The National Science Foundation

Strategic Framework for Investments in Graduate Education

FY 2016-FY 2020

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About the National Science Foundation

The National Science Foundation (NSF) is an independent Federal agency that supports fundamental research at the frontiers of knowledge, across all fields of science and engineering (S&E) and S&E education. With an annual budget of about $7.3 billion (fiscal year 2015), NSF funds approximately 24 percent of all the federally supported fundamental research conducted by America's colleges and universities.

NSF investments in graduate education promote the continued advancement of knowledge in science and engineering (S&E) disciplines, stimulate innovation in the research enterprise, and help build a diverse and high-performing workforce for the Nation. At NSF, about 40,000 graduate students are supported annually at a level of about $1 billion.

The NSF Act of 1950 (Public Law 81-507) sets forth the mission: "*to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes.*"

Executive Summary

Graduate education plays a central role in advancing the Nation's science and engineering research enterprise. It is also increasingly the means by which the Nation develops a diverse and highly technical STEM professional workforce. The view that graduate education in STEM disciplines is an essential asset for achieving national priorities is one of the foundational principles for the *Federal STEM Education 5-Year Strategic Plan:*

> "Advances in science, technology, engineering, and mathematics (STEM) have long been central to our Nation's ability to manufacture better and smarter products, improve health care, develop cleaner and more efficient domestic energy sources, preserve the environment, safeguard national security, and grow the economy. For the United States to maintain its preeminent position in the world it will be essential that the Nation continues to lead in STEM, but evidence indicates that current educational pathways are not leading to a sufficiently large and well-trained STEM workforce to achieve this goal." (The Committee on STEM Education, National Science and Technology Council, 2013, p. vi)

The primary purpose of this Strategic Framework for Investments in Graduate Education is to state the Foundation's goals in supporting graduate education, and to formulate a set of strategic objectives that describe the ways that NSF plans to meet those goals.

The first section of this framework describes the rationale for its creation and outlines the coordination strategy for its development and implementation. The next section discusses the importance of graduate STEM education to the Nation's scientific discovery and innovation. It

presents the need to better prepare students for today's jobs and those of the future, and summarizes the primary challenges facing graduate education.

The framework then presents three goals that serve as the foundation of the NSF investments in graduate education, along with a set of strategic objectives for these investments.

The goals of NSF investments in graduate education:

- **Advance Science and Engineering (S&E) Research:** Support graduate students and graduate education to enable long-term contributions of new knowledge at the frontiers of science and engineering.
- **Broaden Participation to Promote Excellence in Research and Build the Next Generation STEM Workforce:** Recruit graduate students from a variety of geographic, demographic, social, and educational backgrounds to promote the advancement of science and a highly qualified professional workforce.
- **Build Effective Models of Graduate Education and Workforce Development:** Support the development and use of innovative models and evidence based approaches in graduate education, including education and research about promising practices and program effectiveness.

The following five strategic objectives demonstrate how the Foundation will advance these goals over the next five years.

- **Advance Science and Engineering (S&E) Research**
  - ***Objective 1: Prepare the Discoverers of Tomorrow***
- **Broaden Participation to Promote Excellence in Research and Build the Next Generation STEM Workforce**
  - ***Objective 1: Invest in Broad Research and Education Experiences***
  - ***Objective 2: Support Research on Cultivating Diverse and Effective Science Teams***
- **Build Effective Models of Graduate Education and Workforce Development**
  - ***Objective 1: Convene a National Dialogue on S&E Graduate Education***
  - ***Objective 2: Enhance What NSF Knows About Investments in S&E Graduate Education***

The implementation of these objectives involves coordination across NSF and with its stakeholders. The primary coordinating activity across NSF is an Agency Priority Goal on Graduate Student Preparedness[1], which is included in the NSF FY 2017 Performance Plan.

[1] https://www.performance.gov/content/improve-stem-graduate-student-preparedness#overview

Background and Context for this Strategic Framework

The development of this strategic framework for investments in graduate education included input from several stakeholder communities. In July 2014, the Foundation convened the Graduate Education Strategic Planning Committee to review NSF investments in graduate education and training. The Committee included representatives from every NSF Directorate as well as liaisons with the National Center for Science and Engineering Statistics and the NSF Office of Budget, Finance, and Award Management. Over the course of a year, the Committee surveyed the state of graduate education in the United States, analyzed the portfolio of NSF programs supporting graduate education, and developed a report to guide NSF's future investment in graduate education and training.

