several faculty members who had never worked with undergraduates have had successful mentoring experiences, some of which resulted in joint publications. Graduate student supervisors have also been instituted for the Undergraduate Math Club, the members of which became more involved in the minicourse/panel discussion/colloquium series. These new activities were informal and broadly accessible.

The VIGRE project at the University of Maryland, College Park, was designed to change the culture of the department, but in several important ways progress has been disappointingly modest. The department's many failed attempts for a VIGRE grant led to a winning proposal that has been almost impossible to administer as proposed; the project became so complicated that it risked defeating the very goals that VIGRE was meant to accomplish. Some unwieldy parts of the project were eliminated, and others were substantially modified as it became clear that their demands on the faculty and staff outweighed their benefits.

Another disappointment of the VIGRE grant concerns the lack of permanent graduate program reform, an ongoing problem because topics courses in areas basic to current research are not guaranteed to continue to attract the necessary enrollment. Also, students still take 6 or more years to complete their doctorates.

Approaches to Evaluating VIGRE Achievements

Final reports from awardees also present a positive picture of the impact of the grants. For example, summarizing their first VIGRE award, the leadership team at the University of Washington wrote:

> VIGRE support has made a significant impact on the three departments involved in this endeavor:
>
> - The number of majors in the mathematical sciences has dramatically increased.
> - The graduate programs in the mathematical sciences have grown in both size and quality.
> - Undergraduate research projects, some with industry, have been initiated in all three departments.
> - Communication among our departments has improved substantially, particularly at the graduate level, and cross-departmental committees of VIGRE fellows and postdocs are helping to run the VIGRE program.
> - The VIGRE program has grown from one focusing only on applied aspects to one encompassing all aspects of the mathematical sciences.
> - Panel discussions on job interviews (for graduate students) and on graduate studies (for undergraduates) have been a success.
> - The curriculum has been reformed at both the undergraduate and the graduate level in all departments.
> - K-12 outreach activity has increased in all departments.[8]

[8] Final Report from VIGRE Grant DMS-9810726, University of Washington, available at http://www.math.washington.edu/vigre/vigre-docs/VIGRE1FinalReport.pdf. Accessed June 26, 2009. Note that most awardees do not put their reports on their Web sites.

To evaluate the achievements of the VIGRE program, one can ask whether individual elements of the program are effective. One approach to such an evaluation focuses on comparing the effectiveness of each element. For example, hypothetically, the mentoring program might be judged successful, while another component might not have achieved the goals set by NSF. Alternatively, one might ask whether one awardee's approach to a VIGRE component is better than that of other awardees. The committee considered all of these approaches, but it did not attempt to evaluate the experiments conducted by the individual departments in the process of applying for, administering, and conducting their VIGRE grant. More broadly, it would like to be able to answer this question: Is the community better off overall—are the mathematical sciences in the United States healthier with VIGRE than they would be without VIGRE? That difficult question is taken up in the next section.

VIGRE APPLICATIONS AND AWARDS

Figure 5-1 shows the annual number of proposals to the VIGRE program from 1998 through 2007 and the number and percentages of successful applications. Note the high success rate of about 40 percent in 2000, and just 4 years later the low rate of about 10 percent in 2004. The success rate has been rising recently, but the drop in the number of proposals is startling. (Recall that VIGRE is now part of EMSW21, so fewer VIGRE awards are made.)

As noted in Chapter 3, 52 departments at 39 different institutions have been awarded VIGRE grants over the lifetime of the program (excluding Louisiana State University, whose award was too recent to be included in this study).

Tables 5-2 and 5-3 reveal the patterns of applications from institutions that have never succeeded in receiving VIGRE funding. Table 5-2 lists the number of proposals considered in a given year's competition that came from departments that never received an award.

Figure 5-2 shows the number of VIGRE awards. It shows the number of VIGRE grants that were funded each year since the program's inception, the number of VIGRE grants in operation each year, and the total number of submitted proposals each year.

A total of seven grants have been renewed for a second 5-year period, and nine grants have been terminated after 3 years.

In order to learn more about how the VIGRE program is perceived and how departments decide whether or not to invest in the effort to apply, the committee sent an e-mail to the 238 chairs of mathematics, applied mathematics, and statistics departments that have never received VIGRE funding.[9] Responses were received from 122 of these departments. (The committee suspects that these responses might be more heavily weighted with feedback from departments that are unhappy with the VIGRE program, and thus the information should be interpreted with that in mind.) As the committee had suspected, many of the departments have never applied for a VIGRE award. Of those 122 departments, 47 said that they had applied for an award,[10] and 75 said that they had not. Of those who had not, some gave no reason and some gave multiple reasons including the following:

- Did not expect to receive an award (27),
- Conditions of award are too burdensome (15),

[9] E-mail dated November 15, 2007, from the Committee to Evaluate the NSF's Vertically Integrated Grants for Research and Evaluation (VIGRE) Program to 238 chairs of mathematics, applied mathematics, and statistics departments that have never received VIGRE funding.

[10] NSF does not reveal information about proposals that are denied funding, so the committee did not have access to this number or to related information through NSF.

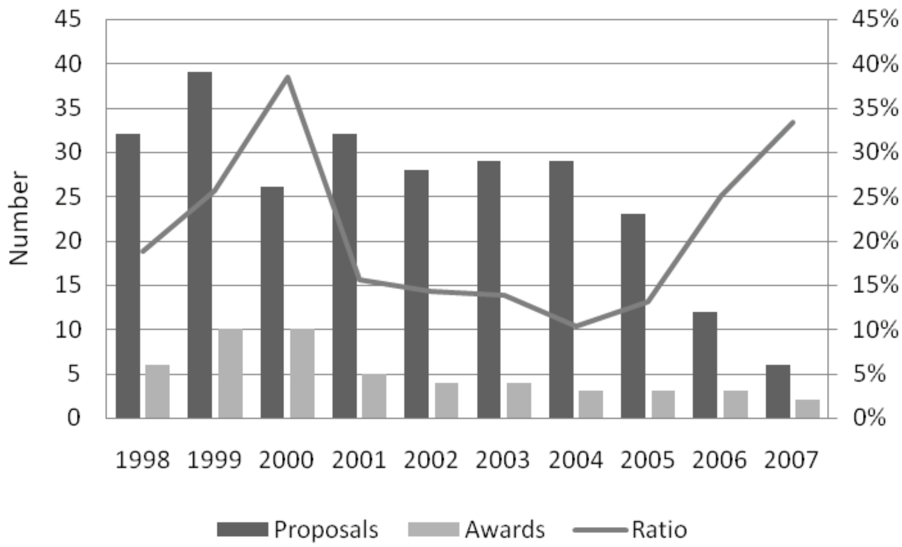

FIGURE 5-1 Number of VIGRE proposals and new awards and percentage of successful applications. SOURCE: Data provided by the National Science Foundation.

TABLE 5-2 Number of Proposals from One or More Departments at an Institution That Never Received a VIGRE Award, by Year, 1999-2008

Year	Number of Proposals
1999-2000	23
2000-2001	21
2001-2002	24
2002-2003	24
2003-2004	25
2004-2005	19
2005-2006	6
2006-2007	5
2007-2008	1

SOURCE: Data provided by the National Science Foundation.

TABLE 5-3 Number of Unfunded Proposals from Institutions, Among Those That Never Received a VIGRE Award

Number of Proposals	Number of Departments
1	22
2	18
3	13
4	7
5 or more	4

SOURCE: Data provided by the National Science Foundation.

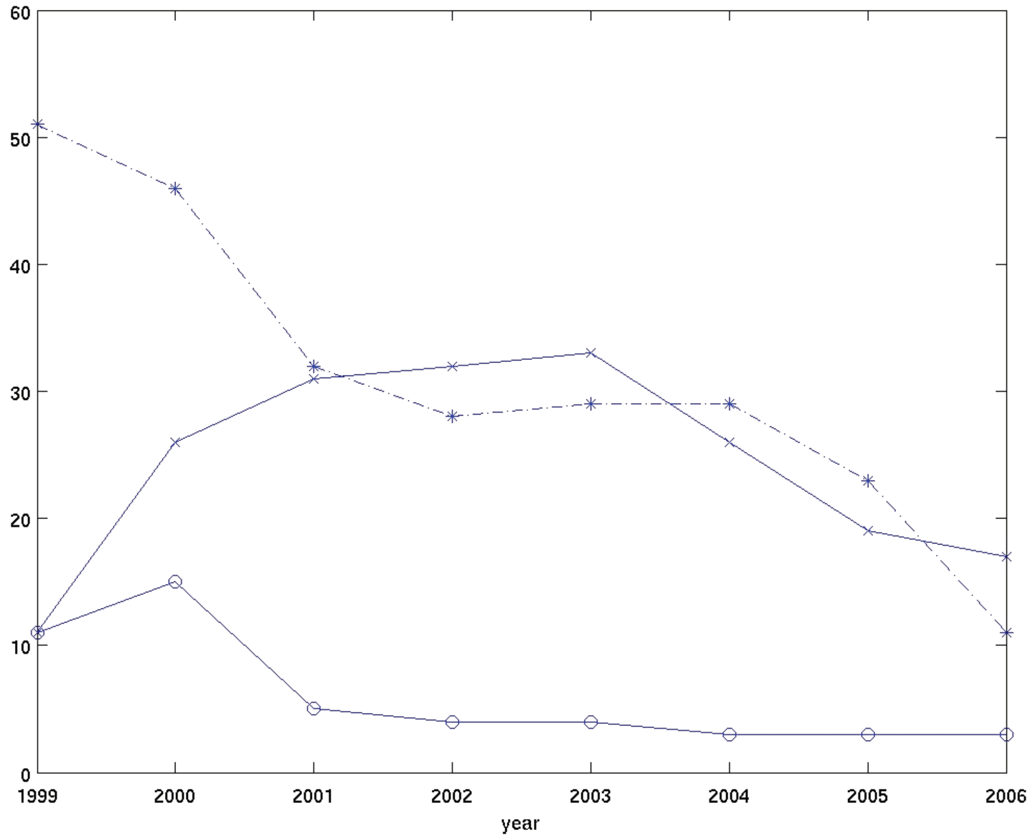

FIGURE 5-2 Grants for the Vertical Integration of Research and Education in the Mathematical Sciences, 1999-2006: the number of awards made by year (bottom solid line), the number awards in operation each year (upper solid line), and the total number of submitted proposals by year (dotted line). SOURCE: Data provided by the National Science Foundation.

- Insufficient interest within department (14),
- Application process is too burdensome (12),
- A VIGRE award is not the preferred way for our department to advance mathematics and/or statistics (12),
- Our department already undertakes activities that would be pursued via a VIGRE award (10), and
- Other (27 responses, ranging from "Not aware of the opportunity" to "We have the impression that NSF does not have that much interest in funding biostatistics departments. It is a lot of work to apply, so we haven't.").

However, applying for a VIGRE grant, regardless of receiving an award, might have had some positive effects on a department. Some departments told the committee in response to its e-mail that they had made changes in preparation for applying, including changing or improving the curriculum and adding components of vertical integration.

The committee was unable to determine from available data any pattern about which departments were selected for pre-award site visits and which were not. Many of the top mathematics departments in the United States repeatedly applied for a VIGRE grant and were not selected for site visits for reasons that remain unclear both to the proposers and to the committee. The only clear pattern that the committee observed is that funding was always denied if a site-visit team reported the lack of a plan or that faculty was unaware of a plan.

The American Mathematical Society classifies PhD-granting mathematics departments (other than those representing themselves as "applied mathematics" departments) in Groups I, II, and III according to the National Research Council's ratings of departments (NRC, 1995). The highest group—Group I—is further broken down into Group I Public and Group I Private. Of the 48 Group I departments, 30 (60 percent) eventually received a VIGRE grant for at least 3 years; this breaks down further to 13 of the 23 Group I Private departments (52 percent) and 17 of the 25 Group I Public departments (68 percent). In Group II, which contains 56 departments, 7 VIGRE awards were made (12.5 percent), and no awards were made to Group III departments.

Thus, the large majority of VIGRE grants went to top-ranked mathematics departments. Even so, nearly half of the Group I Private and one-third of the Group I Public institutions never received VIGRE grants. Harvard University and Princeton University received 5-year grants in the early years of the program, as did the Department of Mathematics at the University of California, Berkeley, and Yale University, although the latter were both terminated after 3 years. The University of Chicago is the only Group I Private department whose VIGRE program was renewed for an additional 5 years. Committee members reported that colleagues in several Group I Private schools had said that their departments have applied without success, sometimes repeatedly, and some did not even receive site visits.

A pattern, evident in Table 5-4, is that VIGRE funding seems to be shifting more and more over time from top-ranked private schools to lower-ranked large state universities. Currently, the only one of the top-10 mathematics departments (according to the NRC [1995] rankings) that has an active VIGRE grant is the University of Chicago.

