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Testimony
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Strengthening Undergraduate and Graduate STEM Education

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Chairman Lipinski, Ranking Member Ehlers, and distinguished members of the Subcommittee, I am Joan Ferrini-Mundy, Acting Assistant Director for the Directorate for Education and Human Resources (EHR) at the National Science Foundation (NSF). Thank you for the opportunity to testify about strengthening undergraduate and graduate science, technology, engineering and mathematics (STEM) education. Advancing the frontiers of science and ensuring a scientifically literate citizenry are paramount, and as the importance of ensuring a next generation of innovators in science and engineering is critical, the NSF continues to provide leadership and research for the ongoing transformation of STEM learning opportunities at all levels. Today we are focusing on undergraduate and graduate education, and the unique and exciting opportunities at NSF for advancing this enterprise, in support of the development of tomorrow's STEM workforce.

I begin with comments about NSF's role in improving the quality and effectiveness of STEM higher education in the United States, and will highlight key programs and provide a summary of NSF's total investment in undergraduate and graduate education. Then I will speak about focus areas in the NSF portfolio in undergraduate and graduate education: interdisciplinarity and other skills essential in STEM; recruitment and retention to STEM fields; and the status of research on learning and teaching in undergraduate and graduate STEM education.

Overview of NSF's Role and Investment

NSF's mission in STEM higher education is to stimulate improvement in the education and development of a diverse and well-prepared workforce. This is done by investing in promising research, innovative programs and talented people. NSF has two complementary roles in the advancing quality and effectiveness in STEM higher education: one is to provide direct support to the nation's most promising students preparing for careers in STEM, via fellowships, traineeships, scholarships, and research assistantships. The other is to catalyze and study innovative approaches to improving STEM learning and workforce development in higher education settings. The two lines of investment are interwoven and reinforce one another. This provides NSF unique opportunities to support the creation of the best environments for student learning and to ensure that promising students access to those environments.

NSF has several programs that explicitly address undergraduate and graduate students. These programs span EHR and other NSF directorates. The FY 2011 request is for approximately $401 million at the undergraduate level and $338 million at the graduate level. See Table 1 for additional detail.

Supporting Students Directly

The investment in developing the STEM professional workforce occurs through several programs at both the graduate and undergraduate levels.

Graduate student support. NSF's Graduate Research Fellowship Program (GRFP) is the country's oldest graduate fellowship program that directly supports students. The first predoctoral and postdoctoral fellowships were awarded by NSF in 1952. Among the recipients are sociobiologist Edward O. Wilson (Pulitzer Prize, 1979 and 1991), physicist Burton Richter (Nobel Prize, 1976) and Sergey Brin, one of the founders of Google. In 2009 1,244[1] Graduate Research Fellowships were awarded to students across the scientific disciplines, attending 137[2] universities. NSF also sponsors a Foundation-wide traineeship program, the Integrated Graduate Education Research and Traineeship (IGERT) program.

NSF uses three mechanisms for supporting graduate students: research assistantships (RAs) fellowships, traineeships, and. There are significant differences among these three training mechanisms in the citizenship requirements for funding, the flexibility in choice of institution and education, the kinds of mechanisms for training both within and beyond the content areas of the student's field(s), and the reporting requirements and follow-up possibilities for the students.

The purpose of a research assistantship is to accomplish work on a PI's grant. The student need not be a US citizen and there need be no information about the student's graduate education. The PI must report the student's name, whether he or she worked more than 160 hours (the appointment may vary in time and duration), and what their role was on the project in the annual and final reports. Nothing else need be reported by the PI. It should be noted that "Most federal financial support for graduate education is in the form of RAs funded through grants to

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[1] This included 387 American Recovery and Reinvestment Act awards and 857 non-ARRA.
[2] This includes 10 international and 127 US institutions.

universities for academic research. RAs are the primary mechanism of support for 69% of federally supported full-time S&E graduate students, up from 66% in 1993. Fellowships and traineeships are the means of funding for 21% of the federally funded full-time S&E graduate students. The share of federally supported S&E graduate students receiving traineeships declined from 15% in 1993 to 12% in 2006, and the share receiving fellowships declined from 11% to 10%."[3] Research awards across NSF provide support to students serving as research assistants.

The Graduate Research Fellowship is different from a research assistantship in the following ways: the student must be a US citizen or permanent resident; the student must be near the beginning of his or her graduate education in an NSF-supported field; the award is portable; the three years of stipend and "cost of education" support may be used during any three years in a five-year window; and, the award is not tied to other duties.