This strategic framework follows from the work of the Committee. It supports the goals of the *NSF Strategic Plan for 2014-2018* (National Science Foundation, 2014), and is part of a coordinated approach to federal investments in graduate education. The rest of this section describes some of the relevant federal context that has guided the development of this framework.

The NSTC Committee on STEM Education (CoSTEM) chartered the Federal Coordination in STEM Education (FC-STEM) Task Force to develop the *Federal STEM Education 5-Year Strategic Plan* (The Committee on STEM Education, National Science and Technology Council, 2013). The intent of that plan is to establish a coordinated, coherent portfolio of STEM education investments across the Federal Government so that efforts and assets are deployed effectively and efficiently. NSF is a participating agency in FC-STEM, and is coordinating with the partnering agencies on the task force to advance the goals of its strategic plan.

The FC-STEM task force established an Interagency Working Group on Graduate STEM Education to advise and assist the FC-STEM subcommittee on the implementation of the *Federal STEM Education 5-Year Strategic Plan*. The working group, which is co-chaired by the National Science Foundation and the Department of Health and Human Services, is charged with developing common objectives and joint milestones for the Strategic Plan's sub-goal to *design graduate education for tomorrow's STEM workforce.*

Among its accomplishments, the interagency working group supported the development of NSF's Graduate Research Internship Program (GRIP), a component of the NSF Graduate Research Fellowship Program (GRFP) as part of its charge to promote collaboration and coherence across the graduate education portfolio. Through this program NSF Fellows enhance their professional development by engaging in mission related research with partnering federal agencies. The interagency working group also collaborated in the creation of a web portal for internship and fellowship opportunities in science[2] across the federal government. This portal is a comprehensive resource for STEM graduate students seeking research opportunities in federal agencies.

[2] http://stemgradstudents.science.gov/

Introduction

The system of graduate education in the United States is highly effective in providing the advanced training for graduate students that is foundational to the S&E research enterprise. The Nation's strategic investment in graduate education has been an important contributor to the country's remarkable record of success in science and innovation.

This view, that graduate education is a national asset and part of the Nation's strategic investment, is also articulated in the report from the Council of Graduate Schools and the Educational Testing Service, *The Path Forward: The Future of Graduate Education in the United States* (Council of Graduate Schools and Educational Testing Service, 2010, p. iv)*:*

> "The United States' system of graduate education is a strategic national asset. Like all valuable assets, it must be attended to and nurtured in order to remain viable and strong. Other countries and regions of the world have recognized the value of graduate education as a vital component of economic development and are making investments accordingly."

NSF seeks to develop the Nation's innovation potential by seamlessly integrating the education of future scientists, engineers, and educators into the broad portfolio of research it supports. This investment strategy generates not only groundbreaking S&E discoveries, but it also equips the future S&E workforce with the knowledge and experience to apply the most advanced concepts and technology to meet national challenges.

The goals of graduate education have been examined in recent reports by the Carnegie Foundation for the Advancement of Teaching, the Council of Graduate Schools, the National Research Council, and professional societies, e.g., the report of the American Chemical Society, *Advancing Graduate Education in the Chemical Sciences* (The American Chemical Society, 2013). These reports endorse our Nation's commitment to preparing graduate students to make long-term contributions to the S&E research enterprise, while also making a compelling case for continuous improvement in graduate education and the importance of broadening its objectives.

The National Academy of Sciences Report, *Reshaping the Graduate Education of Scientists and Engineers* (Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, 1995, p. 17), states "American graduate schools have done a superb job of preparing young scientists and engineers to become original researchers—to become the scientific and technical leaders of the nation. It is the purpose of this report to examine how well graduate school prepares students to integrate and disseminate their knowledge and apply it to the full range of present societal needs."

Several reports offer recommendations for graduate education to be responsive to national priorities and longstanding workforce and demographic trends. Two of the five priority investment areas in the *Federal STEM Education 5-Year Strategic Plan* directly align with these recommendations:

> *Better serve groups historically underrepresented in STEM fields.* Increase the number of underrepresented minorities that graduate college with STEM degrees in the next 10 years and improve women's participation in areas of STEM where they are significantly underrepresented.
>
> *Design graduate education for tomorrow's STEM workforce.* Provide graduate trained STEM professionals with basic and applied research expertise, options to acquire specialized skills in areas of national importance and mission agency's needs, and ancillary skills needed for success in a broad range of careers.