According to the committee's own data collecting, 31 schools applied for 5-year renewals of their VIGRE grants, 7 did not, and 4 did not report back. There seems to be no clear picture as to why schools did not reapply, although 3 noted that they judged their chances of renewal to be small. A few cited administrative burden. Of the 31 departments that applied for renewal, 9 reported to the committee that their reapplications were successful, 19 reported that the reapplications were unsuccessful, and 3 did not respond.

The committee's e-mail polling collected many comments, some fairly angry, to the effect that NSF's evaluation processes for VIGRE proposals were unfair and/or inconsistent. This quote, sent to the committee from the then-chair of a top mathematics department, expresses a common view: "I did not feel that scientific merit was ever a factor in the turndown but we were defeated by a combination of perceptions that . . . was an already very wealthy institution and what I can only describe as a combination of bureaucracy and the NSF staff caring more about doing things that made them look good than truly improved scientific outputs of infrastructure."[11] In particular, among VIGRE schools that failed in their renewal applications, 8 out of 13 were definitely dissatisfied with the valuation process.

The DMS program manager for the VIGRE program, Henry Warchall, explained something of the NSF procedures in an e-mail to the committee:

[11] Response to committee survey dated November 15, 2007.

TABLE 5-4 VIGRE Awards by Department Type, 1999-2008

Year	Active Grants	Group I Departments	Group II Departments	Applied Math/ Statistics	Percent Group I Departments	Percent Applied Math/ Statistics	Percent Group II Departments
1999-2000	18	10	1	7	55.56	38.89	5.56
2000-2001	34	22	2	10	64.71	29.41	5.88
2001-2002	39	26	2	11	66.67	28.21	5.13
2002-2003	39	25	3	11	64.10	28.21	7.69
2003-2004	39	25	3	11	60.10	28.21	7.69
2004-2005	41	25	3	13	60.98	31.71	7.32
2005-2006	32	20	3	9	62.50	28.13	9.38
2006-2007	23	13	2	8	56.52	34.78	8.70
2007-2008	21	9	4	8	42.86	38.10	19.05

SOURCE: Award data from the National Science Foundation.

> I wanted also to mention that none of the recommendations for award or declination of VIGRE proposals were made by a single program director in isolation. The recommendations are always made in consultation at least with other program directors in DMS. The group arriving at the recommendation has varied over the years. Some years, the entire Division (with the exceptions of DMS staff members who had conflicts of interest) was involved in formulating the recommendations. Other times, the VIGRE Management Group or the Workforce program management team were responsible. The variation is due to variation in the administrative structure used to handle the VIGRE proposals. I'll also mention that each VIGRE recommendation is further approved by the DMS Division Director (or designee) after it is formulated by the team of program directors who are involved. Thus, the VIGRE recommendations are by no means the work of a single NSF staff member.[12]

OUTCOMES AT AWARDEE DEPARTMENTS

As might be expected, departments granted VIGRE funding were more positive about the program than were other departments; but even among the former group, comments about the overall success of VIGRE were not unanimous. The committee classifies 7 of the open responses from this group as very positive, 5 as neutral, and 11 negative. The primary complaints concerned the exclusion of foreign students from funding and the excessive demands on faculty time to administer and coordinate the many activities.

Among the 122 non-VIGRE institutions that responded to the committee's e-mail request for information, only 5 declared that VIGRE is a good program. The committee classified 25 responses as being neutral with respect to the program and another 25 as being negative. A common comment, in about 20 percent of all respondents, was that VIGRE was a way for "the rich [to] get richer."[13]

In response to the committee's request for information from VIGRE awardees, 24 responding departments reported that the quality and quantity of mathematics students have gone up in recent years, whereas 4 said that there has not been much change. Non-VIGRE departments saw things quite differently: 24 reported recent improvements and 12 reported recent deterioration. Furthermore, 21 of

[12] Personal communication to the committee from Henry Warchall, program manager, Division of Mathematics and Physical Sciences, National Science Foundation, April 29, 2008.

[13] Response to the committee survey dated November 15, 2007.

the non-VIGRE departments did not see much change in the past few years. Four of the responses could not be clearly classified.[14]

The committee asked those departments that had grants if in fact the VIGRE funding helped. As may be predicted, 18 asserted that it had helped a lot and just 5 said that it helped little or not at all. There were, however, also 5 fairly ambiguous responses.

The committee also asked departments about trends, with results shown in Table 5-5.

As shown in the table, concerning undergraduates, almost all the VIGRE schools—31 in all—said that mentoring of undergraduates by postdoctorals went up during the program; and just 2 schools said that there had not been much change. The committee recorded 28 VIGRE departments reporting increased research experiences for undergradates, and 4 reporting an unchanged level. Summer mathematics programs and camps increased at 18 of the VIGRE departments and, surprisingly, stayed the same at 9. In summary, VIGRE schools nearly uniformly self-reported that numbers and quality of students went up; non-VIGRE departments reported much more varying results. As expected, graduate traineeships and postdoctoral fellowships increased. Interdisciplinary collaboration increased for about two-thirds of respondents. Outreach to K-12 students and teachers increased among half the respondents; it stayed about the same for the others.

The committee also noted an effect on faculty. It received many comments from VIGRE awardees that demands on faculty contributing to the VIGRE program were very great. Some VIGRE departments, in fact, paid faculty for some of their participation, while others did not. The following comment is from a Group I Public university: "It was extremely demanding to administer. Based on my own experience as the director of the program, it is easy for such activities to 'burn out' the faculty who are most involved. This is extremely counterproductive."[15] In response to the committee's inquiry about this issue, NSF's Henry Warchall wrote:

> As far as I am aware, no VIGRE funds were allocated for academic-year faculty salary. I believe that in the beginning years of the VIGRE program, no faculty salary whatsoever was allocated in VIGRE awards. Later, as the first projects received 3rd-year site visit evaluations, the magnitude of the effort required to organize and conduct a successful VIGRE program in a large department became evident, and DMS began to grant requests in VIGRE (and in EMSW21 generally) for faculty summer salary for the purposes of administration only. For several years, it was the operational practice that the amount of faculty salary in a VIGRE award would not exceed 10% of the total budget. In recent years, that strict 10% cap on the amount of faculty salary was relaxed in principle, but faculty salary still constitutes a very small percentage of each EMSW21 award. I am not aware of any academic-year teaching reduction that was funded directly by a VIGRE award.[16]

The committee had no objective way of measuring the effect of the VIGRE program on curriculum change at departments that obtained VIGRE grants. As for non-VIGRE departments, of the 122 who replied to the committee's questionnaire, 47 had applied for a VIGRE grant, and 31 had applied more than once. Of those 47, 21 said the process of applying had stimulated change in their departments, but only 5 explicitly mentioned curriculum review and/or change. Others mentioned vertically integrated seminars and mentoring.[17]

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[14] Ibid.
[15] Ibid.
[16] Personal communication to the committee from Henry Warchall, program manager, Division of Mathematics and Physical Sciences, National Science Foundation, June 20, 2008.
[17] Response to the committee survey dated November 15, 2007.

TABLE 5-5 Trends in Departments That Received a VIGRE Award

Topic Reported On	Reported by Departments (no.) to Have Increased	Reported by Departments (no.) to Have Stayed About the Same	Reported by Departments (no.) to Have Decreased	Not Applicable
Mentoring of students by postdoctorals or graduates	31	2	0	0
Teaching collaborations with departments outside mathematics or statistics	11	21	0	1
Research collaborations with departments outside mathematics or statistics	22	11	0	0
Group activities that include undergraduates, graduates, postdoctorals, and faculty	29	4	0	0
Outreach to K-12 students	16	16	0	0
Outreach to K-12 teachers	17	15	0	0
Summer camps in mathematics/statistics	18	9	0	6
Postdoctoral fellowships	26	6	1	0
Graduate traineeships	25	6	2	0
Undergraduate research experiences	28	4	0	0

SOURCE: Data provided by departments in response to committee survey dated November 15, 2007.

Most VIGRE schools reported in the committee's survey that programs begun under the impetus of VIGRE that required funding (especially graduate and postdoctoral fellowships) would be discontinued, but many reported that low-cost programs such as research-training groups and student-run seminars were likely to continue. The following quote, from a Group I Public university, characterizes the responses on this subject: "My feelings about VIGRE are mixed: VIGRE encouraged and enabled us to do all sorts of wonderful things; this was nice while it lasted, but in the end we failed to get our university to support any of these programs after VIGRE ended, and the post-VIGRE financial situation was brutal."[18]

DMS's RFP already raises this as an issue: "A successful EMSW21 proposal must convince reviewers that the project . . . has a post-EMSW21 plan. The EMSW21 program is intended to help stimulate and implement permanent positive changes in education and training within the mathematical sciences in the U.S. Thus it is critical that an EMSW21 site adequately plan how to continue the pursuit of EMSW21 goals when funding terminates."[19] However, it is not clear that the proposal review process has put enough emphasis on the sustainability of proposed plans.

CONCLUSION

Although it is difficult to attribute changes (e.g., enrollments, degrees) in an institution's mathematical sciences department to the VIGRE program as opposed to other factors, it does seem that the VIGRE program has produced a number of qualitative changes in mathematics and statistics departments that

[18] Ibid.

[19] From the program solicitation: "Enhancing the Mathematical Sciences Workforce in the 21st Century (EMSW21)," NSF 05-595, available at http://www.nsf.gov/pubs/2005/nsf05595/nsf05595.pdf. Accessed June 29, 2009.

have held a grant. These include increasing the integration of students and faculty, providing more opportunities for students, helping effect a more welcoming culture (at least in the sense of mentoring), and introducing somewhat more interdisciplinarity and outreach.

Two further avenues of research are to work (1) to quantify these changes, and (2) to assess the effects of VIGRE funding beyond the departments that received a grant. In the first instance, it seems clear that some effort should be made to survey (in some fashion) administrators, faculty, and students who are or were involved in the VIGRE program as well as students who are not involved, to ascertain their views on the importance and impact of VIGRE funding. In the latter instance, for NSF to maximize the potential of VIGRE funding, at least some of the impact must transcend those who directly receive funding. One could ask, for example:

- What is the effect of VIGRE on the U.S. scientific workforce?
- What is the effect on the culture of mathematical sciences higher education?

Although the second question above seems unanswerable, the committee believes that the first would be answerable if, for instance, NSF tracked and surveyed mathematicians graduating from VIGRE programs. Such a survey could give some indication of the influence of these VIGRE graduates and of those trained by them.

6

Recommendations

The committee identified nine recommendations on the basis of its review of the National Science Foundation's (NSF's) program of Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE) and its accomplishments.

Recommendation 1: Continue the National Science Foundation's program of Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE) but with critical policy and programmatic changes identified in the eight recommendations below.

As discussed in Chapter 2, the VIGRE program was begun in 1998 in an effort to revitalize mathematics education at the undergraduate and graduate levels. In the committee's judgment, the impact of the VIGRE program has been mitigated by a variety of factors, including the following:

- The lack of a consistent statement of program goals and of an explicit expectation of scientific quality in the award process,
- A fluctuating level of funding inconsistent with the magnitude of the reforms desired,
- Overly restrictive programmatic requirements,
- Limitations on participation,
- An undefined assessment process, and
- The absence of a systematic means for disseminating successful innovations to the broader mathematical sciences community.

Nevertheless, the underlying need for a program like the VIGRE program still exists. Moreover, there are impressive examples of the meaningful impact that the VIGRE program has had on the educational programs of some departments, leading to the kind of systemic change called for when the VIGRE program was conceived. Examples of these changes can be found in Cozzens (2008). The committee believes that if the recommendations presented below are incorporated into the VIGRE program, it can better serve its intended purpose and have a wider impact, consistent with the original design of the program.

Recommendation 2: Clarify the goals of the VIGRE program and emphasize scientific quality in making awards.

As discussed in Chapter 2, the committee found considerable confusion over the goals of the VIGRE program, in part because they have shifted over time. Although initially it was not seen as a workforce program, in later requests for proposals (RFPs) it appears to have become one. In order to maximize the impact of the program, the committee believes that a clear, concise, consistent set of goals should be established.

While the goals of the VIGRE program have evolved over time, the following four seem to have been part of the program since its inception:

- Vertical integration of mathematics education and research,
- Greater breadth in the mathematical education of students,
- Improved communication skills for graduates in the mathematical sciences, and
- Increased exposure of students in mathematical sciences to disciplines that require mathematics.

The committee believes that these goals were responsive to the studies that led up to the creation of the VIGRE program and that they are still relevant for the mathematical sciences community. Whether these are the goals that capture the expectations of the National Science Foundation for its program at this point is not for the committee to decide. However, the committee believes that NSF should establish a clear set of goals for the program and emphasize them in future publications and RFP solicitations.

Finally, the committee could find no specific reference to the scientific quality of the proposed activity as a criterion for selecting VIGRE awardees. In the committee's view, this serious omission should be corrected. The goals of the VIGRE program will best be met in the future if funds are granted to individuals and departments that set a high standard for quality in their disciplines.

Recommendation 3: While retaining the VIGRE program's distinctive focus on projects that span the entire spectrum of educational levels from the undergraduate through the post-doctoral associate levels, allow greater flexibility in proposal design by encouraging VIGRE projects that address some, but not necessarily all, of the goals of the VIGRE program.