The IGERT traineeship is similar to the Graduate Research Fellowship (and different from a research assistantship) in the following ways: the student must be a U.S. citizen or permanent resident in an NSF-supported field, and the stipend and "cost of education" allowance are the same. The IGERT traineeship is different from both the research assistantship and Graduate Research Fellowship in that in the IGERT program faculty invent the novel, collaborative, interdisciplinary research themes that form the basis of the trainees' innovative graduate education (in addition to the disciplinary depth that trainees gain in their home departments); faculty recruit trainees for their programs and mentor them; and graduate students receive training in teamwork, communication, career development, ethics and responsible conduct of research, and global perspectives.

It is important to maintain a balance in the portfolio of opportunities that NSF programs offer. The scientific community increasingly views interdisciplinary research as critical to innovation and scientific advances and as a means to respond to emerging complex problems[4]. Over the past decade, academic institutions and federal funding agencies have made efforts to promote interdisciplinary education and research. Although new programs and efforts have arisen, academic institutions and funding agencies remain for the most part organized around disciplines; thus, university structures, evaluation and promotion practices, and funding opportunities often do not facilitate interdisciplinary research.[5] Measurement of interdisciplinary enrollment and degree attainment also remains a challenge, as students often are assigned to only one department or program to avoid duplication in records, and schools are asked to report the enrollment or degree in only one department or program. As interdisciplinary degree programs

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[3] National Science Board (2010). *Science and engineering indicators 2010*. Arlington, VA: National Science Foundation (NSB 10-01).
Note: Funding for GRF increases by $22.32 .million to $158.24 million in FY 11, supporting the Administration priority to triple the number of new graduate research fellowships from 1,000 in FY 2008 to 3,000 by FY 13.
[4] Committee on Science, Engineering and Public Policy (COSEPUP). (1995). Reshaping the Graduate Education of Scientists and Engineers. Washington, DC: National Academies Press.;,
Committee on Facilitating Interdisciplinary Research, Committee on Science, Engineering, and Public Policy (COSEPUP). (2004). Facilitating Interdisciplinary Research. Washington, DC: National Academies Press.;
National Science Foundation, Education and Human Resources Directorate Division of Graduate Education (2008) The impact of transformative interdisciplinary research and graduate education on academic institutions, Arlington , VA: NSF(NSF 09-33)
[5] (NSF 09-33)

become established and award degrees, measurement becomes easier. For example, the number of doctoral degrees increased in interdisciplinary fields such s neuroscience (from 117 in 1982 to 737 in 2006), materials science (from 147 in 1982 to 582 in 2006), and bioengineering (from 59 in 1982 to 525 in 2006)[6].

Undergraduate student support. Undergraduate STEM students receive direct support through NSF's Robert Noyce Teacher Scholarship Program, which directs scholarships to undergraduates preparing for the STEM teaching workforce. In 2009, 1530 prospective STEM teachers benefited from direct support through American Recovery and Reinvestment Act (ARRA) funds in Noyce. The NSF Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM) program awards scholarships to academically talented, financially needy undergraduate students.

Catalyzing Innovation

NSF also has a long and distinguished history of supporting catalytic work to improve STEM learning in higher education. In 1953 NSF co-sponsored a conference at Amherst College on strengthening physics research at liberal arts colleges, using as part of the argument for this the idea that students would benefit greatly from interacting with ongoing research[7] – perhaps an early conceptualization of what has become the Research Experiences for Undergraduates program at NSF. The 1986 "Neal Report"[8] noted that "The only way that we can continue to stay ahead of other countries is to keep new ideas flowing through research: to have the best technically trained, most inventive and adaptive workforce of any nation; and to have citizenry able to make intelligent judgments about technically-based issues. Thus, the deterioration of collegiate science, mathematics and engineering education is a grave long term threat to the Nation's scientific and technical capacity, its industrial and economic competitiveness and the strength of its national defense." This concern prompted a renewed focus on NSF's investment in improving undergraduate STEM education.

Undergraduate education. While improvements in undergraduate instruction are funded in several contexts in EHR, and in some programs in other directorates, the core program through which NSF funds fundamental exploration of learning at the undergraduate level is the newly renamed Transforming Undergraduate Education in STEM (TUES) program, formerly Course, Curriculum, and Laboratory Improvement (CCLI). This name change signals strongly the intention to move beyond small-scale change, and understand what is needed to fully bring about STEM undergraduate education that engages and empowers every student.

