An Examination Of NSF's Programs In Undergraduate Education

Norman L. Fortenberry,
Division of Undergraduate Education, National Science Foundation[1], Arlington, Virginia

Executive Summary

Stimulated, in part, by the release of a report by the Boyer Commission of the Carnegie Foundation for the Advancement of Teaching the National Science Foundation has conducted a review of its undergraduate programs as part of the process of developing a strategic plan for addressing shortcomings in the nation's undergraduate programs.

The Carnegie Report makes ten recommendations for improving undergraduate education. The publicity attending release of the report implied that undergraduate students are short-changed at the 125 research universities. However, the report itself includes a number of vignettes called "Signs of Change" that describe examples of outstanding programs for enhancing undergraduate education at these same institutions. Each highlighted program illustrates one or more ways of carrying out the ten recommended changes in undergraduate education. Many of the programs cited received at least partial support from the Foundation.

The Carnegie Report does not speak to the state of undergraduate education at comprehensive universities, baccalaureate (four-year) institutions, and community colleges (two-year institutions). Recent data show that 84% of all undergraduates are enrolled at these institutions and that 68% of all baccalaureate degrees are awarded by comprehensive universities and baccalaureate (four-year) institutions. Because faculty from all types of higher education institutions are eligible for NSF programs, NSF is having an impact on undergraduate education that extends well beyond the 125 institutions discussed in the Carnegie Report.

Two important reports pre-date the Carnegie Report in calling for reform in SMET undergraduate education-- *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (NSF 96-139) and *From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology* (National Research Council, 1996). Both reports raise important issues about undergraduate SMET education and recommend ways in which to correct them. A third report, *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* (National Research Council, 1999), post-dates the Carnegie Report, builds on previous work, and was written to assist top-level academic officers, faculty, and departments in the critical process of institutionalizing improvements in undergraduate SMET education, and to encourage members of the higher education SMET community to reflect on issues important to undergraduate education. Many of NSF's programs already encourage changes in line with the recommendations in these reports.

Over the past several years, the Foundation has been implementing strategies to enhance the effectiveness of its undergraduate programming by integrating research and education, laying the foundation for education reform, and increasing collaboration across organization boundaries. The new strategies emphasizing undergraduate education take into account and explicitly enhance, the interrelated roles of all segments of the preK-graduate educational enterprise. With sufficient resources, NSF can both strengthen its core programs and address unmet needs and opportunities. Unmet opportunities can be grouped into five areas: 1) systemic reform of curricula and institutions; 2) high-quality instruction by faculty; 3) educational research, materials, and methods; 4) emphasis on meeting the needs of diverse student populations; and 5) student support.

Introduction

The Carnegie Report

In 1998, the Boyer Commission on Educating Undergraduates in the Research University produced a report, *Reinventing Undergraduate Education: A Blueprint for America's Research Universities*. This report, released under the auspices of the Carnegie Foundation for the Advancement of Teaching, discusses education programs at 125 "Research I" and "Research II" universities in the United States. The report makes ten recommendations for improving undergraduate education (Table 1).

The publicity attending release of the report implied that undergraduate students are short-changed at the 125 research universities. However, the report itself includes a number of vignettes called "Signs of Change" that describe examples of outstanding programs at these same institutions that were implemented explicitly to enhance undergraduate education. Each highlighted program illustrates one or more ways of carrying out the ten recommended changes in undergraduate education. Many of the programs cited received at least partial support from the National Science Foundation (NSF).

In November 1997, NSF appointed a Working Group on Undergraduate Education. This Working Group was asked to recommend over-arching, integrative concepts that could be used to guide future investments, Foundation-wide, in undergraduate science, mathematics, engineering, and technology (SMET) education and to frame strategies for transforming the concepts into operational reality. In its May 1998 interim report, the Working Group identified five outcomes that should result from NSF's portfolio of programs in undergraduate education (Table 2).

Although NSF actively pursues all five outcomes, the fifth has proven particularly challenging. A growing number of programs, however, are being explicitly designed to raise college and university administrators' views of the importance of undergraduate teaching to a level that is on a par with that of research. Many of these programs also directly align with the Carnegie recommenda-

1. Make research-based learning the standard
2. Construct an inquiry-based freshman year
3. Build on the freshman foundation
4. Remove barriers to interdisciplinary education
5. Link communication skills and course work
6. Use information technology creatively
7. Culminate with a "capstone," integrative final course
8. Educate graduate students as apprentice teachers
9. Change faculty reward systems
10. Cultivate a sense of community

Table 1

tions.

In October 1998, NSF revised its merit review criteria requiring reviewers, for all programs, to consider how effectively investigators link their research and education responsibilities. A number of basic research programs at NSF now require provision of opportunities explicitly designed for the education of undergraduate students. These programs include: Engineering Research Centers, Science and Technology Centers, Materials Research Science and Engineering Centers, and Faculty Early Career Development.

Other NSF programs make use of the expertise of faculty from research institutions to inform curricular reform at the undergraduate level. Some of these programs also include research opportunities for undergraduate students as integral components of the projects. These programs include: the Louis Stokes Alliances for Minority Participation (LSAMP), NSF Collaboratives for Excellence in Teacher Preparation (CETP), and Combined Research-Curriculum Development (CRCD). The Course, Curriculum and Laboratory Improvement (CCLI) program, initiated in FY1999, provides maximum flexibility for faculty to develop and implement programs that enhance undergraduate education in SMET disciplines, as well as for graduate students and faculty to enhance their abilities to provide excellent undergraduate instruction in these fields.

It should be noted that the Carnegie Report does not speak to the state of undergraduate education at comprehensive universities, baccalaureate (four-year) institutions, and community colleges (two-year institutions). Recent data show that 84% of all undergraduates are enrolled at these institutions and that 68% of all baccalaureate degrees are awarded by comprehensive universities and baccalaureate (four-year) institutions. Because faculty from all types of higher education institutions are eligible for NSF programs, NSF is having an impact on undergraduate education that extends well beyond the 125 institutions discussed in the Carnegie Report.

NSF Undergraduate Education and Training in Context

Undergraduate education must be considered within the context of the Foundation's entire education and training portfolio.