Although it is a worthy aspiration for VIGRE program RFPs to call simultaneously for vertical integration from undergraduate education to postdoctoral research, for department-wide change across all subdisciplines, and for simultaneous and significant change in a department's undergraduate, graduate, and postdoctoral programs, this should not be seen by NSF as the only path to achieving the goals of the program or to realizing the recommendations of the national panels referred to in Chapter 2. The committee has seen many examples of benefits to education, breadth of experience, and culture from interactions across *some* vertical divisions, such as postdoctorals mentoring graduate students or graduate students mentoring undergraduates. The experience of the committee members is that there are benefits to connectivity; but no evidence has been presented that *all* of those elements of vertical integration need to be present in a department in order to see any benefits. NSF's Division of Mathematical Sciences (DMS) has moved recently in the direction of making its workforce programs, such as Research Training Groups and Mentoring Through Critical Transition Points, broader and more flexible. DMS has even issued an open call for workforce proposals without VIGRE's predefined structures. Within the broad goals established for the VIGRE program, awardees should enjoy increased flexibility and should be encouraged to employ additional local initiative.

The committee is very supportive of the departmental nature of the grants, but it believes that the grants should not necessarily require engagement by a major portion of the department. Proposals should be entertained that, for example, build on the particular strengths of a department or that help broaden its impact. Further, the committee believes that the VIGRE program should allow for awards that do not necessarily include vertical integration across the full breadth of a department's educational programs or across all educational levels from the undergraduate to that of postdoctoral fellows. Moreover, proposals involving fewer faculty, with greater release time and staff support, and emphasizing particular elements of the VIGRE programs in the departments should be permitted.

In sum, the committee believes that program requirements should contain fewer "ands" and more "ors." Not all proposals need to satisfy all changes at once. This would encourage a broader range of institutions to apply and contribute.

Recommendation 4: To ensure the sustainability of an institution's successful VIGRE-initiated reforms, establish longer-term original awards and renewal awards, and require and enforce institutional support for grantees in the out-years of awards.

The committee was dismayed to learn that, too often, changes accomplished by individual VIGRE grants have not been sustained. Indeed, responses to the committee's survey of departments of mathematical sciences indicated that many of the achievements at individual programs have not been or will not be continued after the expiration of the VIGRE grant. Because NSF is such a dominant source of support in the mathematical sciences, sustainability of reform efforts in mathematics requires special consideration by the Foundation. In order for the changes envisioned by the VIGRE program to persist, the committee urges NSF to make longer-term awards that require a commitment from the host universities to provide the necessary support to sustain successful new initiatives resulting from VIGRE as funding from NSF phases down and terminates.

Some of this sustainability of reform efforts can be accomplished within the VIGRE program framework. Offering larger awards and a return to the longer wind-down periods of the "centers of excellence"[1] grants of the 1960s would provide incentives for institutions to make continuing commitments to their mathematical science programs (and give them the time to build the required continuing resource base). The centers-of-excellence grants funded new faculty positions in various fields for up to 10 years, with the expectation that institutions would pick up funding for those salaries at the end of that period. Such a model could address the serious challenge, particularly for many public and small private universities, of sustaining various components of a VIGRE grant.

In this spirit, the committee urges that initial VIGRE awards should be for a 5-year period, with a review at the end of the 3rd year. Based on a satisfactory review and an institutional commitment of funds to sustain the VIGRE grant, departments would be granted a second 5 years for a total of 10 years of funding. Departments deemed not to be making satisfactory progress would have their grants terminated, with a 1-year "phase-down" grant, perhaps at a lower level than the initial grant, to accommodate special situations such as support for graduate students and postdoctoral fellows that began in year 4. The committee is not recommending that the second 5-year renewal period necessarily be funded at the same level as the first. The second 5-year award might be smaller, augmented by a requirement of insti-

[1] See http://www.nsf.gov/nsb/documents/2000/nsb00215/nsb50/1960/gldn_age.html. Accessed June 26, 2009.

tutional funding, and could be more focused on the successful aspects of its preceding award. VIGRE awards should be viewed as seed money for change, especially for the first 5 years of funding, with the expectation of sustainability if awards are extended for a full 10 years.

Recommendation 5: Institute a preproposal step into the VIGRE application process.

To encourage the submission of more proposals, the committee urges that NSF institute a preproposal stage for VIGRE awards. Preproposals would be designed to be less detailed and to require less preparation than full proposals. The preparation of proposals for VIGRE projects requires large amounts of faculty and administrative time. The committee's survey indicated that some departments did not apply for VIGRE grants because of the work involved in the application process. The declining number of proposals for VIGRE grants over the years since the program's inception is further evidence that the magnitude of the effort to develop proposals of this scale is not deemed a cost-effective use of time. Requiring the early engagement of a proposing institution's higher administration could lead to stronger institutional commitments to sustain VIGRE-induced change. A carefully constructed preproposal process, in which NSF commented on the strengths and weaknesses of an institution's preproposal, would enable institutions to test ideas with NSF to see if they hold promise without the institution's incurring the enormous expenditures of resources to develop a full-blown proposal. The committee believes that the guidance which departments would gain during a preproposal process would also strengthen the quality of the proposals submitted.

Recommendation 6: Allow international students and postdoctoral fellows to receive financial support from VIGRE projects.

The committee believes that a program designed to increase departmental interaction, communication, and cooperation is ill-served when large portions of the graduate student and postdoctoral population, namely foreign nationals, are excluded. Although foreign students and postdoctoral fellows may participate in VIGRE program activities, they may not receive support from the VIGRE program. In some instances this enhances a tendency for them to be isolated within the department to the detriment of themselves and the detriment of domestic students. Inclusion of such talented students in the VIGRE program would aid their acculturation and English language skills and thus enhance the chance of their remaining permanently in the United States and contributing to the mathematical sciences workforce. Indeed, one aspect of a VIGRE grant might be to encourage activities among foreign students and postdoctoral fellows that improve their English language and teaching skills.

This recommendation is consistent with language in the National Academies' (2005) report *Policy Implications of International Graduate Students and Postdoctoral Scholars in the United States,* which says:

> The United States must be able to recruit the most talented people worldwide for positions in academe, industry, and government. That means that the United States must work to attract the best international talent while seeking to improve and invigorate the mentoring, education, and training of its own S&E [science and engineering] students. This dual goal is especially important in light of increasing global competition for the best S&E students and scholars. (National Academies, 2005, p. 9)

This report goes on, in its recommendations, to further justify the inclusion of foreign graduate students and postdoctoral fellows in the programs of U.S. universities. The findings and recommendations cited below are unambiguous concerning the benefits of greater international participation with little or no negative consequences to the United States.

> Recommendation 2.1 . . . Universities should continue to encourage the enrollment of international students by offering fellowships and assistantships.
>
> Finding 2.2 . . . Many international students and scholars who come to the United States desire to and do stay after their studies and training are completed. Those who return home often maintain collaboration with scientists and engineers in the United States and take with them a better understanding of US culture, research, and the political system.
>
> Finding 3.1 . . . The evidence that large international graduate-student enrollment may reduce enrollment of domestic students is sparse and contradictory but suggests that direct displacement effects are small compared with pull factors.
>
> Finding 3.4 . . . Multinational corporations (MNCs) hire international PhDs in proportions similar to the output of university graduate and postdoctoral programs for their US research laboratories and often hire US-trained PhDs for their nondomestic laboratories. (National Academies, 2005, pp. 5-11)

Recommendation 7: Expand the scope of the VIGRE program to include students preparing to apply advanced mathematics in nonacademic settings.

Chapter 2 identifies the need for well-prepared master's- or doctoral-level professionals who can use sophisticated mathematics in nonacademic settings. Examples include professions involving financial mathematics, biostatistics, K-12 education, and a range of areas at the interfaces of the computational sciences, including computational mathematics and, more recently, advanced analytics. The experience and impact of the Professional Science Masters program,[2] developed by the Sloan Foundation, offer a good example of how such programs can be vertically integrated into a department's degree programs.

The committee urges that the VIGRE program's scope be expanded to allow support for such efforts in doctorate-granting departments. These would not require large funding, because many of these programs, as with the master of business administration, typically are job-market driven and do not require significant student stipend support.

Recommendation 8: Create a rigorous assessment process with a small number of carefully chosen benchmarks for which data can be collected and compared across VIGRE projects on an annual basis.

The VIGRE program was launched with no apparent plan for assessing the effectiveness of the program. No quantifiable goals were set, and no predetermined data elements to measure performance were defined. If the program is to be continued, this deficiency must be addressed. As noted in Chapter 5, it is difficult at this point to disentangle the quantitative and qualitative changes in departments that can be attributed to a VIGRE grant from those that occurred as a result of other factors.

Assessment needs to occur both at the macro level for the program as a whole and at the level of individual program grantees. As part of the assessment strategy, NSF needs to develop a limited set of supporting data elements, aligned with the goals of the program, that it will systematically collect from VIGRE-supported departments. The committee suggests that the data collection specifically include the following:

[2] See http://sciencemasters.com. Accessed June 16, 2009.

- A small, carefully chosen set of metrics, conforming as much as possible to data collected more broadly by NSF and the American Mathematical Society or submitted to the Department of Education, that can be collected with relative ease by all projects and required of all projects annually;
- A database to track students and postdoctoral fellows supported by participating VIGRE institutions beyond the expiration of the grants;
- Ten years of benchmarking data from grantees as opposed to the current 5-year requirement; and
- Survey instruments to collect data from VIGRE program participants (e.g., students, postdoctoral fellows, faculty), to measure the impact of the program on individuals supported by it.

Further, the committee believes that NSF's expectations of awardees must be clarified. NSF should develop a consistent evaluation strategy for VIGRE grantees and, as noted above, a limited set of metrics that must be collected by all projects and reported annually. The evaluation strategy must be carefully constructed so as not to work against the need for simplification and flexibility that the committee has noted in Recommendation 3. Overall, the system of 3rd-year review by means of self-assessment and site visit is working well. The evaluation process should be transparent, and the results of the evaluation need to be used in renewal reviews.

Recommendation 9: Develop systematic and highly visible strategies for the dissemination of successful VIGRE projects.

From the beginning, the VIGRE program should have been conceived of as a national program, offering the possibility of fundamental change in mathematics education through the dissemination of successful programs and best practices. A number of strategies could be taken to improve the dissemination of the practices and accomplishments of the VIGRE program.

First, for example, awardees should be expected to engage more fully in efforts to disseminate their activities and outcomes, with dissemination plans included in the proposals. Each awardee should maintain a VIGRE Web site, and access to Web sites should be maintained by the institution after the funding ends, to provide a record of the program. Departments should be encouraged to disseminate examples of their VIGRE activities by, for example, developing resources that could be picked up by other departments. Examples of such resources would include Webcasting lectures or symposia and providing syllabi.

Second, NSF should take the lead in developing a framework and infrastructure for information and communication mechanisms that would encompass all workforce program grants, which could include the following:

- Encouraging textbook development and other ways of capturing curriculum reform;
- Sponsoring the creation and promotion of a "portal" to all VIGRE Web sites. This portal would enable any mathematics or statistics department to identify and implement activities pioneered at the VIGRE-award institutions that might work for their own department. A model is the NSF ADVANCE (Advancement of Women in Academic Science and Engineering Careers) program portal at http://research.cs.vt.edu/advance/index.htm (because the VIGRE program is now one component in a suite of workforce programs, the focus of a "what works" portal should not be limited to the VIGRE program but should encompass the full range of associated programs; strategies that work should not be artificially constrained by program boundaries);

- Sponsoring meetings, sessions at meetings of the mathematics and statistics professional societies, and workshops; and
- Encouraging structured engagement of the NSF Mathematical Science Research Institutes.

Third, the committee suggests that NSF develop at least a pilot program of "adaptive implementation grants." The RFP for these grants would invite proposers to base their proposals on the replication or adaptation of successful VIGRE activities, such as those in the "what works" portal, to their own institutions (as is now happening with the UTeach program at the University of Texas at Austin). A good example of what the committee envisions is the ADVANCE program's Partnerships for Adaptation, Implementation, and Dissemination (PAID) awards that support analysis, adaptation, dissemination and use of existing innovative materials and practices that have been demonstrated to be effective.