The vision of the TUES program is excellent STEM education for all undergraduate students. The program supports efforts to bring advances in STEM disciplinary research into the undergraduate experience, and the creation and adaptation of learning materials and teaching

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[6] NSB 10-01; NSF/SRS 1993, 2009c

[7] The Third Annual Report of the National Science Foundation: Appendix VI *Report of the National Science Foundation—Amherst Conference on Physics Research in Colleges*. 1953. Arlington, VA. [Appendix VI]

[8] Neal, Homer A., Chair, NSB Task Committee on Undergraduate Science and Engineering Education (1986). *Undergraduate science, mathematics, and engineering education.* National Science Foundation: Washington, DC. 1986 (NSB 86-100) (pg. 1).

strategies that embody what is established through research about how students learn. It encourages projects that develop faculty expertise, promote widespread implementation of educational innovations, and prepare future K-12 teachers. Projects that explore cyberlearning, that is, learning with cyberinfrastructure tools such as networked computing and communications technologies, are of special interest. The program supports projects at all scales and stages of development, ranging from small, exploratory investigations to large, comprehensive projects. The goals of this program reflect national concerns about producing skilled STEM professionals (including K-12 teachers) and citizens knowledgeable about STEM and how it relates to their lives. The program seeks to build on the community of faculty committed to improving undergraduate STEM education.

At the undergraduate level, a major challenge is that of scaling up across the nation's 4,352 undergraduate institutions (including two-year and community colleges)[9] the implementation of evidence-based improvements to STEM teaching. Much that is known about how to use classroom, laboratory, and personal study time to promote student learning in ways that are more effective than conventional lecturing has still not been widely adopted. Such practices include peer engagement in instruction and practice; computer-bsed classroom communication systems and homework tools that provide real time feedback on student understanding; case-based and problem-based approaches to material; and laboratory and design work that engage students in unsolved problems rather than cookbook exercises[10]. The current TUES program announcement especially encourages projects that have the potential to transform the conduct of undergraduate STEM education. The program requires that each project conduct both formative and summative evaluation of effectiveness in meeting it goals and participate as requested in a program-level evaluation. And, as new technologies emerge and the experiences and characteristics of student populations shift, continued research and development to advance knowledge about student learning and effective instructional practices that lead to deep learning at the undergraduate level is essential. It will also be important to think in terms of leveraging NSF's investment through interactions with organizations, movements, and interests with potential national impact on faculty practice.

To promote more effective undergraduate education for teachers, such efforts as the Collaboratives for Excellence in Teacher Preparation (1993-2002) and the Math and Science Partnerships (2002-present) have required a strategy that brings together STEM faculty, education faculty, and practitioners to improve the disciplinary preparation of teachers. This focus not only brings STEM expertise to teacher preparation, but also brings a growing cadre of STEM faculty, many of whom had no formal training in pedagogy, in contact with a knowledge base around effective practices for supporting learning. As projects insist that college-level

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[9] U.S. Department of Education, National Center for Education Statistics, *Education Directory, Colleges and Universities*, 1949–50 through 1965–66; Higher Education General Information Survey (HEGIS), "Institutional Characteristics of Colleges and Universities" surveys, 1966–67 through 1985–86; and 1986–87 through 2007–08 Integrated Post-secondary Education Data System, "Institutional Characteristics Survey" (IPEDS-IC:86–99), and Fall 2000 through Fall 2007.

[10] See, for example, Heid, Kathleen M., (1988). Resequencing skills and concepts in applied calculus using the computer as a tool. *Journal for Research in Mathematics Education*, **19** (1) 3-25. Hake R.R. (1998). Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses *Am. J. Phys*. 66, 64- 74 (1998). Reprint [ajpv3i.pdf] (84kB).

courses for teachers model good teaching, undergraduate education for all students can be transformed.

There is excitement across NSF about plans for a new Comprehensive Broadening Participation in Undergraduate STEM (CBP-US). This program will build on the excellent efforts that have been undertaken in historically black colleges and universities, tribal colleges and universities, Hispanic-serving institutions, Louis Stokes Alliance for Minority Participation (LSAMP) institutions, and other institutions successful in broadening undergraduate participation in STEM. We anticipate moving to new levels of innovation and effectiveness in creating the future STEM workforce by seeking out and engaging promising students from all groups in our society in high quality undergraduate experiences.