As illustrated in Figure 1, undergraduate education plays a central role in the education continuum, receiving students from, and providing teachers to, the K-12 sector; providing students to, and receiving faculty from, the graduate sector. Thus, undergraduate activities are directly affected by, and have great effect upon, activities in the other education sectors. The Foundation recognizes and builds upon these linkages in its programming. In the FY 1999 NSF Strategic Plan under the Government Performance and Results Act (GPRA), the Foundation's undergraduate education and training programs are primarily categorized under Goal #3 (a diverse, globally-oriented workforce of scientists and engineers) and Goal #4 (improved achievement in mathematics and science skills needed by all Americans). A few programs are categorized under Goal #1 (discoveries at and across the frontiers of science and engineering). Appendix A provides a list of NSF education and training programs as categorized under GPRA, including higher education programs that are the subject of this report.

Two important reports pre-date the Carnegie Report in calling for reform in SMET undergraduate education. *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (NSF 96-139) and *From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology* (National Research Council, 1996) raise issues about undergraduate SMET education and recommend ways in which to address important issues. A third report, *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* (National Research Council, 1999), was written to assist top-level academic officers, individual faculty, and academic departments in the critical process of institutionalizing improvements in undergraduate SMET education and to encourage members of the higher education SMET community to reflect on a number of impor-

1. Availability of high quality SMET education for all undergraduate students
2. Effectiveness in teaching and scholarship for SMET faculty in all types of institutions
3. Support of a robust research base that strengthens education in SMET disciplines
4. Development of measures and studies that accurately assess quality of undergraduate SMET education
5. Collective responsibility and leadership for improving undergraduate SMET education.

Table 2

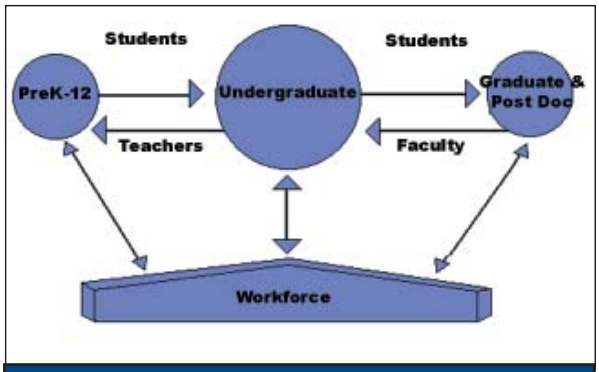

Figure 1. Education and Training Portfolio

tant issues related to undergraduate education. As noted, NSF has been moving relatively aggressively in these directions over the past several years. Many of its programs already encourage changes in line with the recommendations in these reports. New and revised programs will continue to provide opportunities for developing and implementing the recommended reforms.

Major NSF Undergraduate Programs

The Foundation's undergraduate education and training programs are designed to impact specific components of the undergraduate education system and, in the aggregate, provide a foundation for making overall changes in the system. Ultimately, all programs seek to enhance student learning of SMET topics and preparation for a variety of careers. Programs achieve direct leverage by seeking to impact five areas (Table 3).

Table 4 identifies those NSF programs with a major focus on SMET undergraduate education. A "1" indicates a major emphasis, while "2" indicates a secondary emphasis. Descriptions of the individual programs follow. (*Appendix A*, in addition to targeted undergraduate programs themselves, includes other NSF programs that contain significant components that also contribute to the education of undergraduates.)

Action Agenda for Systemic Engineering Education Reform supports development of a new engineering education paradigm that is characterized by active, project-based and context-based learning; horizontal and vertical integration of subject matter; close interaction with industry; broad use of information technology; and successful participation of underrepresented groups in engineering.

Advanced Technological Education (ATE) promotes improvement in the education of science and engineering technicians at undergraduate and secondary school levels. Two-year colleges play leadership roles and are a focus in all projects. The Program has two components: (1) *Centers of Excellence* that are comprehensive national or regional resources providing models and leadership for other projects and serving as clearinghouses for educational materials and methods; and (2) *Projects* that focus more narrowly on design and implementation of new materials, courses, laboratories, and curricula; adaptation of exemplary educational materials, courses, and curricula in new educational settings; preparation and professional development of college faculty and secondary school teachers; and internships and field experiences for students, faculty, and teachers. The ATE program supports both specialized technology courses and the core science and mathematics courses that serve as their prerequisites.

Course, Curriculum, and Laboratory Improvement (CCLI) seeks to improve the quality of SMET education for all undergraduate students by targeting activities affecting learning environments, content, and educational practices at the undergraduate level. The Program supports development of new educational materials (i.e., courses, curricula), emphasizing materials and related instructional practices that are suitable for national distribution; adaptation and implementation of previously developed exemplary materials and practices; and national dissemination projects that provide faculty development opportunities, introducing current and future faculty to new course content and effective educational practices, as well as allowing them to interact meaningfully with experts in the field.

NSF Collaboratives for Excellence in Teacher Preparation (CETP) seeks to make significant and systemic improvements in the preparation of prospective

1. **Curricula and Institutions**
   Providing infrastructure and systemic changes that may also include changes in disciplines across institutions or changes within institutions across disciplines
2. **Faculty**
   Providing for preparation of future members and professional enhancement of existing members of the undergraduate instructional workforce
3. **Courses and Laboratories**
   Providing for changes in educational materials and/or instructional methods in use
4. **Diversity**
   Providing for special emphases directed at increasing the ability of students to compete successfully in SMET courses or to earn associate or baccalaureate degrees in SMET disciplines, irrespective of gender, ethnicity, or physical disability
5. **Students**
   Providing direct personal and financial support to individual students

Table 3: Five Areas of Impact for SMET Education

Program	Curricula/ Institution	Faculty	Courses/ Laboratories	Diversity	Students
Action Agenda for Systemic Engineering Education Reform	2	1	1	1	
Advanced Technological Education (ATE)	1	1	1		2
Course, Curriculum, and Laboratory Improvement (CCLI)	2	1	1		
NSF Collaboratives for Excellence in Teacher Preparation (CETP)	1		1	2	2
Educational Innovations	2		1		
Historically Black Colleges and Universities—Undergraduate Program (HBCU-UP)		1	1	1	
Louis Stokes Alliances for Minority Participation (LSAMP)	1	1		1	1
Minority Institutions Infrastructure (MI-I)	2		1	1	
Research Experiences in Undergraduate Institutions (REU)					1
Research Opportunity Awards (ROA)		1			
Research in Undergraduate Institutions (RUI)		1			1
Collaborative Research at Undergraduate Institutions (C-RUI)		1			1
Undergraduate Mentoring in Environmental Biology (UMEB)				1	1

Table 4: Focus of NSF Undergraduate Education Programs

K-12 teachers of science, mathematics, and technology, ensuring their effectiveness in delivering standards-based education and in responding to varied learning styles, backgrounds, and needs of their students. The CETP program also promotes development of effective strategies for increasing recruitment of quality K-12 teachers.

