STRENGTHENING UNDERGRADUATE AND GRADUATE STEM EDUCATION

HEARING

BEFORE THE

SUBCOMMITTEE ON RESEARCH AND SCIENCE EDUCATION

COMMITTEE ON SCIENCE AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED ELEVENTH CONGRESS

SECOND SESSION

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February 4, 2010

STRENGTHENING UNDERGRADUATE AND GRADUATE STEM EDUCATION

THURSDAY, FEBRUARY 4, 2010

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON RESEARCH AND SCIENCE EDUCATION
COMMITTEE ON SCIENCE AND TECHNOLOGY
Washington, DC.

The Subcommittee met, pursuant to call, at 11:37 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Daniel Lipinski [Chairman of the Subcommittee] presiding.

BART GORDON, TENNESSEE
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RALPH M. HALL, TEXAS
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U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE AND TECHNOLOGY

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WASHINGTON, DC 20515–6301
(202) 225–6375
http://science.house.gov

Hearing on

Strengthening Undergraduate and Graduate STEM Education

Thursday, February 4, 2010
10:30 a.m. – 12:30 p.m.
2318 Rayburn House Office Building

Witness List

Dr. Joan Ferrini-Mundy
Acting Assistant Director
Directorate for Education and Human Resources
National Science Foundation (NSF)

Mr. Rick Stephens
Senior Vice President, Human Resources & Administration
The Boeing Company
Chair, Aerospace Industries Association Workforce Steering Committee

Dr. Noah Finkelstein
Associate Professor of Physics
University of Colorado, Boulder

Dr. Karen Klomparens
Associate Provost and Dean for Graduate Education
Michigan State University

Dr. Robert Mathieu
Professor and Chair of Astronomy
Director of the Center for the Integration of Research, Teaching and Learning (CIRTL)
University of Wisconsin, Madison

HEARING CHARTER

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

Strengthening Undergraduate and Graduate STEM Education

THURSDAY, FEBRUARY 4, 2010
10:30 A.M.–12:30 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

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 21st 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 1990s through early 2000s 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

[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/.*

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 five percent of physical and social sciences students completing doctorates within 10 years.[3] Currently, 70 percent of the science and engineering Ph.D.'s 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.

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 future faculty *how to teach,* especially when many current faculty members are not trained

[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.*

[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.

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 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

[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.*

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* (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
TUES- Transforming Undergraduate Education in STEM	$40.21
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

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

Chairman LIPINSKI. This hearing will now come to order. Good morning and welcome to this Research and Science Education Subcommittee hearing on undergraduate and graduate education in the science, technology, engineering and math fields.

This is an issue that really hits close to home for me. As most of you probably know, I have two degrees in engineering. My wife also has a degree in math and is oftentimes telling me about her experience at a math camp that was NSF funded, a math camp, when she was in college. So this is something that from personal experience I know a good amount about and something that I have really focused on since I have been on this Committee.

Our global competitors have started to realize the economic advantages of investing in innovation. In their 2010 Science and Engineering Indicators report, the National Science Board found that Asian countries are continuing to increase their R&D investments at a much higher rate than we are in the United States, and that it won't be long before they catch up in total expenditures. Last November, Thomson Reuters analyzed 30 years' worth of data from over 10,000 scientific journals and reported that China could surpass the United States as the world's largest producer of scientific knowledge by 2020. They have already surpassed the rest of the world, and are especially good in chemistry and materials science, two fields that are vital for manufacturing.

In 2007, the Science and Technology Committee passed the *America COMPETES Act* to address concerns that the United States was losing its global leadership position in research, development and innovation. One key element of the COMPETES Act, and indeed the foundation of any competitiveness agenda, is ensuring that we give all of our students the chance to get a high quality STEM education.

In 2007, we focused largely on supporting education at the K–12 level by making sure we have highly qualified STEM teachers in every school. This year's reauthorization of the COMPETES Act provides us with the opportunity to take a comprehensive look at undergraduate and graduate STEM education programs and their performance.

