U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON RESEARCH AND SCIENCE EDUCATION

HEARING CHARTER

Strengthening Undergraduate and Graduate STEM Education

Thursday, February 4, 2010
10:30 a.m. - 12:30 p.m.

1. Purpose

The purpose of this hearing is to receive testimony regarding the current state of undergraduate and graduate education in the science, technology, engineering and mathematics (STEM) fields, and to examine ways to improve the quality and effectiveness of STEM education at colleges and universities so that students will be better prepared with the skills needed to join the 21^{st} century workforce. In particular, in preparation for reauthorization of the America COMPETES Act, we will be examining the role of the National Science Foundation in supporting reform in undergraduate and graduate STEM education.

2. Witnesses

- **Dr. Joan Ferrini-Mundy**, Acting Assistant Director, Directorate for Education and Human Resources, National Science Foundation
- **Mr. Rick Stephens,** Senior Vice President, Human Resources and Administration, The Boeing Company
- **Dr. Noah Finkelstein,** Associate Professor of Physics, University of Colorado, Boulder
- **Dr. Karen Klomparens,** Dean and Associate Provost for Graduate Education, Michigan State University
- **Dr. Robert Mathieu,** Professor and Chair of Astronomy and Director of the Center for the Integration of Research, Teaching and Learning (CIRTL), University of Wisconsin, Madison.

3. Overarching questions

- What are the defining characteristics of a high-quality undergraduate and graduate STEM education? What are the fundamental skills and STEM content knowledge that a student should have when entering college? What skills should they be developing during their undergraduate studies in STEM? During their graduate studies?

- What does current research tell us about key characteristics of environments, both inside and outside the classroom, that enable students to develop those skills and succeed in STEM fields? What innovative approaches and programs, at both the undergraduate and graduate level, have been shown to improve student retention and success in STEM fields? Is the level of investment in education research at the undergraduate and graduate level sufficient?

- What are the barriers to implementing reform in STEM education at the undergraduate and graduate level? What kind of pedagogical training is typically provided to incoming and current STEM faculty members? What kind of training should be provided to ensure effective teaching based on current education research? What are the barriers to implementing such training? Are there other cultural and institutional barriers that hinder improved STEM teaching at undergraduate and graduate schools?
- Do current methods of instruction and curriculum content prepare students for success outside of academia? What types of skills does a STEM graduate need to be successful in industry? How can broadening the skill sets of students be improved to ensure that students are prepared to join the workforce?
- What is the role of the Federal Agencies, specifically NSF, in improving STEM education at the undergraduate and graduate level? Is there a need to modify existing NSF programs?

4. Summary

According to the 2005 National Academies report, *Rising Above the Gathering Storm*, **"**Our competitive advantage, our success in global markets, our economic growth, and our standard of living all depend on maintaining a leading position in science, technology, and innovation. As that lead shrinks, we risk losing the advantages on which our economy depends."

The Science and Technology Committee developed the America COMPETES Act in 2007 in an effort to address the challenges that the United States faces with regard to maintaining our competitiveness in a global economy. One such challenge is providing high-quality science, technology, engineering and mathematics (STEM) education to all Americans and at all levels from pre-K through graduate school. Most of our efforts in 2007 were focused at the K-12 level, and in particular ensuring that we have highly-qualified STEM teachers in all schools across the country. As we develop legislation to reauthorize the America COMPETES Act in 2010, we are examining opportunities to support meaningful reform in STEM education at our Nation's institutions of higher education.

There are a variety of factors that affect the quality of higher education in the STEM fields and contribute to recruitment and retention problems at the undergraduate and graduate level. Many students continue to have a less than adequate K-12 education, and are not sufficiently prepared for the rigors associated with postsecondary education. In some STEM fields, students who initially decide to pursue baccalaureate degrees leave the field at high rates to enter other disciplines. At the graduate level, students who drop out of their programs of study often fail to complete advanced degrees altogether, or may stop at a Masters degree when their original intent was to pursue a Ph.D. Although the total number of students who choose to enter STEM disciplines at the postsecondary level continues to increase, many experts have argued that the numbers will be insufficient to meet future workforce needs. Moreover, many industry representatives have testified before this Committee that even students who successfully attain STEM undergraduate or graduate degrees are too often ill prepared for careers outside of academia. The witnesses in today's hearing will discuss innovative approaches to addressing the quality of education and training in the STEM fields at both the undergraduate and graduate level, as well as the role of the National Science Foundation in supporting these efforts.