Educational Innovations supports innovative educational activities that transfer research results into undergraduate curricula in computer and information science and engineering.

HBCU-Undergraduate Program (HBCU-UP) supports Historically Black Colleges and Universities (HBCUs) to strengthen their SMET education and research infrastructure, including support for faculty, research experiences for undergraduates, and scientific instrumentation.

Louis Stokes Alliances for Minority Participation (LSAMP) supports establishment of comprehensive approaches for increasing the quantity and quality of underrepresented minorities who successfully earn baccalaureate degrees in science, mathematics, and engineering and for increasing the number of students who pursue graduate study in these fields.

Minority Institutions Infrastructure (MI-I) seeks to increase minority participation in the academic and research ar-

eas of computer and information science and engineering, with particular emphasis on significantly expanding the numbers of minority students attracted to, and retained in, these disciplines.

Research Experiences for Undergraduates (REU) provides opportunities for undergraduates to participate in faculty-guided mathematics, science and engineering research projects.

Research Opportunity Awards (ROA) provides support for faculty at institutions (including middle and secondary schools) with limited opportunities to participate in research under the aegis of NSF investigators at other institutions.

Research in Undergraduate Institutions (RUI) supports high quality research by faculty with active involvement of undergraduate students in order to strengthen the research environment in academic departments at institutions that are oriented primarily toward undergraduate instruction.

Needs and Opportunities

Evaluations carried out on many of the NSF programs described above provide evidence that these programs achieve stated goals. Over time, however, in response both to experience gained through program operations and to emerging opportunities, evaluations, and feedback of experts in the field, program modifications are identified that show promise for broadening program impact. These modifications generally involve incorporation of best practices and/or pursuing innovative strategies that capitalize on natural synergies across program components.

For example, a major goal of the Course and Curriculum Development (CCD) program, a precursor to the CCLI program, was to create exemplary undergraduate education materials for national dissemination. An evaluation of the CCD program found that exemplary materials and instructional strategies were indeed developed, but noted that successful implementation was most likely to occur at the developer's institution and did not occur at other institutions to the extent desired by NSF. Consequently, the CCLI program was designed with an *Adaptation and Implementation (A&I)* track intended to remove two major barriers to successful transfer. Under *A&I,* institutions and departments seeking to implement materials and instructional strategies developed elsewhere can now obtain support both for their adaptation and for the faculty professional development critical for their success.

Over the past several years, the Foundation has been implementing strategies to enhance the effectiveness of its programming at the undergraduate level. The approach taken integrates research and education, focuses on various aspects of undergraduate education, and lays the foundation for education reform. The strategies are heavily oriented towards developing increased integration of efforts across new lines. They build upon a strong existing program base and provide unique new opportunities in teaching and scholarship that benefit students, faculty, and institutions. The new strategies emphasizing undergraduate education take into account, and explicitly enhance, the interrelated roles of all segments of the preK-graduate educational enterprise.

Unmet needs and opportunities are framed within the context of the existing program portfolio. The core of the current set of programs provides for renewal of the undergraduate curriculum. All other current and envisioned activities assume that the base set of programs are fully implemented and robust. In undergraduate education, unmet needs can be grouped into five major areas that parallel the leverage points identified in Section I above.

Systemic Reform of Higher Education Curricula and Institutions

Undergraduate education takes place within the context of a complex, interrelated system. Change—focused on students, faculty, courses and laboratories, curricula and institutions—is difficult to maintain over time unless all parts of the system support that change. For example, faculty in one department may implement new curriculum to encourage active forms of student learning in all courses. However, if courses in other departments fail to undergo similar changes, it may prove impossible to attain requisite flexible schedules and classroom design. Or, if colleagues at other institutions do not subscribe to similar reforms, faculty may find themselves professionally isolated and have little incentive to sustain reforms over the long term.

Experience with undergraduate SMET education reform has demonstrated the strong degree to which various parts of the educational enterprise must change to ensure significant and sustained improvements in student learning. Two relatively unique types of infrastructure development are critical to reform:

Reform within Institutions When a reasonably large change in pedagogy is required within a given course, students and faculty will benefit most if prerequisite, follow-on, and other complementary courses provide for smooth transitions that accommodate the new course structure. In turn, the advising system, the workloads experienced by the students and faculty, the daily course schedule, and a whole host of other parts of the system may need to change as well. Pervasive changes within an institution require building a comprehensive vertical infrastructure. Curriculum reform mandates that attention be given to all manner of institutional changes to guarantee the success and permanence of the reform effort. The Foundation has experience with such comprehensive efforts through (1) engineering curriculum reform efforts; (2) a pilot institution-wide reform activity that simultaneously enacted revisions to courses and enhancement of student support systems, as well as professional development of faculty and graduate students who would serve as future faculty; and (3) several recognition programs for institutions already actively engaged in exemplary reform activities. The HBCU—Undergraduate Program and the Minority Institutions Infrastructure programs are designed to provide support consistent with these goals.

Knowledge and skills in SMET disciplines are not required only by those desiring to go into technical careers; all students must be prepared to meet the increasing technological sophistication demanded of the workplace and society. It is important to encourage the acquisition of foundational knowledge appropriate to

various career paths and to do so through use of inquiry-rich instructional methods and education materials. The inquiry process develops habits of mind that promote problem-solving and critical thinking skills while strengthening understanding of basic concepts. Within higher education institutions, disciplines do not exist in isolation. Institutions must foster cross-disciplinary learning communities and link curricular and co-curricular effort that improve student access to quality resources and their ultimate mastery of concepts and skills.