In *Envisioning the Future of Doctoral Education,* the Carnegie Foundation for the Advancement of Teaching proposed that the purpose of doctoral training is to create *stewards of the discipline*, a phrase that encompasses both the intellectual and ethical development of the student (The Carnegie Foundation for the Advancement of Teaching, 2006).

In a review of this and other reports on graduate education, the NSF Graduate Education Strategic Planning Committee noted the consistent message that training needs vary by discipline. The Committee affirmed that NSF investments in graduate education should afford the flexibility for each STEM discipline to accommodate its individual needs and goals.

The Committee summarized the primary issues facing graduate education:

- ***Broadening participation:*** While STEM graduate enrollment will continue to reflect trends in undergraduate education, the committee recommends greater emphasis on the enrollment and persistence of women and historically underrepresented minorities in all fields. It is important to note that the broadening participation challenges can vary greatly by discipline.
- ***Expanding skills through professional development opportunities:*** Given the changes in career opportunities and shifting skills needed for success in STEM professions, the reports recommend including professional development opportunities as part of graduate training. Opportunities to obtain transdisciplinary skills and experience would create a more resilient scientific workforce, and would help STEM graduates succeed after graduation.
- ***Leverage private and public partnerships to improve career outcomes:*** Increased collaboration among universities, private industry, and state and federal governments is critical in order to improve graduate student preparation for diverse career pathways outside of academia and tracking career outcomes. There is great variability across disciplines, with some sub-disciplines already successfully placing the majority of doctoral students into private sector positions, often following postdoctoral training. These reports go on to suggest that federal support of graduate education should include professional development opportunities that prepare students for a

range of careers, and for increased investment in partnerships with international institutions to address the global nature of the STEM enterprise.

- ***Setting a research agenda to understand funding models of graduate education:*** Currently, there is limited research on the effects of different support mechanisms for graduate education and training on student preparedness for future careers. For this reason, it would be valuable to identify what constitutes core components in fellowships, research assistantships, traineeships, internships, and other models, within and across disciplines.
- ***Engaging institutions and faculty to support evidence-based practices:*** Conversations with academic institutions are needed to learn more about effective practices in graduate education, and the best ways to develop and implement evidence-based practices for sustainable change, potentially around data collection and metrics.

The calls for increasing collaboration and strengthening the evidence base align with the coordination objectives of the *Federal STEM Education 5-Year Strategic Plan:*

> *Build new models for leveraging assets and expertise.* Implement a concept of lead and collaborating agencies to leverage capabilities across agencies to ensure the most significant impact of Federal STEM education investments.
>
> *Build and use evidence based approaches.* Conduct rigorous STEM education research and evaluation to build evidence about promising practices and program effectiveness, use across agencies, and share with the public to improve the impact of the Federal STEM education investment.

Goals for NSF Investments in Graduate Education

NSF uses three strategic goals to guide the individual and collective efforts involved in achieving the agency's mission: (G1) Transform the frontiers of science and engineering; (G2) Stimulate innovation and address societal needs through research and education; and (G3) Excel as a Federal Science Agency.

NSF investments in graduate education support these agency strategic goals by developing a diverse community of research professionals with the advanced training needed to lead and innovate in STEM intensive careers that will transform science and engineering.

Based upon the recommendations of the NSF Graduate Education Strategic Planning Committee, this framework proposes three strategic goals to guide NSF investment in graduate education. The framework goals are presented in a manner that illustrates their alignment with the goals of the NSF Strategic Plan.

Goal 1: Advance Science and Engineering (S&E) Research

A key goal of NSF's support of graduate students and graduate education is to enable long-term contributions of new knowledge at the frontiers of science and engineering. The National Academy of Sciences report, *Reshaping the Graduate Education of Scientists and Engineers* (Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, 1995, p. 1), describes the fundamental role of graduate education in the research enterprise: "Graduate education is basic to the achievement of national goals in two ways. First, our universities are responsible for producing the teachers and researchers of the future—the independent investigators who will lay the groundwork for the paradigms and products of tomorrow and who will educate later generations of teachers and researchers. Second, graduate education contributes directly to the broader national goals of technological, economic, and cultural development."