Given all of the talk about problems in STEM education at the K–12 level, you may be surprised to hear that a full one third of freshmen entering our Nation's universities intend to major in a science or engineering discipline. But in some critical fields like engineering, where we face an oncoming "gray tsunami" of retirements, there is significant attrition. It is very easy for engineers to leave their programs, for instance to become social scientists, but it is much more difficult for students to transfer into engineering without having spent their freshman year meeting prerequisites in math, physics and chemistry. In fact, only seven percent of engineering graduates did not start out in those fields.

In addition to the numbers, there are concerns that the traditional way of teaching science and engineering doesn't reflect what research tells us about how students really learn.

I was an engineering student once myself and can relate to some of the concerns that we have heard about what is happening in the STEM fields at our colleges and universities. I also know that some of these problems are not new. When I was at Northwestern 20 years ago, I began with many more people in my engineering classes than ended up graduating with a mechanical engineering degree. We certainly did see an attrition through the years.

I am particularly interested in learning what the 21st century undergraduate science and engineering classrooms should look like, and whether our professors are actually imparting the kind of skills that STEM graduates need to be successful in the workforce. At the graduate level, I want to examine how we are preparing future faculty to become good teachers, to hear suggestions on how we can improve the teaching of pedagogical skills and to hear whether we are giving students who pursue nonacademic career paths the skills they need to be successful. I am also interested in the balance between disciplinary and interdisciplinary education at both the undergraduate and graduate levels. And finally, because we are working on the NSF reauthorization, I am particularly interested in hearing recommendations about the role that the NSF can play in instigating and supporting reform efforts in higher education, including through research.

Just last week in the State of the Union address, the President spoke about the need to encourage American innovation. I could not agree more with this. I also agree with the President that one of the most effective ways to support innovation is to improve and invest in STEM education. This investment will allow the scientists, engineers and innovators of the future to build the infrastructure we need, to invent new technologies and products, to create good-paying jobs and to keep the U.S. economy growing.

So I very much look forward to your testimony today. There are ideas that I have from when I was in school as an engineer and would very much like to hear what your suggestions are, what your experiences are and help us moving forward, especially with the Senate authorization.

[The prepared statement of Chairman Lipinski follows:]

PREPARED STATEMENT OF CHAIRMAN DANIEL LIPINSKI

Good morning and welcome to this Research and Science Education Subcommittee bearing on undergraduate and graduate education in the science, technology, engineering, and mathematics (or STEM) fields.

Our global competitors have started to realize the economic advantages of investing in innovation. In their 2010 Science and Engineering Indicators report, the National Science Board found that Asian countries are continuing to increase their R&D investments at a much higher rate than we are in the U.S., and that it won't be long before they catch up in total expenditures. Last November, Thomson Reuters analyzed 30 years worth of data from over 10,000 scientific journals, and reported that China could surpass the United States as the world's largest producer of scientific knowledge by 2020. They have already surpassed the rest of the world, and are especially good in chemistry and materials science—two fields that are vital for manufacturing.

In 2007 the Science and Technology Committee passed the America COMPETES Act to address concerns that the United States was losing its global leadership position in research, development and innovation. One key element of the COMPETES Act, and indeed the foundation of any competitiveness agenda, is ensuring that we give all of our students the chance to get a high quality STEM education. In 2007, we focused largely on supporting education at the K–12 level by making sure we have highly qualified STEM teachers in every school. This year's reauthorization of the COMPETES Act provides us with the opportunity to take a comprehensive look at undergraduate and graduate STEM education programs and their performance.

Given all of the talk about problems in STEM education at the K–12 level, you may be surprised to hear that a full one third of freshmen entering our Nation's universities intend to major in a science or engineering discipline. But in some critical fields like engineering, where we face an oncoming "gray tsunami" of retirements, there is significant attrition. It's very easy for engineers to leave their programs, for instance to become social scientists, but it's much more difficult for students to transfer *into* engineering without having spent their freshman year meeting prerequisites in math, physics, and chemistry. In fact, only 7% of engineering graduates did not start out in those fields. In addition to the numbers, there are concerns that the traditional way of teaching science and engineering doesn't reflect what research tells us about how students really learn.

I was an engineering student once myself, and can relate to some of the concerns that we have heard about what is happening in the STEM fields at our colleges and universities. I also know that some of these problems are not new. When I was at Northwestern 20 years ago, I began with many more people in my engineering classes than ended up graduating with a mechanical engineering degree.