The intellectual and creative strengths of the SMET community need to be applied more forcefully to the preparation of future K-12 teachers. Experience with the NSF Collaboratives for Teacher Preparation (CETP) program and other undergraduate teacher preparation efforts has shown that the quality and attitudes of faculty responsible for educating future teachers are critical to the preparation of these undergraduates. Since the inception of the CETP program, NSF has pursued a strategy of bringing together faculty from schools of education and colleges of arts and sciences to ensure appropriate grounding in both pedagogy and content. Still, greater attention is needed to engage SMET faculty in integrated efforts for both the pre-service preparation and in-service enhancement of teachers. One avenue to explore is facilitating learning communities of K-16 teachers and faculty engaging in the creation, synthesis, and delivery of knowledge.

Reform within Disciplines Across the undergraduate sector, disciplinary structures and institutional cultures are reinforced and maintained through accreditation criteria and professional interactions among faculty within disciplines. Major reforms within disciplines—that affect course content in significant ways—will only be successful if efforts cut across institutions. For example, as a trial effort, the Chemistry Initiative supported by NSF actively engaged faculty at more that 50 institutions to change introductory undergraduate chemistry courses. National dialogue among chemists across the nation allowed the five supported projects to propose more dramatic curricular changes than any one department alone would find reasonable. In addition, scale involvement in this initiative was sufficient to exert influence on national chemistry examinations and other systemic issues. Thus, curricular reform within other disciplines likewise will require large-scale, simultaneous efforts across the nation in order to produce comprehensive change.

Assessment The ultimate beneficiaries of investments in undergraduate courses, laboratories, curricula and faculty enhancement are the students. Thorough evaluations of these efforts, as well as those of departments and institutions, require assessment of student understanding of concepts, as well as problem solving and critical thinking skills. Adding to the complexity in developing useful instruments is the diversity of faculty, disciplines, and institutions in higher education.

To date, there are no broadly accepted assessments of undergraduate student SMET learning and a critical need exists for undergraduate student assessment frameworks and measurable indicators. Particularly useful would be assessments developed with explicit attention to the knowledge, skills, and abilities expected of undergraduate degree recipients. Such assessments could be applied at various levels of examination and would empower individual faculty to improve their instruction, departments to improve their programs, and institutions to further progress toward systemic reform. Higher education assessment activities should provide frameworks and measurable indicators to evaluate: (1) student academic achievement and affective learning outcomes within a program of study that accounts for differences in learning styles, rates of intellectual development, and career goals, and (2) the quality of departmental and institutional environments in support of student learning (e.g., faculty teaching, academic support systems).

High Quality Instruction by Faculty

Educational Resources In order to maximize the rate at which innovations in undergraduate SMET education are implemented and institutionalized, faculty must be given continuing opportunities to maintain fluency with the latest developments in their fields. The information technology revolution makes possible realization of a connective infrastructure across NSF's research and education programs that ensures broad and universal access to the highest quality research and education products and results. Over the past three years, NSF has been exploring application of digital library technology to K-16 education and has initiated development of a National Science, Mathematics, Engineering and Technology Education (SMETE) Digital Library (NSDL). The NSDL will provide wide access to the very best standards- and inquiry-based SMET educational materials and instructional strategies from elementary through graduate school. The Library builds on our nation's investments in information technology, fostering and supporting collaborations among new and future teachers, faculty, and students.

The NSDL is a large undertaking, requiring major investment in development and maintenance. Building the NSDL requires development of a central management structure and a selective core collection/repository of exemplary content. Its maintenance requires continuous updating of hardware and software components; revisions to standards and protocols for accessibility, reliability, and stability; and general oversight of distributed services. The Library platform is the product of collaboration between the Directorates for Education and Human Resources (EHR) and Computer and Information Science and Engineering (CISE) and builds on foundational work supported by the NSF-led multi-agency Digital Libraries Initiative. The NSDL will be a major vehicle for the dissemination of resources developed by NSF core K-16 education programs and will be enhanced by incorporating efforts of the extant Louis Stokes Alliances for Minority Participation Virtual Institute (LSAMP-VI), an integrated network of four specialized Virtual Centers, that synthesizes and disseminates information on educational policy and practice. Through support of instructional innovation and broad access to high quality educational materials, the NSDL initiative promotes improved achievement in SMET skills needed by all Americans.

Opportunities to Maintain Currency Faculty principally engaged in research require opportunities to enhance

their own instructional efforts by learning and applying the latest results from pedagogical research. Similarly, faculty who principally teach undergraduates need opportunities to learn and apply the latest research findings within their disciplines. The Course, Curriculum, and Laboratory Development (CCLI) program provides limited support for such activities within the context of course development and a few large-scale multidisciplinary grants. The Research Opportunity Awards (ROA) program and the Collaborative Research in Undergraduate Institutions (C-RUI) program for the biological sciences provide limited opportunities for faculty in undergraduate and research institutions to engage jointly in disciplinary research. More extensive opportunities for faculty development are needed.

Exemplary Role Models Although a number of NSF programs have succeeded in encouraging faculty at research institutions to take increased responsibility for educating undergraduates, additional strategies are needed to bring further success in this effort. The Foundation actively seeks out opportunities to emphasize the importance of undergraduate SMET teaching, by recognizing and encouraging efforts of research faculty who actively engage in creative instruction at the introductory undergraduate level both for students who plan to pursue advanced study and related careers, as well as those who seek to follow other courses of endeavor. Such distinguished teaching scholars should be recognized for developing interdisciplinary courses and materials, promoting appropriate uses of technology, and focusing attention on the undergraduate preparation of prospective K-12 teachers and they can serve as role models for other faculty. Through national recognition, these scholars could serve as catalysts for improving the state of undergraduate SMET teaching and learning, exploring instructional scholarship, developing new courses, and experimenting with new pedagogy. They could give public lectures for general audiences to make clear the connections between research discoveries and their societal applications. Finally, they could serve as mentors to faculty, graduate students, and undergraduates, thus providing motivation for other faculty to improve undergraduate education and for students to enter careers in science and engineering.