Graduate education. The TUES program has been developed for undergraduate education, in which there is far more uniformity within fields than in graduate education. At the graduate level, the IGERT program requires that faculty develop novel, innovative graduate education and training mechanisms that will enable students to work collaboratively on specific interdisciplinary research problems. A recent evaluation "finds that doctoral students participating in IGERT projects receive different educational experiences than non-IGERT students enrolled in single disciplinary degree programs, and that the IGERT program has been successful in achieving its goal of improving graduate educational programs in science and engineering."[11] A TUES-type program for graduate education might focus upon common issues across graduate education such as how to prepare tomorrow's scientists to be leader in invention, innovation and entrepreneurship. Continued focus on how to catalyze excellence in graduate education, based on the growing knowledge base about adult learning, emerging workforce demands, and graduate program effectiveness, together with opportunities afforded by cyberlearning, could revolutionize graduate education. This type of focus extends beyond the current scope and emphasis of the IGERT program.

Preparation for Tomorrow's Scientists

NSF programs recognize that tomorrow's STEM workforce will encounter scientific challenges that require skills in working across disciplines, and capacity for building new knowledge in advancing scientific frontiers. This entails preparation for interdisciplinary work and development of a range of additional skills and capabilities, beyond content knowledge. Let me describe ways in which our graduate and undergraduate programs help to identify and develop such knowledge and capacity in tomorrow's scientists.

Interdisciplinary preparation. The IGERT program was developed to broaden the graduate education of students to empower them to create new knowledge in areas requiring interdisciplinary research, such as energy, climate change, clean water, and other cutting-edge, emerging areas of science. According to the program evaluation[12], "IGERT students receive more extensive interdisciplinary training than non-IGERT peers, but maintain depth of study in

[11] National Science Foundation, Division of Research, Evaluation, and Communication (2006) *Evaluation of the initial impacts of the National Science Foundation's Integrative Graduate Education and Research Traineeship Program*. Arlington, VA NSF 06-17
[12] NSF 06-17

their chosen fields. IGERT students consistently report greater opportunities to learn about other disciplines, interact with faculty and students from other disciplines, and work on projects involving multiple disciplines. They are better prepared to work in multidisciplinary teams and communicate with people outside their own fields. At the same time, according to both faculty and students, the level of in-depth preparation in students' fields is similar for IGERT and non-IGERT participants." A subsequent 2009 evaluation[13] indicates that IGERT graduates continue to engage in interdisciplinary work in their current positions. The IGERT portfolio faces the challenge of university infrastructures that prioritize disciplinary research].

The CCLI/TUES portfolio includes projects that engage students with complex, unsolved problems that challenge communities, the nation, and the global community. One such project is Science Education for New Civic Engagements and Responsibilities (SENCER), active in more than 40 states. SENCER helps faculty leaders develop courses that teach through complex, capacious civic issues to the basic learning outcomes. Focusing on real world issues is intended to increase student's interest, motivate greater achievement, and help students make connections between learning, their future careers, and their roles as citizens in a democracy

Other NSF programs also aim at interdisciplinarity at the undergraduate level. For instance, the Interdisciplinary Training for Undergraduates in Biological and Mathematical Sciences (UBM) program is a cross-cutting program involving EHR, the Biological Sciences Directorate, and the Mathematical and Physical Sciences Directorates. UMB has as its goal to enhance undergraduate education and training at the intersection of the biological and mathematical sciences and to better prepare undergraduate biology or mathematics students to pursue graduate study and careers in fields that integrate the mathematical and biological sciences. The core of the activity is jointly conducted long-term research experiences for interdisciplinary balanced teams of at least two undergraduates from departments in the biological and mathematical science**s.** And the Nanotechnology Undergraduate Education (NUE) in the Directorate for Engineering aims at introducing nanoscale science, engineering, and technology through a variety of interdisciplinary approaches into undergraduate engineering education. The focus of last year's competition was on nanoscale engineering education with relevance to devices and systems and/or on the societal, ethical, economic and/or environmental issues relevant to nanotechnology.

Development of other critical skills.   NSF programs also support effective efforts to equip undergraduate and graduate students with skills that extend beyond their disciplinary and interdisciplinary knowledge, and that will likely be essential in the future conduct of science. For example, the IGERT program is designed to provide graduate students training in interdisciplinary collaboration (teamwork) and communication skills. In a follow up survey of over 600 IGERT graduates, over 70% reported that the exposure to multi/interdisciplinary research contributed to their ability to obtain positions in the workforce[14]. Evaluation[15] findings also indicate that significantly more IGERT students than graduate students in the control group received training or coursework in professional speaking or presentation skills, communicating to people outside their discipline, or communicating to the general public. The 2009 evaluation