I am particularly interested in learning what the 215 century undergraduate science and engineering classrooms should look like and whether our professors are actually imparting the kind of skills that STEM graduates need to be successful in the workforce. At the graduate level, I want to examine how we are preparing future faculty to become good teachers, to hear suggestions on how we can improve the teaching of pedagogical skills, and to hear whether we are giving students who pursue nonacademic career paths the skills they need to be successful. I am also interested in the balance between disciplinary and interdisciplinary education at both the undergraduate and graduate levels. And finally, because we are working on the NSF reauthorization, I am particularly interested in hearing recommendations about the role that the NSF can play in instigating and supporting reform efforts in higher education, including through research.

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Chairman LIPINSKI. With that I will now recognize Dr. Ehlers for an opening statement.

Mr. EHLERS. Thank you, Mr. Chairman. I am pleased that today we are focusing on federal efforts to improve STEM education and programs in higher education.

As you probably know, I spent something like 22 years trying to do that as a faculty member at Calvin College in Grand Rapids, Michigan.

In the context of reauthorizing the *America COMPETES Act,* I look forward to hearing the insights of our witnesses into what we are doing well, which I hope is a great deal, but also hearing what has to be improved. And we all know that some improvement is needed.

This week the fiscal year 2011 budget request was released by the Administration. Disciplinary research funding at NSF appears to be prioritized over educational research and support for workforce development. While I am still obtaining all the details of the budget, it is unsettling to me that university-based programs supporting the training of STEM teachers, such as the Math and Science Partnership and Noyce programs, received no requested funding increases while the Foundation would continue on a doubling track with an overall eight percent increase. There should be some money, some additional money there, to improve the STEM ed situation.

I am sure the witnesses before us today have some thoughts on the linkages between the research and educational missions of the NSF, and their testimony I believe will be very helpful to us as we evaluate the President's budget request, particularly specific to

STEM education at NSF, and also we hope we will get some ideas on how we can strengthen the COMPETES Act through the reauthorization project.

So I certainly want to thank our excellent witnesses for being here, and I look forward to their testimony.

[The prepared statement of Mr. Ehlers follows:]

PREPARED STATEMENT OF REPRESENTATIVE VERNON J. EHLERS

I am pleased that today we are focused on Federal efforts to improve STEM programs in higher education. In the context of reauthorizing the *America COMPETES Act,* I look forward to hearing the insights of our witnesses into what we are doing well, but also the areas in need of improvement.

This week the fiscal year 2011 budget request was released by the administration. Disciplinary research funding at NSF appears to be prioritized over educational research and support for workforce development. While I am still obtaining the details, it is unsettling to me that university-based programs supporting the training of SIEM teachers, such as the Math and Science Partnership and Noyce programs, received no requested funding increases while the Foundation would continue on a doubling track with an overall eight percent increase.

I am sure the witnesses before us today have some thoughts on the linkages between the research and educational mission of the NSF. Their testimony will help us evaluate the budget request specific to STEM education at NSF at all levels, and ways we can strengthen the COMPETES Act through the reauthorization process.

Chairman LIPINSKI. Thank you, Dr. Ehlers. We will have more of an opportunity in hearings coming up to discuss the budget for the upcoming year, but that is certainly an issue that is not an easy one, but we know there has been a commitment shown to innovation and education. I am very happy that we have done that in the last few years.

If there are members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Thank you, Mr. Chairman and Ranking Member, for holding today's hearing. *Strengthening Undergraduate and Graduate STEM Education* is a topic that must be discussed in order to ensure we are taking the right steps towards increasing American competitiveness and innovation.

Many of the hearings that this committee has worked on in the past focused specifically on identifying and correcting the problems effecting K–12 STEM education. These problems still exist and must be addressed while we strengthen our colleges and universities.

The report, "Rising Above the Gathering Storm", along with others, showed highlighted that our Nation is as not graduating as many STEM professionals as other countries. Members of this committee are interested in correcting the reasons we are falling behind.

Many policymakers, educators, and other professionals worry that the ability of the United States to produce enough scientists will fall short unless action is taken to develop the potential of under-utilized minorities. These professionals argue that a more diverse group of students must be recruited to science study and be equipped to thrive. They are right!