Developing the Next Generation of Faculty As noted previously, the success of teacher preparation depends upon providing undergraduate students with knowledge of SMET content and instructional excellence. The same principle applies to undergraduate education in general—greater attention needs to be applied to producing future faculty who are as well prepared to engage in creative undergraduate instruction, as they are to engage in innovative research.

Educational Research, Materials, and Methods

Applied Research Base A relatively large body of research literature exists on many aspects of teaching and learning. The vast majority of this research, however, has been focused on preK-12 students. A notable exception has been NSF-supported research on student misconceptions and developing conceptual understanding within the discipline of physics. This effort needs to extend to other disciplines and to support studies that relate to the types of SMET classrooms and students that characterize colleges today. Additional studies are needed to determine why certain groups of students choose not to be in SMET courses, and, importantly, to identify those factors that are most important in influencing students to enroll and excel in SMET courses.

This type of research is characterized by the interplay between development of theory and empirical validation of theoretical constructs that expand concepts, techniques, and models of effective higher education in SMET disciplines. Learning of SMET subjects within higher education can be improved by identifying and providing for implementation of effective instructional strategies, learning environments, and institutional practices. Research should inform this improvement across a number of dimensions: (1) increasing understanding of effective teaching and learning within different classroom settings and among courses at different levels as it relates to student progression through higher education and to faculty ability and performance; (2) developing insights into student learning and instructional practices in SMET disciplines; (3) identifying social, cultural, and institutional factors that affect participation in SMET fields; and, (4) investigating the effect of educational technologies on how students think, learn, and approach/solve problems. Research and related studies should also develop information on more global aspects of the higher education system, including (1) indicators to measure success in SMET fields, to evaluate institutional commitment to education reform, and to monitor enablers, barriers, and determinants of institutional innovation, systemic change, performance improvement, and organizational change, and (2) longitudinal studies to determine which education factors are important over the long run in terms of career choice, career success, and transitions between the academic and employment sectors.

Discovery and Inquiry-based Experiences Over the last decade, NSF programs, coupled with well-publicized studies and reports, have been responsible for a dramatic increase in the number of institutions that use discovery-based and inquiry-based laboratory experiences as the core of their SMET courses. Although student access to modern laboratory equipment has always been a critical component of education in science and engineering disciplines, the need for such equipment has escalated as a result of the demands of these more active forms of student learning. Often a department will receive external support for an initial round of equipment, and institutions struggle to replace these instruments periodically. Serious questions remain about the long-term viability of these active forms of learning if equipment needs cannot be met. A limited level of support, as compared to demand, for discovery and inquiry-based experiences is provided within NSF's Course, Curriculum, and Laboratory Improvement (CCLI) and Combined Research and Curriculum Development (CRCD) programs.

The NSF-wide Research Experiences for Undergraduates (REU) program has demonstrated the value of authentic research experiences in motivating students to pursue careers in SMET. Similarly, public service and motivational aspects of service-learning are increasingly being recognized as part of a SMET education. Modern instrumentation should be avail-

able for wide use throughout undergraduate instruction, whether that instruction is course-based, part of on-going research activities, or a component of a service-learning experience. For example, as part of a chemistry laboratory project, undergraduates could be provided equipment necessary to monitor effluents in a stream to help a municipality monitor its pollution reduction efforts; to measure the level of lead in the soil of abandoned lots to ensure a safe play areas for neighborhood children; or to monitor levels of pesticides and herbicides in drainage water as a service to the local agricultural community.

Diversity Emphasis in All Programs

All NSF undergraduate programs include some attention to issues of diversity, though perhaps not as a primary or secondary emphasis. Of particular note in recent years is the Louis Stokes Alliances for Minority Participation (LSAMP) program that has identified a number of highly effective mechanisms for increasing participation of underrepresented groups in the mainstream of undergraduate SMET education. The results of these efforts now need to be disseminated widely and implemented throughout other undergraduate programs. To ensure greater and more effective participation of all segments of the nation's human resource base in the scientific and technological workforce, developments in three areas are needed.

Access Building on previous NSF-funded efforts, a connective infrastructure across all research and education programs is needed to assure broad and universal access to the highest quality research and education products and results. The development of a National SMETE Digital Library (NSDL) represents one important component of such an infrastructure. In addition, the NSDL network would provide opportunities to disseminate broadly programmatic innovations identified in other programs.

Networking Building on the LSAMP Virtual Institutes, information technology linkages need to be established among institutions funded by the LSAMP program, Historically Black Colleges and Universities—Undergraduate Program (HBCU-UP), and NSF Centers programs (e.g., Science and Technology Centers (STCs), Engineering Research Centers (ERCs), Materials Research Science and Engineering Centers (MRSECs)). This type of networking would bring the expertise of the LSAMP and HBCU-UP institutions in increasing the numbers of underrepresented minorities who earn SMET baccalaureate degrees to institutions participating in the NSF-supported Centers. Over time the network could expand to include other minority serving institutions not previously associated with NSF centers. All participating institutions would share knowledge and materials, gaining broader access to faculty expertise, programs of study, research opportunities, role models, and general information (through online learning resources and virtual workshops) and developing an extended student community. Best practices with respect to recruitment of students, building learning communities, tutoring, mentoring, career awareness, research awareness, research experience, and employment opportunities would be featured. Specialized virtual student communities would provide peer support for individuals who currently find themselves isolated due to research interest, gender, ethnicity, or physical ability. The network would have the potential to foster the level of collaboration and connectivity necessary for producing the 21st century workforce.

Creative Approaches Building upon the successful support of projects to pilot, adapt and implement innovations in SMET curriculum development, innovative pilots and implementation sites of creative approaches need to be supported to increase participation by underserved populations (ethnic minorities, women, and persons with disabilities) in the scientific workplace. NSF should identify institutions which are "under-participating" in NSF's research and education programs, have significant enrollments of underserved populations, and seek to apply successful models to provide incentives for enhanced participation by these institutions in NSF grant programs. Attention is also required to the needs of members of underserved populations in highly competitive institutions where they may be relatively few in number and therefore isolated. NSF should expand support for the design, conduct, and dissemination of model projects to promote interest, retention, and advancement in SMET educational and career paths by women, minorities and persons with disabilities are needed. As indicated above, such efforts should be derived from a strong educational research base.