The central function of preparing graduate students for research is also described in the Carnegie report, *Envisioning the Future of Doctoral Education* (The Carnegie Foundation for the Advancement of Teaching, 2006)*:* Graduate education involves preparation for *generating* new knowledge, *conserving* the most important findings, and *transforming* knowledge by connecting it to ideas from other fields.

NSF investments in graduate education advance these goals through a broad portfolio of opportunities for disciplinary and interdisciplinary research, as well as innovative models of graduate education.

Goal 2: Broaden Participation to Promote Excellence in Research and Build the Next Generation STEM Workforce

The global competitiveness of the United States in the 21st century depends directly on the readiness of the Nation's STEM workforce. The demographic evolution in the United States is reflected in a strong, growing workforce whose makeup is changing rapidly.

The National Science Board report *Revisiting the STEM Workforce* (The National Science Board, 2015, p. 22) notes that the future of the S&E workforce requires "that the full range of STEM and non-STEM career pathways be available to all Americans. This imperative is undergirded by two foundational principles: first, that every individual in the United States is afforded the opportunity to reap the benefits of advancements in science and technology; second, that our ability to respond to national needs and remain globally competitive will require the capabilities and ingenuity of individuals of diverse backgrounds."

The diversity of science and engineering communities is also integral to transforming the frontiers of science and engineering. The National Research Council study *Enhancing the Effectiveness of Team Science* (The National Research Council, 2015) emphasizes that the inclusion of people from diverse backgrounds and viewpoints in scientific teams increases research productivity and innovation by introducing creative perspectives and diverse modes of thinking.

NSF is committed to increasing access for currently underrepresented groups to STEM education and careers through its investments in graduate research and education. Graduate students should be broadly recruited from a variety of geographic, demographic, social, and educational backgrounds to promote the advancement of science and national priorities.

Goal 3: Build Effective Models of Graduate Education and Workforce Development

Graduate education should prepare graduate students to tackle complex challenges from a broad array of professional settings in a diverse, knowledge-based, and innovation-driven economy. Graduate education and training should also prepare students for the changing nature of the conduct of science (e.g. multidisciplinary training, international perspectives) within the tradition of scholarship that is core to graduate training, as well as for diverse career paths in R&D including academia, the private sector, government and science policy. A strong evidence base of programs and practices is vital to meeting these broad objectives.

In accordance with recommendation of the *Federal STEM Education 5-Year Strategic Plan* to build and use evidence based approaches, investments in graduate education should be informed by research and program evaluation that best support the next generation of discoverers. This includes rigorous STEM education and research about promising practices in graduate education and program effectiveness.

The NSF Graduate Education Strategic Planning Committee notes that, in contrast to undergraduate education, there is not a comprehensive body of research on significant aspects of graduate education. The need for a systematic gathering of data to help address the challenges facing U.S. graduate education is described in *The Path Forward: The Future of Graduate Education in the United States* (Council of Graduate Schools and Educational Testing Service, 2010). As examples, the report calls for federal government support of studies aimed at understanding aspirations and creating career pathways for students, along with careers in the 21st century and the pathways that lead to them.

Strategic Objectives

Goal 1: Advance Science and Engineering (S&E) Research

Strategic Objective 1: Prepare the Discoverers of Tomorrow

Investing in "discoverers" – that is, building a diverse and talented next generation of STEM research leaders and professionals across sectors – is NSF's primary investment focus in graduate education. NSF will continue to support the education and training of graduate students to become leaders in science through an emphasis on their role in scientific discovery.

Although the majority of NSF's investments in graduate students come through faculty research grants that support research assistants, NSF directorates have instituted several additional programs to support graduate students, ranging from dissertation completion awards to traineeship and fellowship mechanisms that advance the progress of science and engineering for the nation.

Each S&E discipline supported by NSF provides a unique context for inspiring the discoveries that drive the advancement of science. The importance of this disciplinary context is noted in a number of reports, and is affirmed by the NSF Graduate Education Strategic Planning Committee. The discipline specific nature of professional stewardship is a central tenet of *Envisioning the Future of Doctoral Education*.

Goal 2: Broaden Participation to Promote Excellence in Research and Build the Next Generation STEM Workforce

Strategic Objective 1: Invest in Broad Research and Education Experiences

In addition to preparing graduate students to create new knowledge, NSF investments should promote the production of scientists and engineers with the knowledge, skills, and professional preparation to lead innovation and adapt discoveries to meet society's needs. One approach to developing these connections is through partnerships involving other government agencies and private and international entities. Such partnerships leverage NSF resources and help ensure that fundamental research outcomes are translated into benefits to society. NSF should continue to support development opportunities for graduate students that broaden their research experience and complement what is available at their home institutions.