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Appendixes

Appendix A

Biographies of Committee Members

William E. Kirwan (*Chair*) has been chancellor of the University System of Maryland since August 2002. A widely respected academic leader, Dr. Kirwan served as president of Ohio State University for 4 years (1998-2002) and as president of the University of Maryland, College Park, for 10 years (1988-1998). Prior to his presidency, he was a member of the University of Maryland faculty for 34 years. Dr. Kirwan is also a nationally recognized authority on critical issues shaping the higher-education landscape. He is a sought-after speaker on a wide range of topics, including diversity, access and affordability, cost containment, accountability, economic impact, gender equity, financial aid, partnerships, and innovation. Along with his national and international presentations on key issues, Dr. Kirwan has authored several pieces and has been profiled as a national education leader in academic and mainstream publications. In May 2006, Dr. Kirwan was appointed to serve on the Knight Commission on Intercollegiate Athletics and became co-chair of the commission in May 2007. He also serves on the board of directors of the Council for Higher Education Accreditation and is a member of the Business-Higher Education Forum. He is past chair of the National Association of State Universities and Land-Grant Colleges (NASULGC) board of directors and of the American Council on Education's board. He is the current chair of NASULGC's Committee on Student Learning and Accountability. He was appointed by President Clinton to serve as a member of the National Commission on Mathematics and Science Teaching for the 21st Century, and he chaired the National Research Council's Commission on the Mathematical Sciences in the Year 2000, which produced the 1991 report *Moving Beyond Myths: Revitalizing Undergraduate Mathematics*. President George W. Bush appointed Dr. Kirwan to the Board of Advisors on Historically Black Colleges and Universities. Dr. Kirwan received his bachelor's degree in mathematics from the University of Kentucky and his master's and doctoral degrees in mathematics from Rutgers, The State University of New Jersey, in 1962 and 1964, respectively. He is a member of several honorary and professional societies, including Phi Beta Kappa, Phi Kappa Phi, the American Mathematical Society, and the Mathematical Association of America. A prolific scholar, he is co-editor of the book *Advances in Complex Analysis* and has published many articles on mathematical research. The recipient of many honors, Dr. Kirwan has been elected to the Hall of Distinguished Alumni at both the University of Kentucky and Rutgers University. He also was selected to receive the Rutgers

University Award for Career Achievement on the occasion of the 50th anniversary of the founding of that university's graduate school. Dr. Kirwan received the 2004 National Innovators Award, the highest honor awarded by Minority Access, Inc., recognizing his commitment to diversity and to improving the recruitment and retention of minorities. In 2002, he was elected a fellow of the American Academy of Arts and Sciences. Dr. Kirwan received the Maryland Senate's First Citizen of Maryland Award in 1998, and on February 15, 2007, he became the 16th recipient of the Maryland House of Delegates Speaker's Medallion, which recognizes Maryland citizens who have demonstrated exemplary service to the House and to the State of Maryland.

Efraim Armendariz is chair of the Department of Mathematics at the University of Texas at Austin, a position that he has held since 1991. Dr. Armendariz received the BA and MS degrees in mathematics from Texas A&M University in 1960 and 1962, respectively, and received the PhD in mathematics from the University of Nebraska (Lincoln) in 1966. He has published more than 40 research articles in this area, as well as a book on elementary number theory, and has supervised 6 doctoral students in mathematics, 3 in science and mathematics education, and 31 master's students. Dr. Armendariz has also been actively involved in the development of educational programs that address questions of accessibility, as well as development of secondary mathematics teachers. In 1988, he established the Emerging Scholars Program at the University of Texas at Austin, an intervention program designed to enhance academic success in calculus among students of mathematics and science and engineering who are from traditionally underrepresented groups. He is a member of the Mathematical Association of America (MAA). In this capacity he has served as Level III director (1992-1996), chair of the Texas Section (1996-1997), and arrangements chair and organizer for the annual meeting of the Texas Section in April 2000. He has also served and chaired various national committees, including the MAA Committee on Minority Participation in Mathematics. He is currently a member of the board of governors of the MAA, serving as governor-at-large for minority interests. Dr. Armendariz's other professional service includes membership and chairing of postdoctoral selection panels for the National Science Foundation and the Ford Foundation, member of the Human Resources Advisory Committee of the Mathematical Sciences Research Institute, and member of the Committee of Visitors for the NSF Division of Mathematical Sciences.

John A. Burns is the Hatcher Professor of Mathematics at Virginia Polytechnic Institute and State University and the technical director of the Interdisciplinary Center for Applied Mathematics. He has published more than 140 research papers on computational methods for the identification, optimization, and control of systems governed by partial and functional differential equations. He has directed more than 20 PhD students and 10 MS theses. He has served on more than 12 editorial boards, and he was the founding editor of the SIAM [Society for Industrial and Applied Mathematics] Activity Book Series on Advances in Design and Control. He has served as vice president of SIAM, is the past chair of the SIAM Group on Systems and Control, and is a fellow of the IEEE. Dr. Burns's primary interests concern the development of rigorous and practical computational algorithms for the design and optimization of engineering and biological systems. He has applied his research to a wide variety of areas, including fluid dynamics, smart materials, large-space structures, nanodevices, aerodynamic design, and energy-efficient buildings. Dr. Burns has been a consultant and adviser to Booz Allen and Hamilton, NASA Langley Research Center, the Air Force Research Laboratory, the Defense Advanced Research Projects Agency, the Babcock and Wilcox Company, Solers Inc., and the United Technologies Research Center. He has held several academic visiting positions in the United States and Europe.

C. Herbert Clemens is a professor of mathematics at the Ohio State University, specializing in complex geometry. Prior to joining Ohio State, he was on the faculty of Columbia University and the University of Utah. He is the winner of a Fulbright Fellowship and a Sloan Fellowship, and currently chairs the U.S. National Committee on Mathematics of the National Research Council.

Dona L. Crawford is associate director for computation at the Lawrence Livermore National Laboratory (LLNL). She is responsible for the development and deployment of an integrated computing environment for terascale simulations of complex physical phenomena. This environment includes high-performance computers, scientific visualization facilities, high-performance storage systems, network connectivity, multi-resolution data analysis, mathematical models, scalable numerical algorithms, computer applications, and necessary services to enable laboratory mission goals and scientific discovery through simulation. Prior to her LLNL appointment in July 2001, Ms. Crawford had been with Sandia National Laboratories since 1976, serving on many leadership projects, including the Accelerated Strategic Computing Initiative, the Nuclear Weapons Policy Board, and the Nuclear Weapons Strategic Business Unit. Ms. Crawford has served on advisory committees for the National Science Foundation, the National Research Council, and the Council on Competitiveness. She is on the Civilian Research and Development Foundation Board, is a member of the IEEE and the Association for Computing Machinery, is active in the U.S. high-performance networking and computing conference series, and participates in community outreach activities to promote mathematics and science. She holds a BS degree in mathematics from the University of Redlands, California, and an MS degree in operations research from Stanford University.

Christine M. Cumming is first vice president of the Federal Reserve Bank of New York and serves as its chief operating officer. She is an alternate voting member of the Federal Open Market Committee. Dr. Cumming joined the Bank's staff in September 1979 as an economist in the International Research Department. While on the Bank's International Capital Markets staff, she worked on topics such as the liquidity of banks and securities firms and the international competitiveness of U.S. financial institutions. In the 1990s, Dr. Cumming was a senior officer in Bank Supervision. She was active in the work of the Basel Committee, including the development of the market risk amendment to the Basel Accord and of risk management guidance for banks and bank supervisors. Prior to being named to her current position, she was executive vice president and director of research with responsibility for the Research and Market Analysis Group. Dr. Cumming earned a PhD in economics from the University of Minnesota.

Lawrence Craig Evans is a professor in the Department of Mathematics at the University of California at Berkeley (UCB). He is a highly respected core mathematician. He is director of the Center for Pure and Applied Mathematics at UCB and is a member of the National Research Council's Board on Mathematical Sciences and Their Applications. He recently won the prestigious Leroy P. Steele Prize for Seminal Contributions to Research, awarded by the American Mathematical Society.

Charles L. Fefferman is a professor in the Department of Mathematics at Princeton University. He received his bachelor's degrees in physics and mathematics at the age of 17 from the University of Maryland and a PhD in mathematics at 20 from Princeton University. Dr. Fefferman received full professorship at the University of Chicago at the age of 22, making him the youngest full professor ever appointed in the United States. At 24, he returned to Princeton to assume a full professorship there, a position that he still holds. He won the Alan T. Waterman Award in 1976 and the Fields medal in 1978 for his work in mathematical analysis, and he was elected in 1979 to the National Academy of Sciences.

Martin Golubitsky is Distinguished Professor of Mathematics and Physical Sciences at Ohio State University and director of the Mathematical Biosciences Institute. His research centers on the theory and application of bifurcation theory, particularly in the presence of symmetry. He received his PhD in mathematics from the Massachusetts Institute of Technology (MIT) in 1970 and has held positions at the University of California at Los Angeles, MIT, Queens College of the City University of New York, Arizona State University, and the University of Houston. Dr. Golubitsky is a fellow of the American Academy of Arts and Sciences and the American Association for the Advancement of Science (AAAS) and the recipient of the 1997 University of Houston Esther Farfel Award and the 2001 Ferran Sunyer I Balaguer Prize for *The Symmetry Perspective*. He has been elected to the Councils of the Society for Industrial and Applied Mathematics (SIAM), AAAS, and the American Mathematical Society. Dr. Golubitsky was the founding editor-in-chief of the *SIAM Journal on Applied Dynamical Systems*, chair of the SIAM Activity Group on Dynamical Systems, and president of SIAM.

Mark L. Green is a professor in the Department of Mathematics at the University of California at Los Angeles (UCLA). He received his BS from the Massachusetts Institute of Technology (MIT) and his MA and PhD from Princeton University. After teaching at the University of California at Berkeley and MIT, he came to UCLA as an assistant professor in 1975. He was a founding co-director of the NSF-funded Institute for Pure and Applied Mathematics. Dr. Green's research has taken him into several areas of mathematics: several complex variables, differential geometry, commutative algebra, Hodge theory, and algebraic geometry. He received an Alfred P. Sloan fellowship and was an invited speaker at the International Congress of Mathematicians in Berlin.

Leo P. Kadanoff is a professor of mathematics and statistics at the University of Chicago. He is a theoretical physicist who has contributed widely to research in the properties of matter, to the development of urban areas, and to statistical models of physical systems. His best-known contribution was in the development of the concepts of "scale invariance" and "universality" as they are applied to phase transitions. More recently, he has been involved in the understanding of the onset of chaos in simple mechanical and fluid systems. His academic degrees were received from Harvard University in the period 1957-1960. After a postdoctoral period at the Neils Bohr Institute in Copenhagen, he joined the staff of the University of Illinois in 1962 and became a professor of physics there in 1965. During this period he carried out research activities aimed at understanding the properties of matter, especially the phenomenon of superconductivity, and he performed research and development work aimed at heat protection for ballistic missiles. In 1966-1967, he carried out research into the organization of matter in "phase transitions" that led to a substantial modification of physicists' way of looking at these changes in the state of matter. This work led to his receipt of the Buckley Prize of the American Physical Society (1977), the Wolf Foundation Prize in 1980, and the 1989 Boltzmann Medal of the International Union of Pure and Applied Physics. Dr. Kadanoff moved to the University of Chicago in 1978, where he became the John D. and Catherine T. MacArthur Distinguished Service Professor of Physics and Mathematics. At the University of Chicago, he has also been particularly interested in complexity, fluid flow, and the applications of computers to physical calculations. He is a member of the National Academy of Sciences, of the American Academy of Arts and Sciences, and of the American Philosophical Society as well as being a fellow of the American Physical Society and of the American Association for the Advancement of Science. During the past decade, he has received the Quantrell Award (for excellence in teaching) from the University of Chicago, the Centennial Medal of Harvard University, the Onsager Prize of the American Physical Society, the Grande Medaille d'Or of the Academy des Sciences de l'Institut de France, and the National Medal of Science (U.S.).

Daniel L. Solomon is professor of statistics and dean of the College of Physical and Mathematical Sciences at North Carolina State University. Dr. Solomon began his career in 1968 at Cornell University, moving through the ranks to professor of biological statistics and heading the Biometrics Unit there from 1977 to 1981. In 1981, Dr. Solomon came to North Carolina State University as professor and head of the Department of Statistics, a position that he held until 1993. He was named dean of the college effective July 1, 2000. Dr. Solomon is a fellow of the American Statistical Association, founding member of the corporation for the National Institute of Statistical Sciences, and current chair of the governing board of the Statistical and Applied Mathematical Sciences Institute.

Lynn Arthur Steen is professor of mathematics and special assistant to the provost at Saint Olaf College. After receiving his PhD from the Massachusetts Institute of Technology (MIT), he focused his early professional energy on research experiences for undergraduates and on mathematical exposition, the communication of mathematical research to the broader public. In this capacity he served as mathematics secretary of the American Association for the Advancement of Science (AAAS) and as the first mathematics editor for *Science News*. In the 1980s, he helped lead national efforts to modernize the teaching of calculus. During 1985-1986 he served as president of the Mathematical Association of America and later as chair of the Council of Scientific Society Presidents. Recently he has worked with Achieve, Inc., to upgrade standards for school mathematics and with the National Council on Education and the Disciplines to stimulate attention to quantitative literacy across college campuses. The author of more than 200 articles on mathematics and education, Dr. Steen has served as both a member of and staff director for the National Research Council's Mathematical Sciences Education Board. Dr. Steen is a fellow of the AAAS, the 1989 recipient of a Board of Directors Special Award from Sigma Xi, the 1992 Distinguished Service to Mathematics award from the Mathematical Association of America, and three honorary ScD degrees.