The problem is that many minority students are not prepared properly for the rigor of STEM disciplines when they enter college. Some students who decide to enter these disciplines in college decide to drop out due to poor grades, and end up pursuing other degrees. We are losing many potential STEM professionals due to a lack of adequate K–12 preparation.

A lack of resources will negatively affect any student. Economic inequality, residential segregation, and often inadequate urban schools place minority students suffering from these conditions at a disadvantage. Those minority students who are more likely to end up in schools with fewer or deficient resources are less likely to succeed because of societal inequity.

Studies have also shown that students who are *aware* of the low expectations expected of them are more likely to meet those *low* expectations. Research also shows other negative consequences evident are self-confidence, attitudes, and achievement if these students feel they are not viewed as a source of talent from the beginning. This fact negatively affects too many women and minority students.

Our country is missing out on far too many future scientists due to inequities. I am interested in hearing from today's witnesses on how we can address some of these issues.

Thank you Mr. Chairman, I yield back.

Chairman LIPINSKI.At this time, I would like to introduce our witnesses. First, we have Dr. Joan Ferrini-Mundy who is the Acting Assistant Director for the Directorate for Education and Human Resources at the National Science Foundation. Mr. Rick Stephens is a Senior Vice President for Human Resources & Administration at the Boeing Company and is also the Chair of the Aerospace Industries Association Workforce Steering Committee. Dr. Noah Finkelstein is an Associate Professor of Physics at the University of Colorado, Boulder. And we will skip right now to Dr. Robert Mathieu who is Professor and Chair of Astronomy as well as Director of the Center for the Integration of Research, Technology and Learning at the University of Wisconsin, Madison.

And now I will yield to Ranking Member Dr. Ehlers to introduce our witness. That is why we skipped over you briefly. So Dr. Ehlers?

Mr. EHLERS. Thank you, Mr. Chairman. Let me first also mention that of the other witnesses I am not introducing, we have someone who was at Michigan State University for a number of years. I think I feel slightly responsible for having her end up there because I gave her the sales pitch about what I was trying to do, and she left greener pastures and came to MSU. And then when I discovered the opening here at NSF, I persuaded her to leave Michigan and come here. She is very versatile, and I am pleased to see her on the panel. The main introduction that I have to give is Dr. Karen Klomparens. You must be Dutch. She has served as the Dean of the Graduate School and Associate Provost for Graduate Education at Michigan State University since 1997. Now, when you look at her, you realize she must have gotten into that position as a young genius and has done a great job there. She is a professor of plant biology and is on leave as Director of MSU's Center for Advanced Microscopy. She has been on faculty at MSU for 32 years and fully understands the challenges faced by the higher educational system in preparing students in STEM education. She is not only an advocate for quality graduate education at MSU but also for improving the relationships between traditional STEM departments and departments of education, and I might just editorialize for a minute here. I think that is extremely important, and every opportunity I have had to speak to university presidents and deans, I have told them the most important thing they can do is to get the science departments and the education department or education college working together on this problem. And I found that many universities that I have visited and attended, that there is a major issue of disdain between the educators and the scientists. There should not be. This is a problem they both have to actively work together on.

She has shared with me some of the work that MSU is doing to a new math education doctoral program, and that looks very exciting. I think that Arizona State at Tempe, Arizona, has something similar, and other universities are beginning that. So you have plowed the way, Ms. Klomparens, for other universities. I think that is an example of the future of graduate education in preparing STEM teachers.

I thank you for the opportunity to give that background. I yield back.

Chairman LIPINSKI. Thank you, Dr. Ehlers. As our witnesses should know, you will each have five minutes for your spoken testimony. Your written testimony will be included in the record for the hearing. When all of you have completed your spoken testimony, we will begin with questions. Each member will have five minutes to question the panel. We will now start with Dr. Ferrini-Mundy. Dr. Ferrini-Mundy?