Such investments align with the coordination strategy of the *Federal STEM Education Five-Year Strategic Plan,* and they respond to the call to *"*reaffirm, revitalize, and strengthen substantially the unique partnership that has long existed among the nation's research universities, the federal government, the states, and philanthropy by enhancing their roles and linkages and also providing incentives for stronger partnership with business and industry*"* from the report *Research Universities and the Future of America: Ten Breakthrough Actions Vital to Our Nation's Prosperity and Security* (Committee on Research Universities; Board on Higher Education and Workforce; Policy and Global Affairs; National Research Council, 2012, p. 1).

In FY 16-17 NSF will have an Agency Priority Goal on STEM graduate student preparedness for entering the workforce. As part of this priority goal, NSF will fund 75 supplements to existing awards and three to five summer institutes to provide STEM doctoral students opportunities to expand their knowledge and skills to more broadly prepare them for a range of careers.

Strategic Objective 2: Support Research on Cultivating Diverse and Effective Science Teams

This strategic objective also supports the NSF strategic objective to integrate education and research to support development of a diverse STEM workforce with cutting-edge capabilities.

NSF should invest in the development of models and research on how to attract the broadest range of highly-qualified students to S&E majors and professions. It should support the development of learning environments that engage students in scientific teams and collaborations that lead to cutting-edge research and diverse career trajectories. NSF should support efforts to study, evaluate and scale the most promising academic and industry practices.

These investments advance the goal of the *Federal STEM Education Five-Year Strategic Plan* to better serve groups historically underrepresented in STEM fields, and the National Research Council's call to "secure for the United States the full benefits of education for all Americans, including women and underrepresented minorities, in science, mathematics, engineering, and technology."

Goal 3: Build Effective Models of Graduate Education and Workforce Development

Strategic Objective 1: Convene a National Dialogue on S&E Graduate Education

NSF should use its role as a convener and source of data to engage the nation to explore the changing nature of the conduct of science, the increased need for interdisciplinary as well as disciplinary research experiences, and the need to prepare graduates for diverse career paths. Possible activities include surveying the current practices of colleges and universities, studying

employer needs, and sponsoring regional workshops across the nation with external stakeholder communities (e.g., professional societies, advisory committees, industry, and federal partners, private foundations and international funding organizations).

A national dialogue on graduate education is seen by many as a critical step in implementing a national strategy. In *Reshaping the Graduate Education of Scientists and Engineers* (Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, 1995, p. 89), this need is stated in clear terms: "At present, there is neither the conceptual clarity nor the factual basis for us to lay out a coherent policy. We are concerned that many prevailing views are obsolete or obsolescent." The report recommends "a searching national discussion that includes representatives of government, universities, employers, and professional organizations should examine the goals, policies, conditions, and unresolved issues pertaining to graduate-level human resources." Recent reports on graduate education offer evidence that a constructive national dialogue on graduate education has emerged, and they provide a pathway for deeper engagement.

The National Research Council, in its report *Research Universities and the Future of America: Ten Breakthrough Actions Vital to Our Nation's Prosperity and Security* (Committee on Research Universities; Board on Higher Education and Workforce; Policy and Global Affairs; National Research Council, 2012, p. 15), calls for the United States to "improve the capacity of graduate programs to attract talented students by addressing issues such as attrition rates, time to degree, funding, and alignment with both student career opportunities and national interests."

Strategic Objective 2: Enhance What NSF Knows About Investments in S&E Graduate Education

There are several activities underway aimed at enhancing knowledge about NSF investments in graduate education.

First, NSF will enhance the effectiveness of its investments in graduate education through robust data collection and analysis to model and optimize its multiple investment mechanisms. In FY 2016, NSF principal investigators will be able to list a unique identifier (ORCID ID)[3] on all research proposals. The Graduate Research Fellowships Program will also provide an option for applicants to include his or her ORCID ID.[4] NSF has the opportunity to learn from and potentially build upon these identifiers to create common metrics for more comprehensive data analysis across its entire investment in graduate education, (particularly for research assistantships). Better data collection,

[3] http://orcid.org/

[4] The information provided by the applicant's ORCID ID will be used to inform GRFP of future career outcomes. The information will not be used by the panel in the determination of GRFP awards.

management, and analysis will help NSF understand its impact on a range of scientific and career outcomes, share best practices with external stakeholders, and inform better coordination of federal investment in graduate education.