Karen L. Vogtmann is a professor of mathematics at Cornell University, specializing in geometric group theory. She has held faculty positions at the University of Michigan, Brandeis University, and Columbia University, and research positions at the Mathematical Sciences Research Institute at the University of California at Berkeley and the Institute for Advanced Study at Princeton University, as well as at various international institutions. She is a member of the U.S. National Committee on Mathematics and of the Scientific Advisory Board of the Mathematical Science Research Institute. She is also a member of the board of trustees of the American Mathematical Society (AMS) and is the board liaison to the Committee on Science Policy. She served previously as a vice president of the AMS and as a member of the AMS Committee on Education.

Eric W. Welch is an associate professor and director of graduate studies in the Public Administration Program at the University of Illinois at Chicago (UIC). His research focuses on environmental policy, science and technology policy, research and development (R&D) performance evaluation, and electronic government. His research has been published in such journals as *Transportation Research–D*, *Policy Sciences*, *Environmental Science and Policy*, *Journal of Public Policy and Management*, *Political Communication*, and *Journal of Public Administration Research and Theory*. He is currently working on a book on R&D evaluation methods titled *The New Generation of R&D Evaluation Methods: A Cross-National Review of Performance Measurement*, to be published by Edward Elgar. Professor Welch is involved in numerous research projects, including an NSF-funded effort on Women in Science and Engineering: Network Access, Participation and Outcomes; a longitudinal evaluation of research outcomes of the Mid-America Earthquake Center; and an ongoing research contract with the Chicago Transit Authority to undertake transit-relevant research in the Chicago metropolitan area. Professor Welch arrived at UIC in 1999 after research appointments at the U.S. Center for Economic Studies, the Center for Technology and Information Policy at Syracuse University, the International Institute for Applied Systems Analysis, and the Japan National Institute for Environmental Studies.

Shmuel Winograd is an IBM Fellow at the IBM Thomas J. Watson Research Center. He received his BSc and MSc in electrical engineering from the Massachusetts Institute of Technology (MIT) in 1959 and his PhD in mathematics from New York University in 1968. He joined IBM in 1961 as a research staff member and was appointed IBM Fellow in 1972. In 1970-1974, and again in 1980-1994, he was the director of the Mathematical Sciences Department at IBM Research. Dr. Winograd's research interests include complexity of computations and the design of efficient algorithms. He is a fellow of the IEEE and the Association for Computing Machinery, a member of the Society for Industrial and Applied Mathematics, and was elected to membership in the National Academy of Sciences, the American Academy of Arts and Science, and the American Philosophical Society. He is a former chair of the National Research Council's Board on Mathematical Sciences and Their Applications.

Appendix B

The Mathematical Sciences in the 1980s and 1990s

TABLE B-1 Federally Financed and Total Academic Research and Education Expenditures in Mathematics and Statistics, 1980-1998

Year	Federally Financed Academic R&D Expenditures (U.S. $)	Total Academic R&D Expenditures (U.S. $)	% Federal
1980	61,246	78,112	78
1981	67,780	87,112	78
1982	71,829	96,419	74
1983	76,518	106,408	72
1984	92,317	123,149	75
1985	96,979	127,730	76
1986	114,359	151,561	75
1987	131,952	177,246	74
1988	149,959	198,863	75
1989	157,315	214,638	73
1990	160,910	221,752	73
1991	170,544	230,179	74
1992	183,262	247,719	74
1993	203,122	272,250	75
1994	205,346	282,046	73
1995	204,928	278,952	73
1996	208,197	288,570	72
1997	202,208	289,802	70
1998	214,289	310,710	69

NOTE: R&D, research and development.
SOURCE: National Science Foundation, "Survey of R&D Expenditures at Universities and Colleges," accessed via WebCASPAR, http://webcaspar.nsf.gov.

TABLE B-2 Sources and Mechanisms of Support for Full-Time Graduate Students in Mathematics and Statistics Doctorate-Granting Institutions in the United States, 1980-1998 (number, by year)

Source of Support	Mechanism of Support	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
NSF	Fellowships	97	61	55	81	76	85	93	104	114	126
NSF	Traineeships	6	9	10	9	1	5	1	1	1	1
NSF	RA	149	152	158	131	193	223	253	319	340	339
NSF	TA	6	3	1	NA	NA	1	2	3	NA	5
NSF	Other	4	2	4	2	9	7	8	9	8	4
NIH	Fellowships	NA	NA	1	3	2	NA	NA	NA	NA	3
NIH	Traineeships	7	3	5	6	2	2	3	3	1	3
NIH	RA	27	19	19	19	18	16	13	19	21	19
NIH	TA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NIH	Other	NA	2	NA	NA	NA	NA	3	2	3	3
HHS (except NIH)	Fellowships	5	1	NA	NA	NA	NA	1	NA	NA	NA
HHS (except NIH)	Traineeships	4	4	NA	NA	NA	NA	NA	NA	1	NA
HHS (except NIH)	RA	9	6	14	13	4	2	3	6	2	8
HHS (except NIH)	TA	3	NA	NA	NA	NA	1	1	NA	NA	NA
HHS (except NIH)	Other	3	NA	NA	NA	NA	NA	NA	NA	NA	NA
DOD	Fellowships	9	4	6	7	6	11	14	17	23	27
DOD	Traineeships	NA	NA	NA	NA	NA	1	1	11	7	5
DOD	RA	101	77	80	94	109	127	146	146	183	148
DOD	Other	219	262	288	209	189	247	271	264	300	215
Other federal	Fellowships	15	18	22	26	16	23	23	21	32	95
Other federal	Traineeships	5	1	3	7	6	4	11	1	1	30
Other federal	RA	135	86	106	93	87	110	123	145	120	148
Other federal	TA	18	40	21	17	13	28	7	4	5	16
Other federal	Other	46	46	25	43	31	36	22	15	27	24
Nonfederal	Fellowships	633	597	603	577	666	738	778	718	772	751
Nonfederal	Traineeships	123	116	108	102	150	137	112	141	191	172
Nonfederal	RA	363	420	468	453	461	520	500	476	560	642
Nonfederal	TA	5,580	5,705	6,051	6,428	6,611	6,776	7,144	7,454	7,589	7,808
Nonfederal	Other	437	423	472	444	511	487	549	595	635	585
Self-support	Other	1,897	2,095	2,293	2,191	2,148	2,229	2,306	2,569	2,576	2,504

Source of Support	Mechanism of Support	1990	1991	1992	1993	1994	1995	1996	1997	1998
NSF	Fellowships	136	139	120	114	132	130	126	95	90
NSF	Traineeships	2	2	2	5	21	19	22	21	23
NSF	RA	335	302	324	332	346	287	257	256	261
NSF	TA	16	6	9	17	17	28	25	12	4
NSF	Other	2	3	2	2	2	10	5	2	6
NIH	Fellowships	4	3	52	15	1	1	NA	1	1
NIH	Traineeships	6	10	11	9	11	10	14	13	8
NIH	RA	27	48	43	43	55	46	44	47	57
NIH	TA	1	3	1	3	NA	1	NA	1	NA
NIH	Other	1	NA	4	4	1	5	3	4	2
HHS (except NIH)	Fellowships	NA	NA	NA	NA	NA	6	7	21	22
HHS (except NIH)	Traineeships	8	NA	NA	NA	NA	NA	NA	NA	NA
HHS (except NIH)	RA	2	4	6	6	8	18	12	9	10
HHS (except NIH)	TA	NA	NA	1	NA	NA	NA	NA	NA	NA
HHS (except NIH)	Other	NA	1	NA	NA	NA	NA	2	NA	NA
DOD	Fellowships	52	42	38	42	42	35	30	22	18
DOD	Traineeships	7	8	3	3	6	1	4	1	.
DOD	RA	112	121	139	159	129	125	119	154	89
DOD	Other	196	205	206	195	195	161	198	186	176
Other federal	Fellowships	200	327	246	225	123	124	123	96	85
Other federal	Traineeships	29	55	79	65	31	42	20	14	23
Other federal	RA	134	169	172	196	205	183	183	159	124
Other federal	TA	25	29	11	20	33	19	24	21	38
Other federal	Other	38	26	28	19	39	36	19	17	7
Nonfederal	Fellowships	734	854	960	967	918	1,001	999	971	888
Nonfederal	Traineeships	129	132	125	176	175	150	119	130	110
Nonfederal	RA	725	712	726	700	791	792	681	764	674
Nonfederal	TA	7,829	7,728	7,717	7,546	7,584	7,245	7,078	6,665	6,524
Nonfederal	Other	632	695	676	529	545	459	513	430	546
Self-support	Other	2,483	2,632	2,978	3,138	2,816	2,476	2,339	2,032	1,965

NOTE: NA, not available; NSF, National Science Foundation; RA, Research Assistant; TA, Teaching Assistant; NIH, National Institutes of Health; HHS, Health and Human Services; DOD, Department of Defense.

SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://webcaspar.nsf.gov.

TABLE B-3 Mathematics Doctorate Holders Employed in Academia in the United States, 1981-1999

Year	Mathematics Doctorate Holders Employed in Academia (no. in thousands)	Academic Mathematics Doctorate Holders with Federal Support (%)
1981	12.4	21.3
1983	12.9	30.1
1985[a]	13.6	21.5
1987	13.8	31.1
1989	14.5	33.5
1991	15.2	34.5
1993[a]	15.5	18.8
1995[a]	14.6	22.3
1997[a]	15.6	20.9
1999	15.2	29.1

[a] Not comparable to the other years and understates the degree of federal support by virtue of asking whether work performed during the week of April 15 was supported by the government. In other years, the question pertains to work conducted over the course of a year.

SOURCE: Adapted from NSB (2004), Appendix Tables 5-26 and 5-32.

TABLE B-4 Number and Percentage of Full-Time Graduate Students in Mathematics and Statistics at Doctorate-Granting Institutions in the United States, by Gender, Race, and Citizenship, 1980-2006

Year	Total (no.)	Female (no.)	Female (%)	U.S. Citizens and Permanent Residents (no.)	U.S. Citizens and Permanent Residents (%)	Under-represented Minorities (no.)	Under-represented Minorities (%)
1980	9,543	2,209	23	NA	NA	NA	NA
1981	9,853	2,426	25	NA	NA	NA	NA
1982	10,421	2,647	25	6,626	64	345	5
1983	10,593	2,776	26	6,431	61	365	6
1984	10,812	2,802	26	6,374	59	326	5
1985	11,318	3,016	27	6,602	58	346	5
1986	11,911	3,216	27	6,865	58	393	6
1987	12,539	3,367	27	7,155	57	445	6
1988	13,014	3,523	27	7,341	56	421	6
1989	13,208	3,775	29	7,329	55	461	6
1990	13,416	3,886	29	7,630	57	501	7
1991	13,822	4,057	29	8,053	58	491	6
1992	14,248	4,271	30	8,599	60	551	6
1993	14,089	4,268	30	8,693	62	633	7
1994	13,741	4,214	31	8,458	62	607	7
1995	12,984	4,030	31	7,927	61	649	8
1996	12,562	4,005	32	7,552	60	623	8
1997	11,772	3,810	32	6,975	59	617	9
1998	11,308	3,741	33	6,730	60	586	9
1999	11,388	3,952	35	6,269	55	588	9
2000	11,382	3,907	34	6,062	53	578	10
2001	12,040	4,198	35	6,301	52	616	10
2002	13,149	4,660	35	6,958	53	646	9
2003	13,988	4,869	35	7,407	53	692	9
2004	14,357	4,922	34	7,774	54	695	9
2005	14,652	4,909	34	8,012	55	732	9
2006	14,995	5,086	34	8,271	55	785	9

NOTE: NA, not available. There is no "unknown" for citizenship and gender. Underrepresented minorities include black, non-Hispanic; American Indian or Alaska Native; and Hispanic. Race/ethnicity data include other/unknown in the denominator. Race/ethnicity is only known for U.S. citizens/permanent residents.

SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://webcaspar.nsf.gov.

TABLE B-5 Degrees Awarded in Mathematical Sciences in the United States, 1980-2006, by Degree Level

Year	Bachelor's	Master's	Doctorate
1980	11,473	2,868	744
1981	11,173	2,569	728
1982	11,708	2,731	720
1983	12,662	2,856	701
1984	13,511	2,770	698
1985	15,389	2,903	688
1986	16,531	3,184	729
1987	16,515	3,327	739
1988	15,981	3,434	749
1989	15,314	3,430	859
1990	14,674	3,684	892
1991	14,784	3,632	1,038
1992	14,931	3,665	1,058
1993	14,853	3,751	1,146
1994	14,632	3,804	1,118
1995	13,851	3,932	1,190
1996	13,076	3,742	1,122
1997	12,723	3,599	1,123
1998	12,094	3,525	1,177
1999	NA	NA	1,083
2000	11,735	3,295	1,050
2001	11,455	3,280	1,010
2002	12,273	3,408	920
2003	12,882	3,706	993
2004	13,755	4,297	1,076
2005	14,840	4,598	1,205
2006	15,311	4,896	1,327

NOTE: NA, not available; detailed national data were not released by the National Center for Education Statistics for the academic year ending in 1999.
SOURCE: Adapted from NSF, Division of Science Resources Statistics (2008), Table 35.