STATEMENT OF DR. JOAN FERRINI-MUNDY, ACTING ASSISTANT DIRECTOR, DIRECTORATE FOR EDUCATION AND HUMAN RESOURCES, NATIONAL SCIENCE FOUNDATION

Dr. FERRINI-MUNDY. Chairman Lipinski, Ranking Member Ehlers, and distinguished members of the Subcommittee, I am Joan Ferrini-Mundy, Acting Assistant Director of the Directorate for Education and Human Resources at the National Science Foundation. Thank you for the opportunity to testify today about strengthening undergraduate and graduate science, mathematics, engineering and technology, or STEM, education.

The National Science Foundation has two roles in STEM higher education. One is to provide direct support to the Nation's most promising students. We do this through fellowships, traineeships, scholarships and research assistantships in several programs across the entire Foundation. Our flagship program is the Graduate Research Fellowship program, founded at NSF in 1952. At the undergraduate level, for example, we have the Robert Noyce Teacher Scholarship program which provides prospective teachers with support for their education.

A second NSF role is to catalyze innovation to improve STEM learning at the undergraduate and graduate levels. The Course Curriculum and Laboratory Improvement program, CCLI, which is being renamed as Transforming Undergraduate Education in STEM, or TUES, is an example of a program that does this. The program vision is excellent STEM education for all undergraduate students.

CCLI and TUES fund projects that develop, implement and evaluate innovative practices in undergraduate STEM learning. We are funding projects to determine what it takes to scale-up effective practices in undergraduate settings across the country.

Some of our programs address both roles. The Integrated Graduate Education Research and Traineeship program, IGERT, provides traineeships to STEM doctoral students and catalyzes graduate program innovation. IGERT PIs develop research and learning opportunities to prepare tomorrow's scientists to solve interdisciplinary research problems.

We are also very interested in the question of how to best prepare tomorrow's scientists to be leaders in invention, innovation and entrepreneurship.

The scientists of tomorrow need skills beyond their disciplinary content preparation. We see efforts in proposals to build skills in teamwork, communication to technical and non-technical audiences, leadership and teaching at the graduate level. Proposals to our undergraduate programs are exploring how to develop 21st century skills and capacity to engage with challenging societal problems.

NSF's programs are also aimed at improving recruitment into the STEM fields. This includes seeking students from groups that have been traditionally underrepresented in STEM. At the graduate level, students are attracted by opportunities for interdisciplinary research and summer workshops introducing them to the culture of graduate school. And of course, targeted scholarships and stipends certainly help in recruitment.

Faculty-to-faculty connections and cultivating relationships with minority-serving institutions can make a difference in bringing a diversity of students into STEM. Many of the students who begin college with the intention of pursuing a STEM career move to other fields in their first or second year of college, and there are some practices that seem to help stem this attrition. For example, early efforts to shore up weak high school preparation, such as summer programs prior to the freshman year, show some promise. So does focusing on at-risk students through cohort building, peer and faculty mentoring and offering of career advice. Chances to do research with faculty, internships and summer programs also help with both recruitment and retention in STEM.

NSF also invests in research on learning and teaching as a part of catalyzing improvement in STEM higher education. At the undergraduate level, the body of work is quite robust, coming through discipline-based work in physics, mathematics, engineering, chemistry and the geosciences, as well as other areas. We recently have funded the National Research Council to undertake a comprehensive consensus study of discipline-based education research in the natural sciences to build our body of knowledge further. There is less research available about graduate STEM learning and education, and we are trying to encourage more work in this area. Recently funded projects are examining issues of interest in graduate education such as the effects of inquiry-based science teaching, and the role of context and learning practices in laboratories.

The Nation must build a STEM workforce that is ready for innovation and global leadership. To do this, we need to continually improve the effectiveness of STEM education in colleges and universities for undergraduate and graduate students alike. This means creating stimulating compelling opportunities for STEM learning and for research. NSF is supporting innovative initiatives to attract and prepare tomorrow's science and engineering workforce during the critical undergraduate and graduate years.

Thank you for the opportunity to describe our efforts.

[The prepared statement of Dr. Ferrini-Mundy follows:]

PREPARED STATEMENT OF JOAN FERRINI-MUNDY

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 (ERR) 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 U.S. 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 universities

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

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 become established and award degrees, measurement becomes easier. For example, the number of doctoral degrees increased in interdisciplinary fields such as 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

[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)

[6] NSB 10–01; NSF/SRS 1993, 2009c

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 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. 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

[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), (p. 1).