Second, NSF's National Center for Science and Engineering Statistics (NCSES) maintains a rich set of information about doctoral degree recipients collected via statistical surveys from the universe of degree recipients at the time their degree is awarded and from a sample of degree recipients over the course of their careers. A new survey activity, the *Early Career Doctorates Survey*[5], to be launched in 2016 gathers demographic, employment, and education information about doctoral degree recipients who received their degrees within the past 10 years.

Third, the NSF Evaluation and Assessment Capability (EAC) will provide centralized support and resources for data collection, analytics, and the design of evaluation studies and surveys. These activities will enable NSF to more consistently evaluate the impacts of its investments, to make more data-driven decisions, and to establish a culture of evidence-based planning.

Conclusion

This strategic framework outlines three goals that will serve as the foundation for NSF investments in graduate education over the next five years. Its five strategic objectives describe the mechanisms and approaches that NSF will use to advance these goals.

The three appendices in this document provide additional context and details concerning the plan's objectives. Appendix I provides information on NSF investments in graduate education. It includes an analysis of the primary mechanisms NSF uses to support graduate education, and also contains a brief summary of the evaluations of some NSF-wide graduate education programs. Appendix II provides additional details about the NSF programs that contribute to the goals and objectives of this Strategic Plan. The appendix does not provide a comprehensive catalogue, but rather a survey of the main programs and activities across NSF that comprise the Foundation's investment in graduate education.

There are several important issues in graduate education that are not discussed in this Strategic Plan. The purpose of Appendix III is to note some of these issues and to invite further discussion.

[5] http://www.nsf.gov/statistics/srvyecd/

Appendix I: NSF Investments in Graduate Education

Analysis of Support Mechanisms

The National Science Foundation invests roughly $1 billion dollars annually in graduate education in support of over 40,000 students. Approximately 60% of these funds are applied to research assistantships that contribute to the research objectives of NSF-funded awards. Graduate fellowships that recognize and support promising students comprise about 36% of the NSF investment in graduate education. These fellowships also have a goal of broadening participation in NSF supported disciplines. Traineeships, which are financial awards given to graduate students selected by the institutions, comprise about 3% of funds. Traineeships generally include goals to catalyze and advance interdisciplinary research, promote professional development, and improve graduate education. Approximately 1% of the investment is devoted to research on the reform of graduate education.

The balance of the three mechanisms comprising NSF's graduate education investment is a matter of significant interest to NSF and its stakeholders. An evidence based understanding of the strengths and weaknesses of these support mechanisms would benefit NSF's stewardship of this investment. While there have been attempts to examine these strengths and weaknesses, there has not been a comprehensive study of all three using common metrics.

There are challenges in using existing data to determine causal impact on student achievement by support mechanism:

- Most students receiving NSF funds are supported by multiple mechanisms over the course of their graduate careers. Data from NCSES indicate that the majority of doctoral recipients are supported by four or more mechanisms.
- The dominant mechanism of graduate student support varies by discipline.
- Self-reported data from graduate students and faculty are often incomplete.
- There is a lack of comparative data across all support types.

Nevertheless, it is important to achieve a better understanding of how each of the primary support mechanisms contributes to the goals of graduate education. NSF would especially benefit from an evidence base that advances this understanding as it pertains to the priorities of the *Federal STEM Education 5-Year Strategic Plan* to better serve groups historically underrepresented in STEM fields, and to design graduate education for tomorrow's STEM workforce.

Evaluations of NSF Graduate Education Programs

Since 1998, the National Science Foundation has invested in the development of innovative models of graduate education through programs like the Alliance for Graduate Education in the Professoriate (AGEP), and the Integrative Graduate Education for Research Traineeship (IGERT) awards. A key component of these programs is the regular evaluation of program effectiveness and the publication of this information in peer-reviewed journals or refereed conference proceedings. Despite differing research foci, several overarching themes have been reported to yield positive experiences for graduate students. These include:

- Establishing formal and informal mechanisms of communication between graduate students, research mentors, and program facilitators.
- Creating cohorts and project teams that provide an opportunity for peer mentoring both within and between cohorts.
- Developing clear milestones to improve graduate student accountability at various stages in the program.
- Building institutional infrastructure that supports interdisciplinary research and mentorship for graduate students.