TABLE B-6 Number and Percentage of Mathematics and Statistics Doctorates in the United States, by Gender, Race, and Citizenship, 1980-2006

Year	Doctorates (no.)	Female (no.)	Female (%)	U.S. Citizens and Permanent Residents (no.)	U.S. Citizens and Permanent Residents (%)	Under-represented Minorities (no.)	Under-represented Minorities (%)
1980	744	95	13	583	81	30	5
1981	728	112	15	525	74	44	8
1982	720	96	13	499	72	37	7
1983	701	113	16	459	69	31	7
1984	698	115	16	444	65	49	11
1985	688	106	15	419	64	42	10
1986	729	121	17	402	59	52	13
1987	739	125	17	396	57	52	13
1988	749	121	16	386	56	38	10
1989	859	155	18	428	55	43	10
1990	892	158	18	423	50	45	11
1991	1,038	199	19	517	50	57	11
1992	1,058	205	20	508	50	53	10
1993	1,146	264	23	590	53	59	10
1994	1,118	236	21	657	59	63	10
1995	1,190	265	22	771	67	52	7
1996	1,122	231	21	648	59	45	7
1997	1,123	263	24	629	59	58	9
1998	1,177	297	25	673	60	79	12
1999	1,080	276	26	604	58	55	9
2000	1,050	259	25	574	56	58	10
2001	1,009	275	27	528	55	63	12
2002	917	265	29	443	50	64	14
2003	992	264	27	517	54	72	14
2004	1,074	304	28	509	49	83	16
2005	1,197	324	27	538	47	94	17
2006	1,320	393	30	613	48	90	15

NOTE: The percentage female is the number of females divided by the number of females plus the number of males. In some cases gender was unknown. The same is true for citizenship. Underrepresented minorities include black, non-Hispanic; American Indian or Alaska Native; and Hispanic. The percentage of underrepresented minorities is divided by total doctorates, which include some people for whom race/ethnicity is "other/unknown."
SOURCE: National Science Foundation, "Survey of Earned Doctorates/Doctorate Records File," accessed via WebCASPAR, http://webcasper.nsf.gov.

TABLE B-7 Number and Percentage of Doctorates in Mathematical Sciences in the United States Received by U.S. Citizens, 1980-1981 to 2007-2008

Year	Total Doctorates by U.S. Institutions	Total U.S. Citizen Doctoral Recipients	Percent
1980-1981	839	567	68
1981-1982	798	519	65
1982-1983	744	455	61
1983-1984	738	433	59
1984-1985	726	396	55
1985-1986	755	386	51
1986-1987	739	362	49
1987-1988	798	363	45
1988-1989	884	411	46
1989-1990	929	401	43
1990-1991	1,061	461	43
1991-1992	1,016	430	42
1992-1993	1,197	526	44
1993-1994	1,059	469	44
1994-1995	1,207	567	47
1995-1996	1,150	493	43
1996-1997	1,158	516	45
1997-1998[a]	1,216	586	48
1998-1999	1,133	554	49
1999-1900	1,119	537	48
2000-2001	1,008	494	49
2001-2002	948	NA	NA
2002-2003	1,017	489	48
2003-2004	1,041	441	42
2004-2005	1,116	433	39
2005-2006	1,245	522	42
2006-2007	1,157	500	43
2007-2008	1,235	540	44

[a] Prior to this year, the counts include new doctoral recipients from Group Vb (departments granting doctoral degrees in operations research/management science). The figures for 1997-1998 excluding Vb are 1,163 new doctoral recipients, of which 565 are U.S. citizens. In addition, prior to 1982-1983, the counts include new doctoral recipients from computer science departments.

SOURCE: Davis (1999), Phipps et al. (2008a).

TABLE B-8 Number and Percentage of Doctorates in Mathematical Sciences in the United States, 1980-1981 to 1998-1999, by Gender

Year	Total U.S. Citizen Doctoral Recipients (no.)	Male (no.)	Female (no.)	Percent Female (%)
1980-1981	567	465	102	18
1981-1982	519	431	88	17
1982-1983	455	366	89	20
1983-1984	433	346	87	20
1984-1985	396	315	81	20
1985-1986	386	304	82	21
1986-1987	362	289	73	20
1987-1988	363	287	76	21
1988-1989	411	313	98	24
1989-1990	401	312	89	22
1990-1991	461	349	112	24
1991-1992	430	327	103	24
1992-1993	526	381	145	28
1993-1994	469	345	124	26
1994-1995	567	426	141	25
1995-1996	493	377	116	24
1996-1997	516	368	148	29
1997-1998[a]	586	423	163	28
1998-1999	554	367	187	34

[a] Prior to this year, the counts include new doctoral recipients from Group Vb (departments granting doctoral degrees in operations research/management science). The figures for 1997-1998 excluding Vb are 565 U.S.-citizen new doctoral recipients, of which 409 are male and 156 are female. In addition, prior to 1982-1983, the counts include new doctoral recipients from computer science departments.

SOURCE: Davis (1999), Phipps et al. (2008a).

TABLE B-9 Number of Postdoctoral Fellows in Mathematics and Statistics at Doctorate-Granting Institutions in the United States, 1980-2006

Year	Postdoctoral Fellows (no.)
1980	162
1981	113
1982	194
1983	170
1984	203
1985	226
1986	201
1987	229
1988	284
1989	224
1990	248
1991	206
1992	201
1993	224
1994	239
1995	262
1996	326
1997	307
1998	279
1999	351
2000	385
2001	353
2002	393
2003	449
2004	468
2005	496
2006	574

SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://webcaspar.nsr.gov.

Appendix C

Data Requested from Departments

This appendix presents the questionnaires sent by the Committee to Evaluate the NSF's Vertically Integrated Grants for Research and Education (VIGRE) to all PhD-granting departments of mathematics, applied mathematics, and statistics in the United States. A questionnaire was sent to chairs of departments that had received VIGRE awards and to chairs of departments that had never received a VIGRE award. For additional details, see the subsection entitled "Information Collected by the Committee" in Chapter 1 of the report.

Questions to VIGRE awardees

1. Please enter the name of your department and institution. (This information is only for record-keeping purposes and will not be released.)

Department Name ____

Institution Name ____

2. After the initial 5-year VIGRE award, did you apply for a renewal?

- ◯ Yes
- ◯ No

1. If you did apply for a renewal, was your department successful?

- ◯ Yes
- ◯ No

If not, what do you think happened?

____

1. If no, why not (check all that apply)?

- ☐ Administering the grant was too large a burden
- ☐ Implementing the VIGRE-funded activities was too much burden on the faculty
- ☐ We thought our chances of renewal were too small to warrant the effort required to submit a proposal
- ☐ The PI (or other VIGRE people) left the institution
- ☐ VIGRE funding was insufficient to cover costs
- ☐ Given other funding sources and needs, we decided that VIGRE funding was not necessary
- ☐ Insufficient student interest in the VIGRE program to warrant continuation
- ☐ VIGRE requirements would have required us to undertake programmatic changes that were excessive

Other reason (please specify)

____

1. Thinking about your department's activities from just before the award started until the end of the award period, what trends have you seen in the following activities?

	Increased	About the same	Decreased	Not Applicable
Mentoring of students by postdocs or graduates	☐	☐	☐	☐
Collaboration with departments outside math/statistics in teaching	☐	☐	☐	☐
Collaboration with departments outside math/statistics in research	☐	☐	☐	☐
Group activities that include undergraduates, graduates, postdocs and faculty	☐	☐	☐	☐
Outreach to K-12 students	☐	☐	☐	☐
Outreach to K-12 teachers	☐	☐	☐	☐
Summer camps in mathematics/statistics	☐	☐	☐	☐
Postdoctoral fellowships	☐	☐	☐	☐
Graduate Traineeships	☐	☐	☐	☐
Undergraduate research experiences	☐	☐	☐	☐

2. If your award has ended, do you plan to continue all the VIGRE-funded activities?

◯ Yes

◯ No

If no, what activities won't be maintained?

3. Over the past 10 years, what trends, if any, have you seen in the number, quality, or diversity of enrolled undergraduate or graduate majors or postdocs in your department?

continues

4. To what extent do you think the VIGRE award contributed to the trends you noted in the previous question?

5. Do you have any comments about the VIGRE program that you would like to share with us?

6. Time permitting, the committee might like to follow-up with a sample of departments to get a deeper understanding of departments' experiences with this program. May we contact you to follow up? (No comments will be attributed to any individual, department, or institution.) If you are interested, please be so kind as to tell us a convenient way to contact you.

Questionnaire to departments that have never received a VIGRE award

1. Departmental Survey on VIGRE

1. Please enter the name of your department and institution. (This information is only for record-keeping purposes and will not be released.)

Department Name ______

Institution Name ______

2. Has your department ever submitted a proposal to the NSF VIGRE program?

- ○ No
- ○ Once
- ○ More than once

2.

1. Has the process of applying for a VIGRE award led to any changes in the department?

- ○ Yes
- ○ No

If Yes (please specify)

______

3.

1. Why has your department never submitted a proposal (check all that apply)?

- ☐ There was insufficient interest within the department to submit an application
- ☐ Our department already undertakes the activities that would be pursued via a VIGRE award
- ☐ The application process is too burdensome
- ☐ The conditions of the award are too burdensome
- ☐ Did not expect to receive an award
- ☐ A VIGRE award is not the preferred way for our department to advance mathematics/statistics

Other (please specify)

______

4.

1. Does you department currently offer any of the following activities (check all that apply)?

- [ ] Mentoring by faculty
- [ ] Mentoring of students by postdocs or graduates
- [ ] Collaboration with other departments outside math/statistics in teaching
- [ ] Collaboration with other departments outside math/statistics in research
- [ ] Group activities that include undergraduates, graduates, postdocs, and faculty
- [ ] Outreach to K-12 students
- [ ] Outreach to K-12 teachers
- [ ] Summer camps in mathematics/statistics
- [ ] Postdoctoral fellowships
- [ ] Graduate traineeships
- [ ] Undergraduate research experiences

Other (please specify)

2. Over the past 10 years, what trends, if any, have you seen in the number, quality, or diversity of enrolled undergraduate or graduate majors or postdocs?

3. Do you have any comments about the VIGRE program that you would like to share with us?

4. Time permitting, the committee might like to follow-up with a sample of departments to get a deeper understanding of departments' experiences with this program. May we contact you to follow up? (No comments will be attributed to any individual, department, or institution.) If you are interested, please be so kind as to tell us a convenient way to contact you.

Appendix D

The Mathematical Sciences Since 1998

The nature of higher education in the mathematical sciences is not static. Identifying the impact of the National Science Foundations (NSF's) Grants for the Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE) program is made more difficult because this nature continued to evolve during the lifetime of the VIGRE program. This appendix looks briefly at how the field has changed since the VIGRE program began.

Federal funding in mathematics, both by the National Science Foundation and by federal agencies in general, continued to grow from 1999 through 2005, the most recent year for which data are available. The NSF's share of federal funding to academic institutions has oscillated, as shown in Table D-1, but it remains the dominant source of funding for the mathematical sciences.

Although the overall amount of federal funding has grown, NSF's fraction of the total federal obligations to institutions is similar during the VIGRE period and the period prior to the program (see Figure D-1). Note that the NSF's responsibility for graduate student support has gone up from the pre-VIGRE period to the VIGRE period (VIGRE was established in 1998), as shown in the figure.

The average percentage of support provided by NSF to full-time graduate students in mathematics and statistics at doctorate-granting institutions from 1980 to 1998 was 34 percent of all federal funding. During the 1999 to 2006 period it was 55 percent.

Considering the mechanisms of support that NSF uses with respect to graduate students, there is some growing reliance on teaching assistantships. Comparing Table D-2 with Table 2-3 in Chapter 2, one sees that the percentage of graduate students supported by NSF research assistantships has declined somewhat in the years since the establishment of the VIGRE program, while the fraction of students supported by NSF-sponsored teaching assistantships has increased. Of course, most teaching assistantships are provided by universities, so looking at NSF support gives only a partial picture.

Turning from funding to an assessment of the number of students in mathematics and statistics, the committee is pleased to see that the number of full-time graduate students has grown during the VIGRE period, after falling somewhat from 1992 to 1998, and that the number of students is now higher than at any time since 1980. Figure D-2 shows the reversal.

TABLE D-1 National Science Foundation (NSF) Share of Federal Funding to Universities and Colleges for Research in the Mathematical Sciences, 1999-2005 (in thousands of dollars)

Year	NSF Share	Total	Percent
1999	84,975	131,264	65
2000	99,625	211,490	47
2001	105,251	169,702	62
2002	142,298	200,758	71
2003	162,546	230,156	71
2004	184,037	322,989	57
2005	185,390	365,756	51

NOTE: Data are collected by NSF from NSF's "Survey of Federal Funds for Research and Development." Data contained in the survey are provided by agencies.
SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://webcaspar.nsf.gov.