[13] Abt Associates Inc., 2009, Evaluation of the National Science Foundation's Integrative Graduate Education and Research Traineeship Program (IGERT): Follow-up Study of IGERT Graduates. draft final copy received
[14] NSF 06-17
[15] Initial Impacts of IGERT evaluation by Abt Associates Inc. (2006)

preliminary results comparing IGERT and non-IGERT graduates in the workforce reports that IGERT graduates were more likely to be integrating multiple disciplines in thieir work.[16] Many IGERT projects feature internships in non-academic settings. Interdisciplinary teamwork skills can be built in the many interdisciplinary research centers at major universities, as well as by giving graduate students in all fields an opportunity to intern in an industry or government lab. "Government and industry have had more emphasis on and experience in working in teams than academia and, thus, have expertise in this area that should be utilized and adapted for academic contexts."[17]

The NSF Graduate STEM Fellows in K-12 Education (GK-12)[18] program provides an opportunity for graduate students to acquire value-added skills, such as communicating STEM subjects to technical and non-technical audiences, leadership, team building, and teaching while enriching STEM learning and instruction in K-12 settings. At the master's level, this year ARRA funds will support a competition for the Science Master's Program (SMP)[19], intended to prepare graduate students for a variety of workplaces through a strong foundation in the STEM disciplines as well as research experiences, internship experiences, and the skills to succeed in those careers. Faculty recognize the importance of the development of such skills for enabling their students to have a range of career options.

At the undergraduate level, programs emphasize a range of skills that have been hypothesized as critical for participation in the STEM workforce. For instance, we are seeing increasing emphasis in proposals on identifying and developing these including "21st century skills" in the Advanced Technological Education (ATE)[20] program. With an emphasis on two-year colleges the ATE program focuses on the education of technicians for the high-technology fields that drive our nation's economy, and therefore proposals describe the range of skills needed for success in such career areas. The program involves partnerships between academic institutions and employers to promote improvement in the education of science and engineering technicians at the undergraduate and secondary school levels, and this partnership with employers leads to inclusion of a wider range of skill areas. The ATE program supports curriculum development, professional development of college faculty and secondary school teachers, career pathways to two-year colleges from secondary schools and from two-year colleges to four-year institutions, and other activities. ATE projects strengthen the role of community colleges in meeting the needs for businesses and industries in the United States for a well-prepared technical workforce.

Recruitment and Retention in the STEM Fields

Several EHR programs at both the graduate and undergraduate levels are specifically aimed at improving recruitment into STEM fields, particularly recruitment of persons from groups traditionally underrepresented in STEM, a critical approach to ensuring the diversity and depth of the STEM workforce.

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[16] Abt Associates Inc., 2009, Evaluation of the National Science Foundation's Integrative Graduate Education and Research Traineeship Program (IGERT): Follow-up Study of IGERT Graduates. draft final copy received
[17] NSF 09-33 The impact of transformative interdisciplinary research and graduate education on academic institutions
[18] NSF 09-549
[19] NSF 09-607
[20] NSF 07-530

Graduate level. The Alliances For Graduate Education and the Professoriate (AGEP)[21] program focuses directly on recruitment. The solicitation calls for proposers to discuss strategies for recruitment and retention of students from groups underrepresented in science and engineering. A major goal of AGEP is to increase the number of underrepresented minority (URM) students receiving Ph.D.s and going on to the professoriate. Specific objectives of AGEP are (1) to develop and implement innovative models for recruiting, mentoring, and retaining minority students in STEM doctoral and postdoctoral programs, and (2) to develop effective strategies for identifying and supporting underrepresented minorities who want to pursue academic careers. Institutions funded under AGEP report rising doctoral program enrollments, higher levels of retention, steady progress toward degree attainment, increases in PhD production, and successful transitioning of PhD graduates into the workplace (including the professoriate) and more. The national AGEP evaluation[22] has been gathering comparative data about progression and graduation rates to help assess program effectiveness. This evaluation has been expanded to include a tracking component to determine the extent to which the program is contributing to STEM academic careers. AGEP-supported institutions graduated more than twice as many URM PhDs as non-AGEP institutions on average over the period between 2002 and 2007, and differences hold across all URM categories. The data also show that this holds true across STEM disciplines. Similarly, the IGERT program focuses directly on recruitment, and in the solicitation calls for proposers to discuss strategies for recruitment and retention of students from groups underrepresented in science and engineering.