5. Undergraduate and Graduate Enrollment and Degrees

According to the National Science Board's (NSB) biennial report, *Science and Engineering Indicators 2010*[1], the number of bachelor's degrees awarded in the science and engineering fields by U.S. colleges and universities has risen steadily over the past 15 years, and these trends are expected to continue at least through 2017. Even so, the trends vary widely among fields. For example, the number of bachelor's degrees earned in computer science has dropped significantly in recent years. Similarly, the number of master's degrees awarded in the United States increased steadily until dropping slightly in 2007. Master's degrees in engineering and computer sciences have been declining since 2004. The trend for doctoral degrees is more variable, with a decline in the late 1990's through early 2000's and subsequent rise to almost 41,000 in 2007. The largest growth in doctoral degrees occurred in the engineering, biological/agricultural sciences, and medical/other life sciences (due to the doubling of the NIH budget), but computer sciences also saw gains.

Overall, science and engineering students persist and complete undergraduate programs at about the same rate (60 percent) as non-science and engineering students. However, according to the 2005 *Survey of the American Freshman*[2], the longest running survey of student attitudes and plans for college, half of all students who begin in the physical or biological sciences and 60 percent of those in mathematics will drop out of these fields by their senior year, compared with the 30 percent drop out rate in the humanities and social sciences. Furthermore, undergraduate STEM students are educated in diverse institutions, and attrition rates out of STEM fields vary not just by field but by type of institution and by student background.

Graduate completion rates are roughly comparable to undergraduate completion rates. Among students enrolled in doctoral programs in the early 1990s, about 60 percent completed doctorates within 10 years. Again, completion rates vary by discipline, with 64 percent of engineering students, 62 percent of life sciences students, and 55 percent of physical and social sciences students completing doctorates within 10 years.[3] Currently, 70 percent of the science and engineering PhDs granted in the United States come from only 96 research universities. This suggests that targeted reform efforts at a relatively small number of institutions can have a significant impact on the graduate attrition problem.

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[1] All data from this section, unless indicated otherwise, is from the 2008 and 2010 Science and Engineering Indicators: http://www.nsf.gov/statistics/seind10/, http://www.nsf.gov/statistics/seind08/

[2] Higher Education Research Institute (HERI), University of California at Los Angeles, *http://www.heri.ucla.edu/*

[3] Council of Graduate Schools Report 2008 *Ph.D. Completion and Attrition: Analysis of Baseline Demographic Data from the Ph.D. Completion Project* http://www.phdcompletion.org/information/book2.asp

Even with the overall increases in STEM undergraduate and graduate enrollment, many suggest that the number of students entering these disciplines will eventually plateau and fall short of meeting workforce demands. If this projected demand materializes, simply addressing attrition in higher education will not be sufficient to meet workforce needs. Science and engineering degrees will have to be made more attractive to a larger percentage of the population. Reform efforts that address the quality of STEM education at all levels of higher education will help institutions achieve this goal.

6. Transforming the STEM Classroom

Several studies have attempted to identify the issues that contribute to loss of interest in the STEM fields at the undergraduate and graduate levels. Studies performed to determine the causes of attrition find that students leave the field due to reasons such as a loss of interest in the subject matter, other disciplines offering better educational experiences, or feeling overwhelmed with course content. Students who leave STEM disciplines often enter disciplines (some of which are also STEM) that are perceived to be more nurturing and supportive, less competitive, and that have more opportunities for collaborative work.[4]

In addition to these problems with courses for STEM majors, many introductory courses for non-majors fail to foster scientific understanding among the non-science majors. Without a broader context, many students never understand the process of science or the content of the subject matter. According to research in the *Journal of College Science Teaching*, this narrow approach to STEM courses alienates non-majors who graduate with the perception that science is difficult, boring, and irrelevant to their everyday interests.