The Integrative Graduate Education and Research Traineeship (IGERT) program was established in 1998 to meet the challenges of educating U.S. Ph.D. scientists and engineers to have interdisciplinary backgrounds, deep knowledge in chosen disciplines, and technical, professional, and personal skills. The program sought to establish new models for graduate education and training in collaborative research that transcends traditional disciplinary boundaries. It was also intended to facilitate diversity in student participation and preparation, and to contribute to a world-class, broadly inclusive, and globally engaged science and engineering workforce. Several reports have discussed the IGERT program and its impacts, for example (Abt Associates, 2006) and (Abt Associates, 2011).

The 2015 launch of the NSF Innovations in Graduate Education (IGE) Program (a component of the NSF Research Traineeship Program) continues the tradition of encouraging the testing, adaption and/or scaling of new approaches to graduate education. The results of these NSF investments, particularly the conclusions about program effectiveness, can be disseminated beyond the education literature and used to inform the community of stakeholders about approaches that achieve positive outcomes in graduate education. Developing a community consensus about such approaches can in turn be used to implement them on a wider scale nationally.

In May 2008, a two-day workshop was held in Arlington, Virginia with the goal of defining the progress of interdisciplinary research and graduate education and their impacts on academic institutions. The workshop was sponsored by the National Science Foundation (NSF) Directorate of Education and Human Resources, Division of Graduate Education, Integrative Graduate Education and Research Traineeship (IGERT) Program. The results of the workshop are published in (Van Hartesveldt & Giordan, 2008).

An evaluation of the Graduate Research Fellowship Program (GRFP) was completed in 2014, (NORC at the University of Chicago, 2014). The evaluation used data on graduate research fellowship awardees from 1994 to 2011 to address four questions:

- What is the impact of the Fellowship on the graduate school experience?
- What is the impact of the Fellowship on career outcomes?
- What are the effects of the GRFP on institutions?
- Is the program design effective in meeting program goals?

The following is a brief summary of the findings:

- The Fellowship has several positive impacts on the graduate school experience, including likelihood of completion of a Ph.D., time to degree, and greater flexibility in choosing a research direction.
- The positive impacts on career outcomes include an increase in the number of papers presented at meetings, the number of papers published, and the number of grants and contracts awarded as an investigator after graduate school. The Fellowship also has a positive impact on serving on a committee or panel, and providing review services.
- Faculty and administrators generally see the GRFP as having strong positive effects on their departments and institutions. They view the Fellows as high-achieving students who are well qualified for the award.
- In assessing how well the program meets its goal to support individuals with the demonstrated potential to be high achieving scientists and engineers, the evaluation found that GRFP Fellows were more productive than honorable mention designees in terms of several measures of academic and scientific productivity. The evaluation also found that Fellows who have completed the Ph.D. were more likely that the national population of STEM Ph.D. recipients to report research and development as a primary work activity.

Appendix II: Selected Contributing Programs for Strategic Objectives

Goal 1: Advance Science and Engineering (S&E) Research

Strategic Objective 1: Prepare the Discoverers of Tomorrow

The chief mechanism for preparing graduate students to be the discoverers of tomorrow is through their direct participation in high-quality scientific research. NSF investments in research assistantships provide this direct connection to the research it supports. In a similar way, NSF invests in fellowships that identify and support highly promising students to study in the environments that best advance their development as researchers.

NSF investment in discoverers also includes training students in interdisciplinary settings to address large-scale problems of national significance. The National Science Foundation Research Traineeship (NRT) provides an example. The goals of NRT are to support highly effective training of STEM graduate students in an interdisciplinary research area of national priority as well as to create and promote novel, innovative, effective, and scalable models for STEM graduate student training in emerging research emphasis areas. The NRT program is distinguished from prior traineeship programs by its emphasis on training for multiple career pathways, rotating priority research themes, and the inclusion of both masters and doctoral students.

NSF also helps prepare the discoverers of tomorrow by promoting practices that facilitate future scientific discovery, such as faculty mentoring of graduate students using individual development plans. A number of NSF programs call for these plans, including the Mathematical and Physical Sciences AGEP Graduate Research Supplements (NSF 13-071), the EFRI Research Experience and Mentoring Program (NSF 14-114), and the Cultural Anthropology Research Experience for Graduates (NSF 14-031).