Student Support

Affective Support As larger percentages of high school graduates pursue collegiate studies, it becomes increasingly important to provide guidance on how to succeed in college within and beyond the formal curriculum. More than simply how to study are issues of career identification and preparation. The rise of service learning, as well as growing recognition that the formal classroom is only a small part of the undergraduate learning environment, means that effective educational programs promote student/faculty, student/student, and advising, as well as community and other interactions to address the affective component of undergraduate education. Addressing such concerns requires increased skill in student counseling and mentoring by teachers and faculty and explicit efforts to facilitate transitions within the academic continuum (e.g., high school to undergraduate, two-year to four-year college, undergraduate to graduate) and between various academic levels and the workforce. In this regard, applicable lessons learned within the LSAMP and Minority Graduate Education (MGE) programs should be reflected across NSF's undergraduate programming irrespective of whether minority students are the principal audience. The approach of the Action Agenda for Systemic Engineering Education Reform program of looking at the desired outcomes of an entire undergraduate education and structuring activities in support of those outcomes also holds promise.

Financial Support Financial concerns can also intrude on the learning experience. Students with limited economic resources, and, consequently, heavy work schedules, find it difficult to make time available for laboratories and other demands of undergraduate SMET curricula. Recent data have made clear the superiority of grants to loans in regards to student academic persistence and graduation.

Beginning in FY 1999 and extending

through FY 2001, the American Competitiveness and Workforce Improvement Act of 1998 (P.L. 105-277) provides NSF with a portion of the H-1B nonimmigrant petitioner fees to support scholarships for low-income students, enabling them to pursue associate, baccalaureate, or graduate degrees in computer science, computer technology, engineering, engineering technology, or mathematics. By setting aside a limited portion of funds for K-12 education reform and year-round academic enrichment programs, the Act also highlights the need to develop strong science and mathematics skills early in students' academic careers. The NSF Computer Science, Engineering, and Mathematics Scholarships (CSEMS) program implements the scholarship portion of the Act which limits the level of support provided to individual students to $2,500 per year—a level which is significantly below tuition levels of most baccalaureate and graduate programs. The CSEMS effort is one focused approach to addressing a portion of the financial barriers facing a limited subset of students. More broad-based efforts are needed to address the full spectrum of potential SMET professionals.

Next Steps

This preliminary plan has identified NSF's current portfolio of undergraduate programs, as well as some unmet needs and opportunities. The next step in development of a strategic plan is to gauge the views of relevant communities of employers, faculty, students, and policy makers to determine what changes—subtractions as well as augmentations—may be required to achieve a portfolio that better meets national needs. We welcome your comments.

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Appendix A

NSF EDUCATION AND TRAINING PROGRAMS

Programs aligned with NSF GPRA Goal #1: *Discoveries at and across the frontiers of science and engineering*

HIGHER EDUCATION LEVEL

Directorate for Education and Human Resources

Centers of Research Excellence in Science and Technology (CREST)—strengthen the research and education capabilities of the nation's most productive minority institutions through support development of centers that integrate education and research. The CREST Centers conduct basic research and serve to increase the number of underrepresented minorities with Ph.D.s in SMET fields.

Research on Education, Policy, and Practice (REPP)—supports cultivation of a research base for implementing innovative undergraduate reform strategies, as well as ways of improving graduate, professional, informal, and lifelong learning.

Directorate for Engineering

Engineering Research Centers (ERC)—provide integrated environments for academe and industry to focus on next-generation advances in complex engineered systems important for the nation's future. The ERC Centers provide intellectual forums that promote collaboration of industry, faculty, and students in the resolution of generic, long-range challenges, producing steady advances in technology and their speedy transition to the marketplace.

Directorate for Mathematical and Physical Sciences

Materials Research Science and Engineering Centers (MRSEC)—support interdisciplinary and multidisciplinary materials research and education while addressing fundamental problems in science and engineering that are important to society. These Centers require the basic research community to explore more effective ways to educate students, to encourage student research participation, and to develop curricula.

Cross Directorate—NSF-wide

Science and Technology Centers (STC)—fund important basic research and education activities and encourage technology transfer and innovative approaches to interdisciplinary problems. The STCs require the basic research community to explore more effective ways to educate graduate and undergraduate students and to encourage student participation.

GRADES K-12 LEVEL

Directorate for Education and Human Resources

Research on Education, Policy, and Practice (REPP)—develops a knowledge base for implementing innovative elementary through secondary reform strategies, as well as ways of improving and informal and lifelong learning.

Programs aligned with NSF GPRA Goal #2: *Connections between discoveries and their use in service to society.*

PUBLIC LITERACY

Directorate for Education and Human Resources

Informal Science Education (ISE)—supports rich and stimulating opportunities outside formal school settings, where individuals of all ages, interests, and backgrounds increase their appreciation and understanding of science, mathematics, engineering, and technology. Learning opportunities take place in diverse environments (e.g., museums, aquaria, zoos, botanical gardens, community groups) and in a variety of media (e.g., broadcast, film, interactive technology, print).

Programs aligned with NSF GPRA Goal #3: ***A diverse, globally-oriented workforce of scientists and engineers***

HIGHER EDUCATION LEVEL

Directorate for Education and Human Resources

Louis Stokes Alliances for Minority Participation (LSAMP)—supports establishment of comprehensive approaches to increase the quantity and quality of underrepresented minorities who successfully earn baccalaureate degrees in science, mathematics, and engineering, and to increase the number of those graduates who go on for graduate study in these fields.

Minority Graduate Education (MGE)—supports development and implementation of innovative models for recruiting, mentoring, and retention of minority students in SMET doctoral programs, as well as development of effective strategies for identifying and supporting underrepresented minorities who want to pursue academic careers.