Research suggests that students' concerns can be addressed in the undergraduate and graduate STEM classroom through implementation of new teaching methods and curricula, and through hands-on learning opportunities. According to The National Academies' Center for Education report *How People Learn*,[5] transformative learning environments shift teaching methodologies to incorporate current pedagogy on the ways that students actually learn the STEM disciplines. Instructors who are acutely attuned to the learner, and can create environments that are learner, knowledge, assessment, and community centered, are the most effective at enhancing student learning. Education researchers have found that a variety of reform efforts, including changes in curriculum and pedagogy, may result in lower attrition than traditional approaches to teaching undergraduate STEM.

Not surprisingly, changes in how current and future faculty are trained have been central to many reform efforts at institutions across the country. According to the *Rising Above the Gathering Storm* report, "the graduate education of our scientists and engineers largely follows an apprenticeship model. Graduate students and postdoctoral scholars gain direct experience under the guidance of veteran researchers." Although the apprenticeship model has proven to be useful in training future scientists, many have argued that it cannot be used to effectively train

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[4] Seymour, Elaine, and Hewitt Nancy. Talking About Leaving: Why Undergraduates Leave the Sciences. Westview Press, 1997

[5] Editors; Bransford, John, D., Brown, Ann, L., and Cocking, Rodney, R. How People Learn. National Academy Press; Committee On Developments in the Science of Learning; Committee On Behavioral and Social Science Education and the National Research Council, 1999

future faculty *how to teach*, especially when many current faculty members are not trained in current pedagogy. Programs to prepare future faculty have been supported by both Federal funds and private endowments. Many programs create professional development communities to train future STEM faculty. In these communities, graduate students apply their research training to determine if the information that they are teaching is conveyed effectively, create environments that are supportive of one another, and bring together diverse groups of students interested in learning how to teach. Since poor teaching has been identified as a major contribution to attrition in STEM, training all new faculty members in current pedagogy can address this issue in a direct manner. Many institutions have incorporated professional development opportunities for current STEM faculty as well, so they can be kept abreast of current education research findings and incorporate new methods of teaching and curriculum in their classroom.

7. Research Opportunities, Interdisciplinary Education and Broader Skills

Transforming the traditional physics, biology or engineering classroom is just one step in addressing the quality of STEM education at both the undergraduate and graduate level. At the undergraduate level, where students traditionally are not provided many opportunities for research, experts have found that research experiences can greatly enhance the undergraduate experience for the student. According to many experts in undergraduate education, research experiences play an important role in providing a context to what the student is taught in the classroom, as well as a better understanding of what it means to be a scientist or engineer. At the graduate level, since the majority of a student's tenure is already spent in research settings, focusing more on factors outside of the classroom may be even more critical to transforming the educational experience.

In addition, numerous reports suggest that both undergraduate and graduate programs should find more ways to combine disciplinary depth with interdisciplinary training and research opportunities. In recent years, many experts have begun to view interdisciplinary research as critical to U.S. scientific leadership in the 21st century, as many of the emerging global problems will increasingly require research that cuts across disciplines. Additionally, many experts have argued that by broadening the scope of study and research opportunities for students, schools might better recruit and retain students with diverse interests in STEM.

Finally, many have argued that in addition to ensuring strong content knowledge and research skills, institutions should incorporate opportunities to develop the so-called "soft" skills of students to better prepare them for diverse career paths. Currently, 42 percent of individuals who hold doctorates in science and engineering fields work in non-academic settings (Science and Engineering Indicators 2010). In 2005 the National Science Board suggested that graduate students should be taught how to "work in multicultural environments, to understand the business context of engineering, and also develop interdisciplinary skills, communication skills, leadership skills, an ability to adapt to changing conditions, and an eagerness for lifelong learning."[6] Many industry leaders have made similar recommendations regarding the necessary

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[6] A National Science Board-Sponsored Workshop; *Engineering Workforce Issues and Engineering Education: What are the Linkages?* October 20, 2005
http://www.nsf.gov/nsb/committees/archive/eng_edu/2005_10_20/summary.pdf

skill sets of undergraduate STEM students.