We have learned from these programs about several elements that are key to recruitment and retention at the graduate level. These include opportunities for interdisciplinary research, faculty-to-faculty connections, summer workshops to introduce students to the culture of graduate school, targeted scholarships and stipends, and cultivating relationships with minority-serving institutions to build the recruitment pipeline.[23]

Undergraduate level. The undergraduate years are a critical juncture both for development of the technical and scientific workforce, and for promoting scientific literacy and engagement for all citizens. At present they are the locus of some of the biggest leaks in the "leaky pipeline" toward a robust technical workforce, and NSF remains committed to improving the situation through strategic investment. A review of proposals to the Science, Technology, Engineering, and Mathematics Talent Expansion Program (STEP) shows that of the students entering college intending to major in STEM areas, many institutions see a large drop, often 30 to 70%, in the number of these students still intending to major in a STEM field by the end of their first year of college. Individual STEP projects typically employ a number of strategies to overcome the challenges that they have identified as causing first-year college students to move out of STEM

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[21] NSF 10-522

[22] Carlos Rodriguez Presentation at the AGEP 12/09-10/2009 Washington DC. 103 AGEP institutions produced 2,878 URM STEM PhDs from 2002-7
180 non-AGEP institutions produced 2,265 URM STEM PhDs from 2002-7
Thus, AGEP institutions produced an average of 27.9 URM PhDs in STEM
And, Non-AGEP institutions produced an average of 12.6 URM PhDs in STEM
Therefore, an AGEP-supported institution produces 2.2 times as many URM PhDs as a comparable non-AGEP institution

[23] NSF 09-33 The impact of transformative interdisciplinary research and graduate education on academic institutions

majors. For example, institutions are able to identify pre-freshmen likely to have difficulty with STEM majors because their high school preparation is weak in critical areas of mathematics and science. With a rigorous academic summer program prior to the freshman year, STEP projects report successes in bringing these students to an academic level where they can succeed in the introductory science and pre-calculus or calculus classes. Within many STEP projects, focusing on at-risk students through cohort building in the first and second years, peer and faculty mentoring, and career advice also have played important roles in improving retention rates for first and second year students intending to major in STEM fields. Efforts at Washington State University, Heritage College, Eastfield College, part of the Dallas County Community College District, and San Jose State University have demonstrated particular success.

Undergraduate programs that support sustained and comprehensive institutional approaches to broadening participation of persons underrepresented in STEM include LSAMP[24], Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)[25], and Tribal Colleges and Universities Program (TCUP)[26]. Findings[27] from the LSAMP program impact evaluation reveal there are three activities or program components that stand out as having a positive relationship with enrollment in and completion of STEM degree programs: research with faculty, internships opportunities, and summer programs.

Research on STEM Teaching and Learning at the Undergraduate and Graduate Levels

Several NSF programs invest in building a knowledge base through research and evaluation of innovative practice to inform the ongoing improvement of undergraduate and graduate education. The Research and Evaluation on Education in Science and Engineering (REESE) program[28] invites proposals that span these levels. In recent years the REESE program has issued a Dear Colleague Letter[29] calling for research on graduate education, in order to stimulate more activity in that area. The TUES, STEP, ATE, and HBCU-UP programs also specifically call for research on undergraduate education. We estimate that about $23 million dollars were invested in FY2009 in research on undergraduate and graduate education, with almost the entire investment at the undergraduate level.

A foundation for research on learning at all levels was established in the National Research Council synthesis report, *How People Learn*[30]. This report describes the progress that has been made through studies on learning and transfer (the ability to use one what has learned in new settings); findings from neuroscience that are showing how learning changes the physical

[24] NSF 10-522
[25] NSF 10-518
[26] NSF 10-501
[27] Clewell,B. C., de Cohen, C. C., Tsui, L., & Deterdening N. (2006) *Revitalizing the nation's talent pool in STEM: sScience, technology, engineering, and mathematics*. Washington, DC: Urban Institute. (311299)
[28] NSF 09-601
[29] Dear Colleague Letter: Research and Evaluation on Education in Science and Engineering (NSF 08-012).
[30] National Research Council (1999). *How people learn: Bridging research and practice*. Committee on Learning Research and Educational Practice, A Targeted Report for Teachers, M.S. Donovan, J.D. Bransford and J.W. Pellegrino, Editors. Commission on Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

structure of the brain; and the results of research in social psychology, cognitive psychology and anthropology that demonstrate that all learning takes place in settings that have particular sets of cultural norms and expectations that influence learning. NSF-funded educational research projects are helping to build this body of cognitive science-based knowledge. The basic principles identified in *How People Learn* apply to learning in higher education.