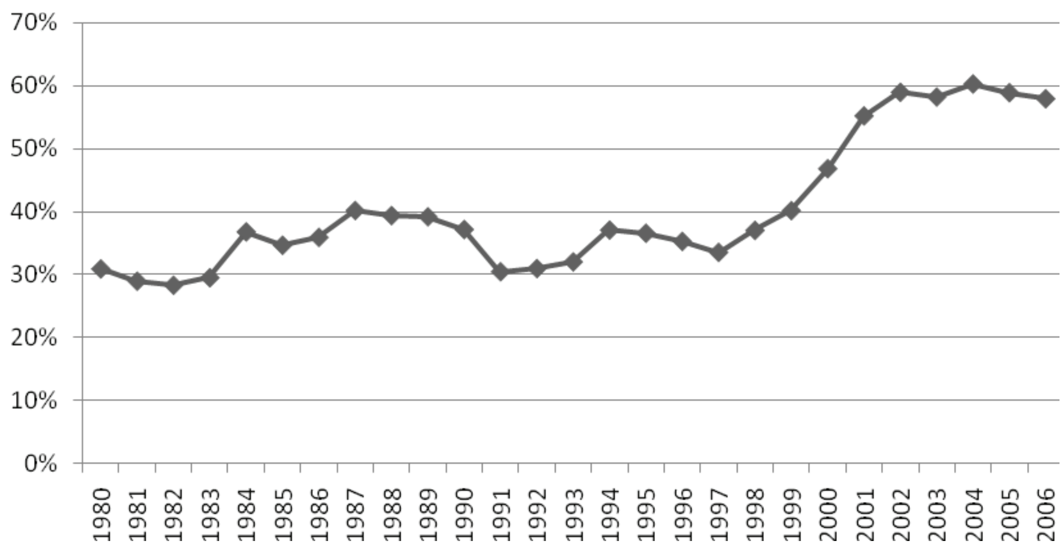

FIGURE D-1 National Science Foundation support to full-time graduate students in mathematics and statistics at doctorate-granting institutions as a percentage of federal support, 1980-2006. SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://webcaspar.nsf.gov.

Data from the American Mathematical Society also show a rise in graduate students over the more recent period, as shown in Figure D-3.

As Figure D-4 shows, the percentage of graduate students in mathematics and statistics who are U.S. citizens or permanent residents has unfortunately not rebounded, although more and more graduate students fall into this category from 2000 to 2006. The percentage of female graduate students, which had been rising between 1980 and 1998, appears to have leveled off. The same is true for underrepresented minorities. This is of concern, and additional research could be directed toward a deeper understanding of changes in the composition of the graduate student body in the mathematical sciences.

TABLE D-2 Percentage of National Science Foundation Support for Full-Time Graduate Students in Mathematics and Statistics, 1999-2006, by Mechanism of Support

Year	Fellowships	Traineeships	Research Assistantships	Teaching Assistantships	Other Mechanisms of Support
1999	24	4	68	2	2
2000	37	6	54	3	1
2001	37	5	54	4	0
2002	33	4	59	3	1
2003	30	3	62	5	1
2004	26	4	65	5	0
2005	26	1	63	9	1
2006	28	3	60	8	1

SOURCE: National Science Foundation-National Institutes of Health, “Survey of Graduate Students and Postdoctorates in S&E,” accessed via WebCASPAR, http://webcaspar.nsf.gov.

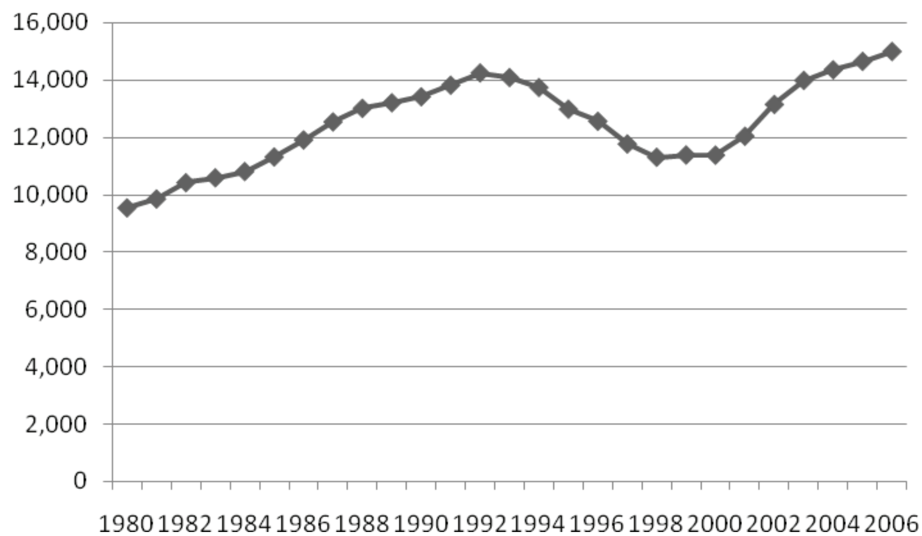

FIGURE D-2 Full-time graduate students in mathematics and statistics at doctorate-granting institutions in the United States, 1980-2006. SOURCE: National Science Foundation-National Institutes of Health, “Survey of Graduate Students and Postdoctorates in S&E,” accessed via WebCASPAR, http://webcaspar.nsf.gov.

AMS data show similar results. The percentage of U.S. citizens among total full-time graduate students in mathematics dropped from 55 percent in 1998 to 49 percent in 2001, then rose to 56 percent in 2007. The percentage of females has remained flat, ranging between 29 and 32 percent between 1998 and 2007. The percentage of underrepresented minorities has also remained flat—at about 10 percent—from 2003 to 2007 (Phipps et al., 2008b).

Digging a bit deeper into data on graduate study, the committee notes that the median time to degree seems not to have changed much during the first 5 years of the VIGRE program, as noted in Table D-3.

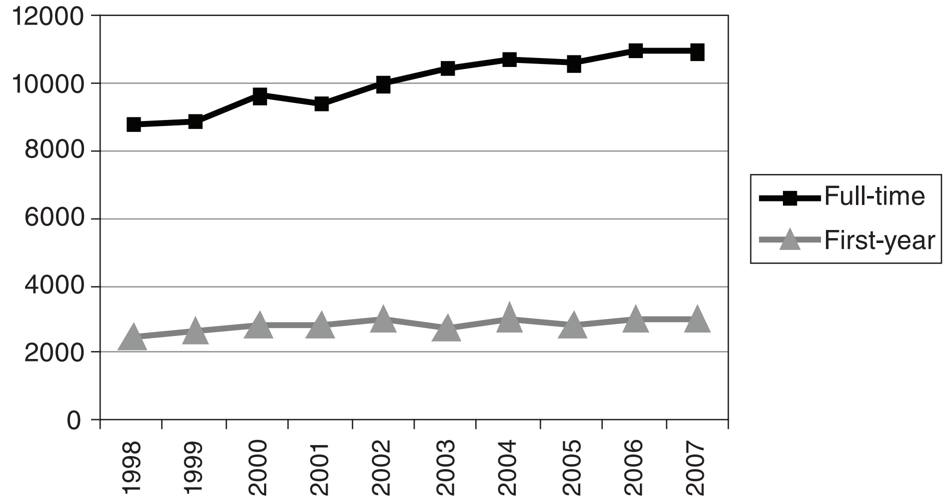

FIGURE D-3 Full-time and first-year graduate students in Groups I, II, III, and Va (departments granting degrees in applied mathematics), fall 1998 to fall 2007. SOURCE: Phipps et al. (2008b).

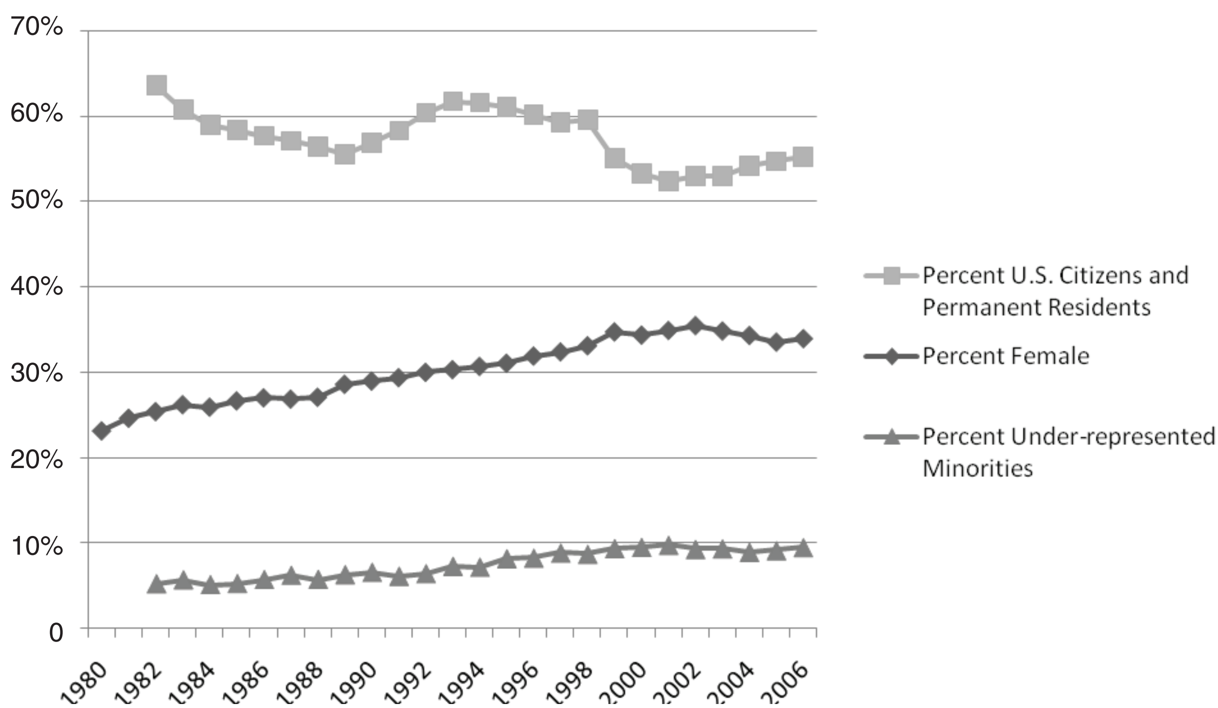

FIGURE D-4 Percentage of full-time graduate students in mathematics and statistics at doctorate-granting institutions in the United States who are U.S. citizens/permanent residents, underrepresented minorities, or female, 1980-2006. SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://webcaspar.nsf.gov.

TABLE D-3 Median Years Elapsed from Bachelor's to Doctoral Degree in Mathematics, 1999-2003

Year	Median Years
1999	8.0
2000	7.6
2001	8.0
2002	7.6
2003	7.7

SOURCE: Adapted from NSB (2006), Appendix Table 2-34.

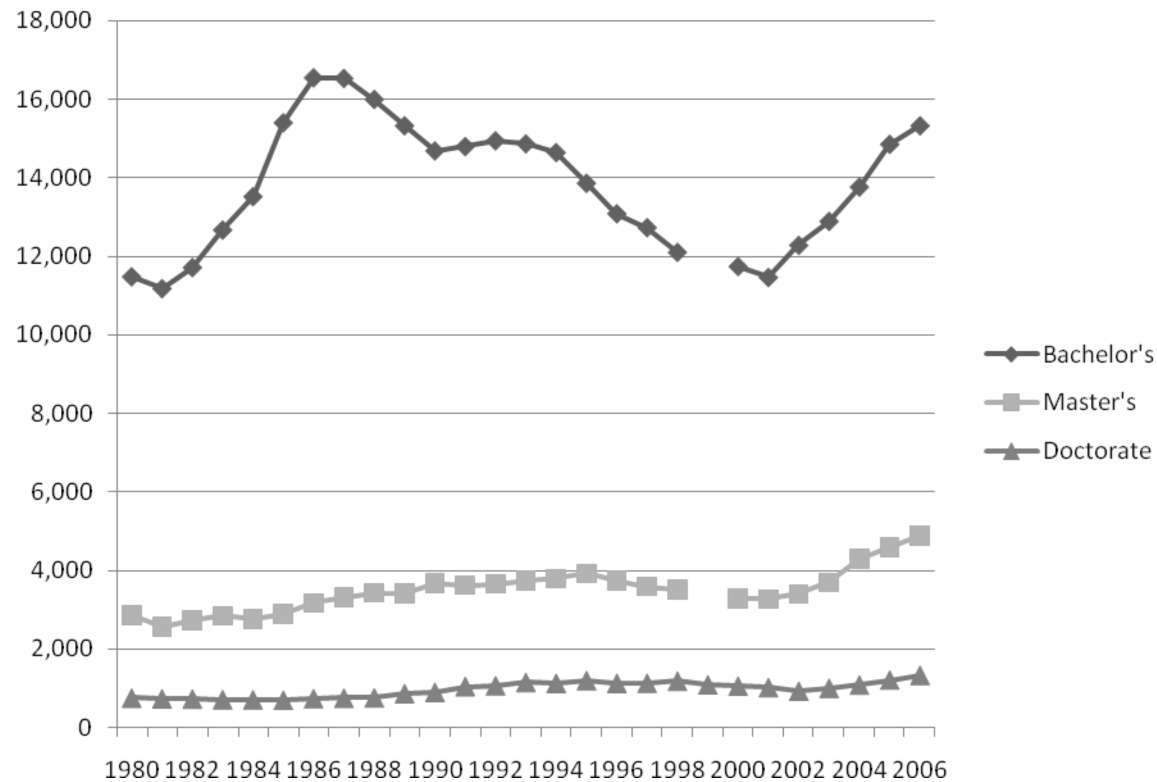

FIGURE D-5 Number of degrees awarded in the mathematical sciences in the United States, 1980-2006, by degree level. SOURCE: Adapted from NSF, Division of Science Resources Statistics (2008), Table 35.