8. Role of the National Science Foundation

The National Science Foundation Act of 1950 established NSF in order to "promote the progress of science and to advance the national health, prosperity, and welfare…" One of the ways that the agency fulfills this mission is by investing in and supporting STEM education at all levels. Many of the programs focused on education and training at the undergraduate and graduate levels are managed by the Education and Human Resources Directorate (EHR). EHR houses both a Division of Undergraduate Education (DUE) and a Division of Graduate Education (DGE).

The Division of Undergraduate Education has a program called *Course, Curriculum and Laboratory Improvement* (CCLI), which supports diverse efforts to reform undergraduate STEM education. In the FY11 budget request, NSF proposes to rename this program *Transforming Undergraduate Education in STEM* (TUES). DUE also offers the NSF *Scholarships in STEM* (S-STEM) for talented students who require financial assistance to complete their studies and the *STEM Talent Expansion Program* (STEP) that can be used to support students studying in emerging STEM disciplines. NSF's *Research Experiences for Undergraduates* (REU) program is a cross-cutting program supported by all research directorates and managed by an intra-agency committee.

The Division of Graduate Education manages the *Graduate Research Fellowships* program (GRF), and the *Integrative Graduate Education and Research Traineeships Program* (IGERT), both of which receive funding from across the Foundation. DGE also supports the *Graduate STEM Fellows in K-12 Education* program (GK-12) and the *Professional Science Masters* program (SMP) that received funding for the first time in the Recovery Act. According to NSF, GK-12 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". [7] There is not a specific place within NSF that focuses solely on graduate curriculum and transforming graduate learning environments.

In addition, some research directorates manage undergraduate education programs either independently or in explicit partnership with EHR. For example, *Interdisciplinary Training for Undergraduates in Biological and Mathematical Sciences* (UBM) is a partnership between the Division of Mathematical Sciences, the Biological Sciences Directorate (BIO) and EHR, and the *Nanotechnology Undergraduate Education in Engineering* (NUE), is in the Engineering Directorate's Division of Engineering Education and Centers.

The National Science Foundation is also the primary sponsor of research on the teaching and learning of STEM at all levels. At the undergraduate level, research is an important component of the education programs described previously. Other programs that support research in higher education include the *Research Coordination Networks in Biological Sciences*

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[7] http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503369

(RCN) and the Engineering directorate's *Innovations in Engineering Education Curriculum and Infrastructure* (IEECI) program as well as EHR's *Research and Evaluation on Education in Science and Engineering* (REESE) program.

Finally, NSF funds a variety of programs designed to increase the participation of historically underrepresented groups in the STEM fields at the undergraduate and graduate level. Increasing diversity at colleges and universities across the country is critical to increasing the numbers of students attaining STEM degrees, and has been shown at many institutions to improve the quality of STEM education for all students at those institutions. The Committee plans to hold a hearing in the upcoming months on the topic of diversity in STEM education. However, these issues clearly go hand in hand and we expect to hear from witnesses in today's hearing about the importance of broadening participation in efforts to transform higher education in the STEM fields.

Table 1 FY11 Requested Funds (in millions) for certain undergraduate and graduate NSF programs*

NSF Program	**FY 2011 Request**
STEP- STEM Talent Expansion Program	$32.53
REU- Research Experiences for Undergraduates	$67.27
GRF- Graduate Research Fellowships	$158.24
IGERT- Integrative Graduate Education and Research Traineeships	$61.80
GK-12- Graduate STEM Fellows in K-12 Education	$52.85

* CCLI (now TUES) is not included in this list because the breakout is not provided in the FY11 budget request.