Research on undergraduate learning. The body of research on undergraduate STEM teaching and learning is quite robust and growing in sophistication. The approach has come largely through efforts in specific disciplines. For example, over the past three decades a well-established Physics Education Research community has developed.[31] In physics, the groundbreaking work of David Hestenes and his colleagues at Arizona State University, funded by NSF in the late 1980s, produced the Force Concept Inventory[32]. This is an assessment to diagnose areas of conceptual difficulty before or after instruction. Subsequently "concept inventories" have been developed in nearly two dozen STEM disciplines.[33] The principle here is that, when faculty can see objective evidence through these inventories of their students' misconceptions and lack of understanding, they are motivated to alter their instructional practice in what will more actively engage the students and develop their understanding.

In mathematics, much of the early research on undergraduate learning conducted in the 1970s and 1980s attempted to catalogue students' misconceptions and alternative conceptions, particularly in the area of calculus[34]. Such work was concurrent with the curricular change in the calculus reform movement. More current research in undergraduate mathematics learning and teaching is aimed at understanding in such areas as differential equations linear algebra, proof and the role of technologies in supporting student understanding. In addition, there is a growing body of work about teacher's mathematical knowledge for teaching that is indicating that more advanced undergraduate mathematics coursework may not necessarily lead to improved outcomes of the pupils of those teachers. [35] In mathematics there is also a professional group, the Special Interest Group of the Mathematical Association of America on Research in Undergraduate Mathematics Education[36], that helps to advance work in the field.

In the biological sciences, statistics, geological sciences, chemistry, and engineering there are emerging lines of work in teaching and learning research, with NSF support. For instance, the Innovations in Engineering Education, Curriculum, and Infrastructure (IEECI) program in the Engineering Directorate supports research on how students best learn the ideas, principles, and practices to become creative and innovative engineers.

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[31] http://www.compadre.org/per/

[32] Halloun, I.A., Hestenes, D. (1985). The initial knowledge state of college physics students. *Am. J. Phys. 53 (11)*, pp. 1043-1048; Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher, 30*, 141-158.

[33] Libarkin, J. 2008. *Concept inventories in higher education science*. Paper developed for NRC Promising Practices in Undergraduate STEM Education Workshop.

[34] Artigue, M.A., Batanero, C., & Kent, P. (2007). Mathematics thinking and learning at the post-secondary level. In F.K.Lester, Jr. (Ed.). *Second handbook of research on mathematics teaching and learning.* Charlotte, NC: Information Age Publishing. pp. 1011-1050

[35] See Hill, H.C., Sleep, L., Lewis, J., & Ball, D.L. (2007). Assessing teachers' mathematical knowledge: What knowledge matters and what evidence counts? In F.K.Lester,Jr. (Ed.). *Second handbook of research on mathematics teaching and learning*. Charlotte, NC: Information Age Publishing. pp. 111-156; Monk

[36] http://www.rume.org/

The TUES program recently funded a comprehensive, consensus study of "Discipline Based Education Research" (DBER) in the natural sciences, to be undertaken by the Board on Science Education (BOSE) of the National Research Council. In 2008, with NSF support BOSE conducted two workshops to explore the research underlying new approaches and promising practices. The workshops illuminated the efficacy of selected promising practices while also highlighting weaknesses and gaps in the research requiring further study. As a major study with emphasis on research in subject-matter learning and teaching, the study builds upon previous reports by the National Research Council, such as *How People Learn.* It will also compare education research emerging from the different STEM disciplines in order to distinguish practices whose efficacy has been clearly demonstrated across the disciplines from those requiring further research to demonstrate efficacy beyond a particular discipline or classroom context. It will summarize the current scope and quality of DBER, suggest ways in which education researchers across scientific disciplines can learn from one another and from the broader research on learning, and identify important areas for future research.

Research on graduate education. The body of research available about graduate STEM education is less well-developed. Work from the well established research area of adult learning can inform graduate education, but does not necessarily focus directly on STEM. Graduate study is a process in which the student becomes an expert and there is a research literature on developing expertise (e.g., the role of deliberate practice by Ericsson and colleagues[37]) which also could be useful. The REESE program is funding a number of studies currently underway that examine specific questions about graduate STEM education. For example, a study recently funded by the REESE program investigates “the impacts of inquiry-based science teaching experiences on the development of STEM graduate students as researchers. The investigators will measure the trajectory and magnitude of change in teaching and research skills over time using an array of relevant and contextualized data sources”[38]. Noah Finkelstein and his colleagues at the University of Colorado are examining the role of context in the practice of physics graduate education. The project examines the issues at the levels of individuals, courses and departments. Bianca Bernstein at Arizona State University is documenting the key sources of discouragement and support for women in STEM doctoral programs and the creation of on-line resilience training modules.[39] And an investigation of the cognitive and learning practices in research laboratories in the emerging transdisciplinary field of integrated systems biology is being studied by Nancy Nersessian at Georgia Institute of Technology.[40] These studies promise to help build a useful base of evidence about how graduate students acquire the cognitive skills to succeed in different STEM disciplines, and continued scientific research will be essential to emerging catalytic work for improving graduate STEM education.