HBCU Undergraduate Program (HBCU-UP)—supports Historically Black Colleges and Universities (HBCUs) to strengthen their SMET education and research infrastructure, including support for faculty, research experiences for undergraduates, and scientific instrumentation. A Program goal is to increase the number and graduation rate of well-prepared underrepresented minority SMET baccalaureate degree graduates to be substantially increased at grantee institutions.

NSF Graduate Research Fellowships (including Women in Engineering and Computer and Information Science Awards)—ensure vitality of the U.S. human resource base of science, mathematics, and engineering by providing three-year graduate fellowships awards to outstanding students who are expected to contribute significantly to research, teaching, and industrial applications in science, mathematics, and engineering.

NSF Postdoctoral Fellowships In Science, Mathematics, Engineering and Technology Education (PFSMETE) — supports Ph.D. graduates in SMET disciplines in addressing challenging issues in education across a broad spectrum of institutions and education levels. Fellows are expected to assume leadership roles in contributing to the Nation's education enterprise.

Advanced Technological Education (ATE)—promotes improvement in the education of science and engineering technicians at undergraduate and the secondary school levels. The Program focuses on two-year colleges and emphasizes importance of their leadership roles in all projects. Large-scale Centers of Excellence are comprehensive national or regional resources that provide models and leadership for other projects and act as clearinghouses for educational materials and methods; smaller, more narrowly focused projects support design and implementation of new materials, courses, laboratories, and curricula; adaptation of exemplary educational materials, courses, and curricula in new educational settings; preparation and professional development of college faculty and secondary school teachers; and internships and field experiences for students, faculty, and teachers. The Program emphasizes the need to strengthen both specialized technology courses and the core science and mathematics courses that serve as prerequisites for such courses.

Directorate for Biological Sciences

The Collaborative Research at Undergraduate Institutions (C-RUI)— supports multidisciplinary collaborative research groups at primarily undergraduate institutions. These groups are composed of three faculty members representing at least two disciplinary areas, and up to ten undergraduates who will work on a project whose subject matter is primarily in the biological sciences and will require a cross-disciplinary approach.

Undergraduate Mentoring in Environmental Biology(UMEB)—supports talented undergraduate students to gain research experience and an enriched educational environment in environmental biology. Proposed projects should include major emphasis on direct student participation in research during the academic year and summer, with individual students continuing in the program for more tan one year. Projects should emphasize factors that encourage and enable members of underrepresented groups to enter and remain in environmental biology.

Directorate for Computer and Information Science and Engineering

Educational Innovations—supports innovative educational activities that transfer research results into undergraduate curricula in computer and information science and engineering.

Minority Institutions Infrastructure (MI-I)—provides funding to increase minority participation in the academic and research areas supported by the CISE Directorate, with particular emphasis on significantly expanding the numbers of minority students attracted to, and retained in, supported disciplines. The MI-I effort supports minority student involvement in research programs, curriculum development projects, mentoring, and outreach at institutions with student enrollment of more than 50 percent from minority groups underrepresented in advanced levels of science and engineering.

Directorate for Engineering

Action Agenda for Systemic Engineering Education Reform—supports development of a new engineering education paradigm, characterized by active, project based learning; horizontal and vertical integration of subject matter; introduction of mathematical and scientific concepts in the context of application; close interaction with industry; broad use of information technology; a faculty devoted to developing emerging professionals as mentors and coaches; and successful participation of underrepresented

groups in engineering.

Combined Research-Curriculum Development (CRCD)—addresses the need to increase the rate at which research advances in important technology areas are incorporated into the upper level undergraduate and graduate engineering curricula.

Directorate for Mathematical and Physical Sciences

Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE) —prepares undergraduate and graduate students, as well as postdoctoral fellows for the broad range of opportunities available to individuals with training in the mathematical sciences. The Program encourages departments in the mathematical sciences to consider the full spectrum of education activities and their integration with research, with particular attention to the interaction of scholars across boundaries of academic age and departmental standing.

Cross Directorate — NSF-wide

Research Experiences for Undergraduates (REU) —provides opportunities for undergraduates to participate in faculty-guided mathematics, science and engineering research projects.

Research in Undergraduate Institutions (RUI)—supports high quality research by faculty with active involvement of undergraduate students in order to strengthen the research environment in academic departments at institutions that are oriented primarily toward undergraduate instruction.

Research Opportunity Awards (ROA)—supports faculty at institutions with limited research opportunities (including middle and secondary schools) to participate in research under the mentorship of NSF investigators at other institutions.

Major Research Instrumentation (MRI)—supports improvement of the scientific and engineering equipment available for research and research training in academic institutions. The MRI program seeks to improve the quality and expand the scope of research and research training in science and engineering, and to foster the integration of research and education by providing instrumentation for research-intensive learning environments.

Integrative Graduate Education and Research Training (IGERT)—enables development of innovative, research-based, graduate education and training activities to produce a diverse group of new scientists and engineers, well-prepared for a broad spectrum of career opportunities. The IGERT program requires a multidisciplinary research theme organized around a diverse group of investigators from Ph.D.-granting institutions.

Professional Opportunities for Women in Research and Education (POWRE)—provides outstanding women with funding opportunities not ordinarily available through regular research and education grants. Goals of the POWRE are to increase representation of women in the nation's science and engineering workforce and encourage their professional advancement.

Faculty Early Career Development (CAREER)—provides junior faculty, within the context of their overall career development, support to engage in research and education of the highest quality and in the broadest sense. The Program is focused on early development of academic careers dedicated to stimulating the discovery process in which the excitement of research is enhanced by inspired teaching and enthusiastic learning.

Minority Research Planning Grants (MRPG)—support preliminary studies and other activities related to the development of competitive research projects and proposals by minority scientists and engineers who have not previously had independent federal research funding. The goal of MRPG is to increase the number of new minority investigators participating in NSF's research programs.

Minority Career Advancement Awards (CAA)—supports research opportunities of minority scientists and engineers by helping experienced investigators acquire expertise in new areas to enhance their research capability, or by making it possible for those who have had a significant research career interruption to update research skills for re-entry into their respective fields.