Goal 2: Broaden Participation to Promote Excellence in Research and Build the Next Generation STEM Workforce

Strategic Objective 1: Invest in Broad Research and Education Experiences

NSF will continue to make investments in graduate education that respond to the need to broaden research and education experiences beyond what is available at the student's home institution. This includes opportunities for graduate students to conduct research in government, international, and industry settings.

The Graduate Research Internship Program (GRIP) provides opportunities for NSF Graduate Research Fellows to enhance their professional development by engaging in mission-related research experiences with partnering agencies across the federal government. Through Graduate Research Opportunities Worldwide (GROW), NSF Graduate Research Fellows engage in research collaborations with outstanding science and engineering research sites around the world.

Grant Opportunities for Academic Liaison with Industry (GOALI) offers graduate student industrial traineeships for full or part-time work in industry under the guidance of an academic advisor and an industrial mentor.

The International Research Experiences for Students (IRES) program supports development of globally-engaged U.S. science and engineering students capable of performing in an international research environment at the forefront of science and engineering. The IRES program supports active research participation by students enrolled as undergraduates or graduate students in any of the areas of research funded by the National Science Foundation.

The East Asia and Pacific Summer Institutes for U.S. Graduate Students (EAPSI) provides research experiences and cultural immersion for U.S. science and engineering graduate students in seven partner countries.

The S&E disciplines represented within NSF invest in broader research experiences for graduate students in the contexts of their disciplines. For example, Cyberinfrastructure Training, Education, Advancement, and Mentoring for Our 21st Century Workforce (CI-TEAM) helps to prepare a diverse, cyberinfrastructure-savvy science and engineering workforce. CI-TEAM supports the integration of science and engineering research activities with efforts to promote, leverage and utilize cyberinfrastructure systems, tools and services.

Enriched Doctoral Training in the Mathematical Sciences (EDT) supports efforts to enrich research training in the mathematical sciences at the doctoral level by preparing Ph.D. students to recognize and find solutions to mathematical challenges arising in other fields and in areas outside academic settings. Graduate research training activities supported by EDT prepare participants for a broader range of mathematical opportunities and career paths than has been traditional in U.S. mathematics doctoral training.

Strategic Objective 2: Support Research on Cultivating Diverse and Effective Science Teams

The Innovations in Graduate Education (IGE) track of the National Science Foundation Research Traineeship Program (NRT) supports piloting, testing, and evaluating novel, innovative, and

potentially transformative approaches to graduate education, both disciplinary and interdisciplinary, to generate the knowledge required for their customization, implementation, and broader adoption.

The Broadening Participation in Engineering (BPE) Program is a Directorate-wide initiative dedicated to supporting the development of a diverse and well-prepared workforce of engineering graduates. The Broadening Participation in Engineering Program supports projects to engage and develop diverse teams that can offer unique perspectives and insights to challenges associated with increasing diversity in engineering research and education.

The EHR Core Research (ECR) program of fundamental research in STEM education provides funding in STEM learning, STEM learning environments, STEM workforce development, and broadening participation in STEM.

Goal 3: Build Effective Models of Graduate Education and Workforce Development

Strategic Objective 1: Convene a National Dialogue on S&E Graduate Education

NSF will continue to work with its partners and stakeholders to expand and advance the dialogue on the key issues in S&E graduate education. NSF expects to host a summit on graduate education in late 2016 as part of this effort.

The S&E disciplines are also engaged in dialogues about the role of graduate education in their disciplines. For example, through its Dear Colleague Letter, *Graduate Education in Chemistry* (NSF 15-055), the Division of Chemistry invites the community to submit proposals for conferences that assess the current status and develop plans for alternative approaches to research and graduate education in Chemistry[6].

Appendix III: Issues for Further Discussion

There are several important issues in graduate education that are not discussed in the previous sections. The purpose of this appendix is to identify some of these issues and to invite further discussion. They are relevant to the implementation of this Strategic Plan, and are a part of the continuing dialogue on graduate education:

[6] http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf15055

- The global context for graduate education and the role of international graduate students in the United States.
- The complementary roles of master's and doctoral programs in STEM disciplines, and the role of NSF in advancing the objectives of each.
- The challenge of coordinating Federal investments in graduate education.
- The evolution from "pipeline" to "pathways" in STEM education.

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