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[37] Ericsson KA, Krampe RT, Tesch-Römer C. The role of deliberate practice in the acquisition of expert performance. Psychol Rev. 1993;100:363-406.

[38] *Effects of Inquiry-Based Teaching Experiences on Graduate Students? Research Skill Development* (0723686, PI David Feldon): Project abstract at the University South Carolina Research Foundation

[39] *CareerBound: Internet-Delivered Resilience Training to Increase the Persistence of Women Ph.D. Students in STEM Fields* (061235, PI Bianca Bernstein)
Large Empirical Emerging Topics: CareerWise II: Enhanced Resilience Training for STEM Women in an Interactive, Multimodal Web-Based Environment (090618, PI Bianca Bernstein)

[40] *Becoming a 21st Century Scientist: Cognitive Practices, Identity Formation, and Learning in Integrative Systems Biology* (090615 PI Nancy Nersessian)

Conclusion

Continually improving the quality and effectiveness of STEM education in colleges and universities, for undergraduate and graduate students alike, is essential to building a STEM workforce ready for innovation and global leadership. This improvement requires tapping the potential of students from all groups, particularly those who have been traditionally underrepresented in STEM, attracting them to the study of STEM, and retaining their interest through degree completion and into the workforce. It also depends on creating the most stimulating and compelling educational settings and opportunities for STEM learning and research. These values drive NSF's investment strategies across undergraduate and graduate education. NSF programs directly support some of the nation's most promising students as they prepare for STEM careers, and catalyze and evaluate innovative approaches to improving STEM learning in higher education. A body of research on teaching and learning serves as the foundation and is growing alongside continued efforts to improve STEM education. NSF is leading innovative initiatives to prepare the workforce of the tomorrow during the critical undergraduate and graduate years.

Thank you for the opportunity to describe our efforts, and I would be happy to answer any questions at this time.

Table 1. Selected NSF Undergraduate and Graduate Learning Programs
Dollars in Millions

	FY 2010 Estimate	FY 2011 Request
Undergraduate Programs	**383.35**	**296.18**
Advanced Technological Education (ATE)	64.00	64.00
Louis Stokes Alliances for Minority Participation (LSAMP)	44.75	-
LSAMP Bridge to the Doctorate	*[17.00]*	*n/a*
Climate Change Education Program (CCE)	10.00	10.00
Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)	32.00	-
Tribal Colleges and Universities Program (TCUP)	13.35	-
Engineering Education (EE) Program	12.85	12.85
Federal Cyber Service: Scholarship for Service (SFS)	15.00	15.00
GEO-LSAMP Linkages	1.00	1.00
Research Experiences for Undergraduates (REU)	66.66	67.27
REU Sites	*[16.96]*	*[16.67]*
REU-Supplements	*[49.70]*	*[50.60]*
Robert Noyce Teacher Scholarship (NOYCE)	33.00	33.00
STEM Talent Expansion Program (STEP)	32.53	32.53
Transforming Undergraduate Education in Science, Technology, Engineering, & Mathematics (TUES), formerly CCLI	42.21	40.53
Undergraduate Biology Education (UBE)	15.00	20.00
Undergraduates Research Collaborative	1.00	-
Graduate Edcuation Programs	**323.28**	**332.81**
Robert Noyce Teacher Scholarship (NOYCE)-10A	22.00	22.00
Alliances for Graduate Education and the Professoriate (AGEP)	16.75	16.75
East Asia & Pacific Summer Ints. For U.S. Graduate Students (EAPSI)	2.40	2.40
GEO Teach	3.00	2.00
Graduate Research Diversity (GRD)	1.50	1.50
Graduate Research Fellowships (GRF)	135.92	158.24
Graduate Teaching Fellows in K-12 Education (GK-12)	54.31	52.85
Integrative Graduate Education & Research Traineeship (IGERT)	69.23	61.80

Next Generation Workforce (NGW)	1.00	-
Pan-American Advance Studies Institutes	0.10	0.20
Enhancing the Mathematical Sciences Workforce of the 21st Century (EMSW21), incl. Vertical Integration of Graduate Research & Education (VIGRE)	17.07	17.07
Undergraduate/Graduate Programs	**-**	**103.10**
Comprehensive Broadening Participation of Undergraduates in STEM	-	103.10
Total Undergradate/Graduate Support	**706.63**	**732.09**