K-12 LEVEL

Directorate for Education and Human Resources

Teacher Enhancement (TE)—provides professional development opportunities to broaden and deepen the disciplinary and pedagogical knowledge of preK-12 teachers, improving their ability to deliver rich and challenging education in science, mathematics, and technology to all students.

NSF Collaboratives for Excellence in Teacher Preparation (CETP)—seeks significant and systemic improvement in the SMET preparation of prospective preK-12 teachers by providing for the recruitment and development of future teachers who are successful in addressing the varied learning styles, backgrounds, and needs of their students.

Presidential Awards for Excellence in Mathematics and Science Teaching (PAEMST) — recognizes exemplary career performance of science and mathematics teachers, grades K-12, in each state and the four U.S. jurisdictions. Award recipients serve as role models for their colleagues and as leaders in the improvement of science and mathematics education.

Programs aligned with NSF GPRA Goal #4: *Improved achievement in mathematics and science skills needed by all Americans.*

HIGHER EDUCATION LEVEL

Directorate for Education and Human Resources

Course, Curriculum, and Laboratory Improvement (CCLI)—Seeks to improve the quality of SMET education for all undergraduate students by targeting activities affecting learning environments, content, and educational practices at the undergraduate level. Provides for projects in the areas of Educational Materials Development, emphasizing the development of new educational materials and practices suitable for national distribution; Adaptation and Implementation, calling for the adaptation and implementation of previously developed exemplary materials and practices; and National Dissemination, supporting opportunities for faculty development that prepare current faculty, as well as future faculty, to introduce

new content into undergraduate courses, to investigate effective educational practices, and to interact meaningfully with experts in the field.

Program for Gender Equity in Science, Mathematics, Engineering, and Technology (PGESMET)—promotes changes in education, academic and professional climates through increased awareness of the interests, needs and capabilities of girls and women; in instructional materials and teaching methods to increase interest, retention, and achievement of girls and women in SMET disciplines; and in availability of student enrichment resources (e.g., mentoring).

Program for Persons with Disabilities (PPD)—promotes changes in academic and professional climates, increasing the awareness and recognition of the needs and capabilities of students with disabilities; promoting the accessibility and appropriateness of instructional materials, media, and educational technologies; and increasing availability of student enrichment resources including mentoring activities.

Presidential Awards for Excellence in Science, Mathematics and Engineering Mentoring (PAESMEM) —identifies outstanding mentoring efforts/programs designed to enhance the participation of groups underrepresented in science, mathematics and engineering. Honors awardees who serve as exemplars to their colleagues and leaders in the national effort to more fully develop the Nation's human resources in science, mathematics and engineering.

K-12 LEVEL

Directorate for Education and Human Resources

Statewide Systemic Initiatives in Science, Mathematics, and Technology Education (SSI)—encourages improvements in science, mathematics, and technology education for preK-12 levels through comprehensive systemic changes in the education systems of states.

Urban Systemic Program in Science, Mathematics, and Technology Education (USP)— supports urban school districts that have an established infrastructure for change and have begun implementation of systemic reform for K-12 science and mathematics education for all students. A goal of the Program is to foster partnerships between urban school districts and two- and four-year colleges and universities to continue to strengthen and accelerate the reform process, as well as to increase implementation of system-wide improvements in student learning for science, mathematics, and technology, grades K-12.

Rural Systemic Initiatives in Science, Mathematics, and Technology Education (RSI)—stimulates system-wide preK-12 education reform of science, mathematics, and technology in rural, economically disadvantaged regions of the nation, particularly those that have been underserved by NSF programs and sustains improvements through encouraging community participation in instructional and policy reform.

Instructional Materials Development (IMD)—supports development and implementation of standards-based instructional materials models and related student assessments that enable preK-12 students to acquire a sophisticated understanding of content knowledge in science, mathematics, and technology, as well as higher-order thinking and problem-solving abilities.

Informal Science Education (ISE)—funds rich and stimulating opportunities outside formal school settings, where individuals of all ages, interests, and backgrounds increase their appreciation and understanding of science, mathematics, engineering, and technology. Learning opportunities take place in diverse environments (e.g., museums, aquaria, zoos, botanical gardens, community groups) and in a variety of media (e.g., broadcast, film, interactive technology, print).

Directorate for Computer and Information Science and Engineering

Connections to the Internet Program—encourages research and education institutions and facilities to connect to the Internet. The Program provides opportunities for connections for K-12 institutions, libraries, and museums that utilize innovative technologies for Internet access, as well as new connections for higher education institutions.

Notes

1. *The views expressed are those of the author and do not necessarily represent the policies and opinions of the Division of Undergraduate Education or the National Science Foundation.*

Dr. Norman L. Fortenberry has been Division Director of the Division of Undergraduate Education (DUE) of the National Science Foundation (NSF) since November 1996. DUE serves as the focal point of NSF's agency-wide effort in undergraduate education. DUE's programs and leadership efforts seek to strengthen and ensure the vitality of undergraduate education in science, mathematics, engineering and technology (SMET) for all students as they prepare for their futures as SMET professionals, K-12 teachers, technicians, civic leaders, and responsible citizens in an increasingly technological society.

Dr. Fortenberry also serves as NSF's Official Liaison to Community Colleges.

Since January 2000, Dr. Fortenberry has served as Acting Division Director of the Division of Human Resource Development (HRD). HRD's mission is to promote efforts to increase the participation and advancement of underrepresented groups and institutions at every level of SMET education and research.

Dr. Fortenberry's previous position was as Executive Director of the National Consortium for Graduate Degrees for Minorities in Engineering and Science, Inc. (The GEM Consortium) after serving as Associate Program Director, Program Director, and Staff Associate in DUE from 1992 to 1995. Before joining the NSF staff in 1992, Dr. Fortenberry was Assistant Professor of Mechanical Engineering and Associate Director of Minority Engineering Programs at Florida A&M University/Florida State University College of Engineering in Tallahassee, Florida. At FAMU/FSU, he had sponsored research programs in the area of design theory and methodology.

Dr. Fortenberry was awarded the S.B., S.M., and Sc.D. degrees (all in mechanical engineering) by the Massachusetts Institute of Technology. His specialization was Applied Mechanics and Design.