Figure D-5 looks at degree production in the mathematical sciences. The falling number of bachelor's degrees awarded from 1980 to 1998 has been reversed since 2001 and is almost back to the peak of degrees awarded in the mid-1980s. Likewise, the number of master's degrees and PhDs awarded has also grown during the VIGRE period.

Turning to doctorates, the committee notes that the percentage of doctorates awarded to U.S. citizens and permanent residents, although rising during the early 1990s, is declining overall, as shown in Figure D-6. By contrast, the percentage of female and underrepresented minorities who received doctorates has generally been growing.

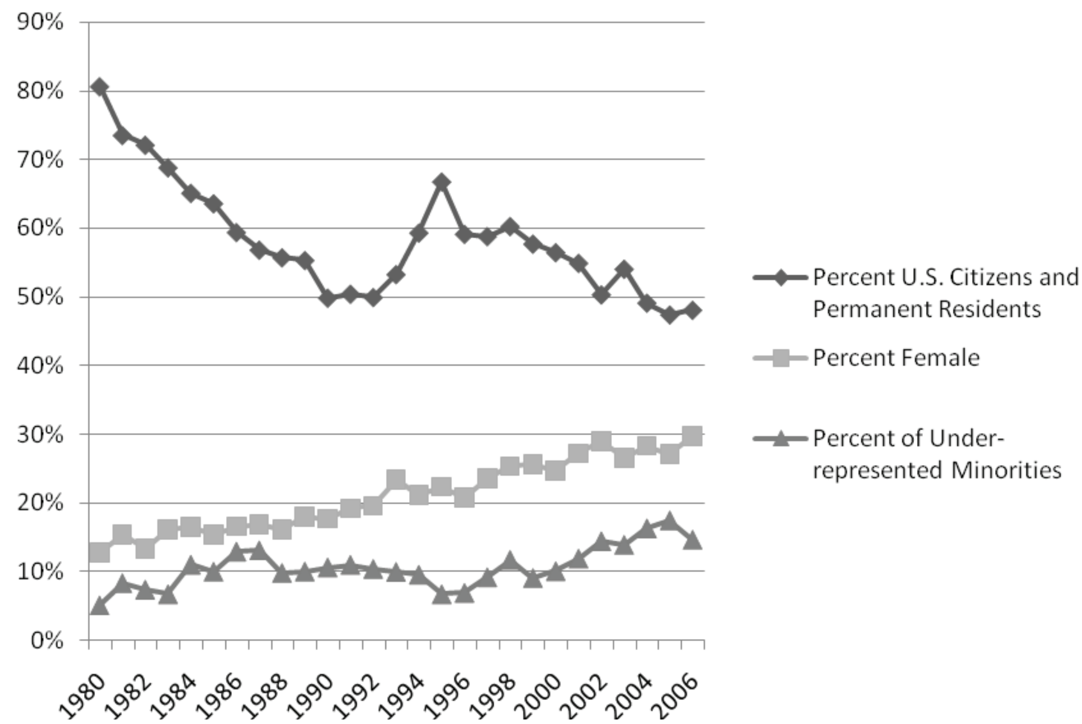

FIGURE D-6 Percentage of mathematics and statistics doctorates in the United States, by gender, race, and citizenship, 1980-2006. NOTE: The percentage female is the number of females divided by the number of females plus the number of males. In some cases gender was unknown. The same is true for citizenship. Underrepresented minorities include black, non-Hispanic; American Indian or Alaska Native; and Hispanic. The percentage of underrepresented minorities is divided by total doctorates, which include some people for whom race/ethnicity is "other/unknown." SOURCE: National Science Foundation, "Survey of Earned Doctorates/Doctorate Records File," accessed via WebCASPAR, http://webcaspar.nsf.gov.

Looking at recent doctorates and where they were planning to go after receiving their doctorate, the committee sees similar trends during the VIGRE program (Table D-4) and the earlier period represented in Table 2-5 in Chapter 2. For all years, about one-third of new PhDs in mathematics planned to go directly into a postdoctoral appointment. (Because the total number of PhDs is rising, this translates into more postdoctorals.)

As might be expected given the goals of the VIGRE program, the number of postdoctoral fellows in mathematics and statistics has risen quite a bit since the VIGRE program started, as shown in Figure D-7.

Finally, the committee collected some information on VIGRE-like activities taking place in recent years in departments that did not receive a VIGRE award. Those data are presented in Table D-5.

All of the trends discussed above need to be considered as background or context when assessing the impact of the VIGRE program.

TABLE D-4 New Doctorate Recipients with Definite Commitments to Postdoctoral Study or Research, by Broad Field of Doctorate, 1999-2005

Field of Doctorate	1999	2000	2001	2002	2003	2004	2005
	Number						
Total recipients with commitments, all fields	25,975	26,711	26,889	25,984	26,167	26,280	27,383
Total planning postdoctoral study	7,090	6,978	7,109	7,195	7,784	8,210	8,786
Science and engineering, total	6,485	6,386	6,346	6,445	6,988	7,405	7,952
Mathematics	215	213	217	239	258	269	298
	Percentage						
Total planning postdoctoral study	27	26	26	28	30	31	32
Science and engineering, total	39	38	37	40	43	45	45
Mathematics	30	29	31	36	37	36	36

SOURCE: National Science Foundation, *Science and Engineering Doctorate Awards*, Arlington, Va., various years.

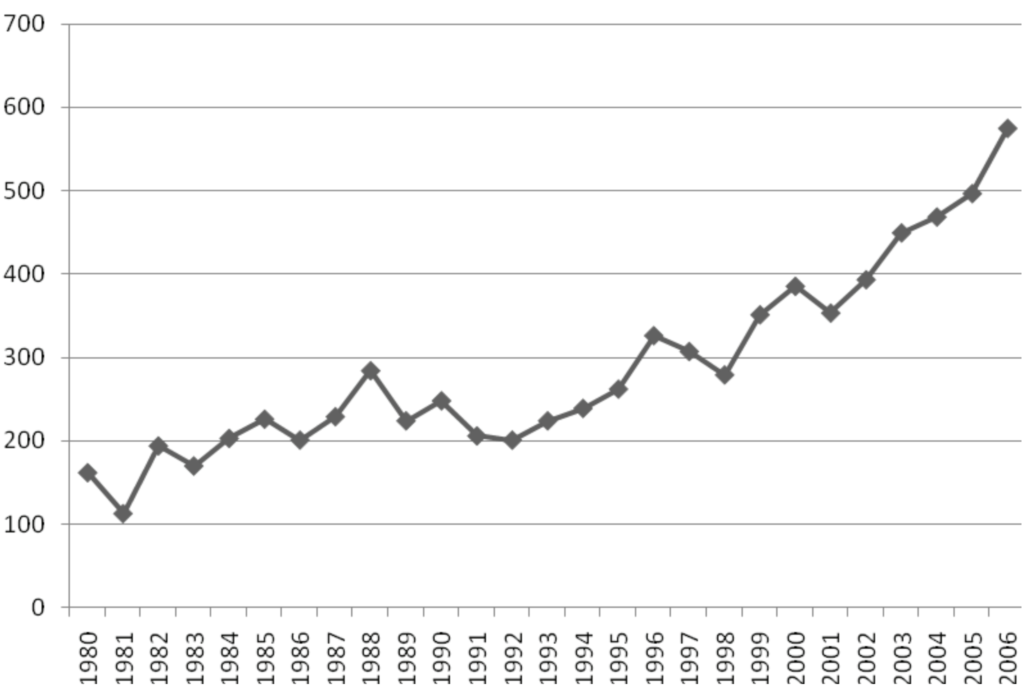

FIGURE D-7 Number of postdoctoral fellows in mathematics and statistics at doctorate-granting institutions in the United States, 1980-2006. SOURCE: National Science Foundation-National Institutes of Health, "Survey of Graduate Students and Postdoctorates in S&E," accessed via WebCASPAR, http://webcaspar.nsf.gov.

TABLE D-5 "VIGRE-like" Activities of Departments That Did Not Receive a VIGRE Award

Topic	Number
Outreach to K-12 students	40
Outreach to K-12 teachers	53
Summer camps in mathematics/statistics	30
Postdoctoral fellowships	44
Graduate traineeships	57
Undergraduate research experiences	71
Mentoring by faculty	95
Mentoring of students by postdoctorals or graduates	31
Teaching collaborations with other departments outside of mathematics or statistics	67
Research collaboration with other departments outside of mathematics or statistics	92
Group activities that include undergraduates, graduates, postdoctorals, and faculty	50
Other activities	11

SOURCE: Committee request for information. Total number of departments responding was 122.

Appendix E

Presentations to the Committee

JUNE 27, 2007
KECK CENTER OF THE NATIONAL ACADEMIES,
WASHINGTON, D.C.

Program Evaluation
Eric W. Welch, University of Illinois at Chicago; *Committee Member*

VIGRE Beginnings
Don Lewis, University of Michigan (retired)

Evolution and Current Status of VIGRE
Henry A. Warchall, National Science Foundation

JUNE 28, 2007
KECK CENTER OF THE NATIONAL ACADEMIES,
WASHINGTON, D.C.

VIGRE at the University of Chicago
J. Peter May, University of Chicago

VIGRE at Stony Brook
Alan C. Tucker, State University of New York, Stony Brook

OCTOBER 8, 2007
BECKMAN CENTER, IRVINE, CALIFORNIA

Increasing the Quantity and Quality of the Mathematical Sciences Workforce Through Vertical Integration and Cultural Change (discussion of forthcoming book)
Margaret Cozzens, Rutgers University

Discussion of VIGRE (through teleconference)
Calvin Moore, University of California, Berkeley
William Rundell, National Science Foundation

Roundtable of VIGRE Sites
Jesús de Loera, Alexander Woo, and Yvonne Lai, University of California, Davis
Deborah Nolan, University of California, Berkeley
Robert Green, Thomas Ward, and Craig Citro, University of California, Los Angeles

OCTOBER 9, 2007
BECKMAN CENTER, IRVINE, CALIFORNIA

Data Availability
John Sislin, *NRC staff*

Appendix F

Acronyms

ADVANCE	Advancement of Women in Academic Science and Engineering Careers
AFOSR	Air Force Office of Scientific Research
AMS	American Mathematical Society
ARO	Army Research Office
ASA	American Statistical Association
COSEPUP	Committee on Science, Engineering, and Public Policy
DARPA	Defense Advanced Research Projects Agency
DHHS	Department of Health and Human Services
DMS	Division of Mathematical Sciences
DMS/NSF	Division of Mathematical Sciences/National Science Foundation
DOD	Department of Defense
DOE	Department of Energy
EMSW21	Enhancing the Mathematical Sciences Workforce in the 21st Century
GIG	Group Infrastructure Grant
GSS	Graduate Students and Postdoctorates in Science and Engineering
IPEDS	Integrated Postsecondary Education Data System
MAA	Mathematical Association of America
MCTP	Mentoring through Critical Transition Points
MPS	Mathematics and Physical Sciences Directorate

NASA	National Aeronautics and Space Administration
NIH	National Institutes of Health
NRC	National Research Council
NSA	National Security Agency
NSF	National Science Foundation
NSF R&D	National Science Foundation Research and Development
ONR	Office of Naval Research
OSTP	Office of Science and Technology Policy
PAID	Partnerships for Adaptation, Implementation, and Dissemination
PI	principal investigator
R&D	research and development
REU	Research Experience for Undergraduates
RFG	Research Focus Group
RFP	request for proposals
RIT	Research Interaction Team
RTG	Research Training Group
SDR	Survey of Doctoral Recipients
S&E	science and engineering
SED	Survey of Earned Doctorates
SEP	Special Emphasis Panel
SHE	science, engineering, or health
SIAM	Society for Industrial and Applied Mathematics
TA	teaching assistantship
USDA	U.S. Department of Agriculture
VIGRE	Grants for Vertical Integration of Research and Education in the Mathematical Sciences