[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.

no formal training in pedagogy, in contact with a knowledge base around effective practices for supporting learning. As projects insist that college-level 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."[10] 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,[11] "IGERT students receive more extensive interdisciplinary training than non-IGERT peers, but maintain depth of study in 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[12] 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

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[10] 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.

[11] NSF 06–17.

[12] 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.

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 sciences. 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.[13] Evaluation[14] 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 preliminary results comparing IGERT and non-IGERT graduates in the workforce reports that IGERT graduates were more likely to be integrating multiple disciplines in their work.[15] 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."[16]

The NSF Graduate STEM Fellows in K–12 Education (GK–12)[17] program provides an opportunity for graduate students to acquire value-added skills, such as communicating SEEM 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),[18] 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 SEEM 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)[19] 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 techni-

[13] NSF 06–17.

[14] Initial Impacts of IGERT evaluation by Abt Associates Inc. (2006).

[15] 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.

[16] NSF 09–33 The impact of transformative interdisciplinary research and graduate education on academic institutions.

[17] NSF 09–549.

[18] NSF 09–607.

[19] NSF 07–530.

cians 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.

Graduate level. The Alliances For Graduate Education and the Professoriate (AGEP)[20] 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 Ph.D. production, and successful transitioning of Ph.D. graduates into the workplace (including the professoriate) and more. The national AGEP evaluation[21] 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 Ph.D.'s 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.[22]

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 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

[20] NSF 10–522.

[21] Carlos Rodriguez Presentation at the AGEP 12/09–10/2009 Washington DC. 103 AGEP institutions produced 2,878 URM STEM Ph.D.'s from 2002–07.

180 non-AGEP institutions produced 2,265 URM STEM Ph.D.'s from 2002–07.

Thus, AGEP institutions produced an average of 27.9 URM Ph.D.'s in STEM.

And, Non-AGEP institutions produced an average of 12.6 URM Ph.D.'s in STEM.

Therefore, an AGEP-supported institution produces 2.2 times as many URM Ph.D.'s as a comparable non-AGEP institution.

[22] NSF 09–33 The impact of transformative interdisciplinary research and graduate education on academic institutions.

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 1University, 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,[23] Historically Black Colleges and Universities Undergraduate Program (HBCU–UP),[24] and Tribal Colleges and Universities Program (TCUP).[25] Findings [26] 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[27] invites proposals that span these levels. In recent years the REESE program has issued a Dear Colleague Letter[28] 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 FY 2009 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.*[29] 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 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.[30] 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.[31] This is an assessment to diagnose areas of conceptual difficulty before or after instruction. Subsequently “concept inventories” have been

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[23] NSF 10–522.
[24] NSF 10–518.
[25] NSF 10–501.
[26] Clewell, B. C., de Cohen, C. C., Tsui, L., & Deterdening N. (2006). Revitalizing the nation’s talent pool in STEM: Science, technology, engineering, and mathematics. Washington, DC: Urban Institute. (311299).
[27] NSF 09–601.
[28] Dear Colleague Letter: Research and Evaluation on Education in Science and Engineering (NSF 08–012).
[29] 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.
[30] *http://www.compadre.org/per/*.
[31] 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.

developed in nearly two dozen STEM disciplines.[32] 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.[33] 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.[34] In mathematics there is also a professional group, the Special Interest Group of the Mathematical Association of America on Research in Undergraduate Mathematics Education,[35] 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.

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)[36] 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."[37] Noah Finkelstein and his colleagues at the Univer-

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

[33] 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.

[34] 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.

[35] *http://www.rume.org/.*

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

[37] *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.

sity 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.[38] 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.[39] 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.

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.

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[38] *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: Career Wise II: Enhanced Resilience Training for STEM Women in an Interactive, Multimodal Web-Based Environment* (090618, PI Bianca Bernstein).

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

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 Education 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 Undergraduate/Graduate Support	**706.63**	**732.09**

BIOGRAPHY FOR JOAN FERRINI-MUNDY

Dr. Joan Ferrini-Mundy is the Acting Assistant Director of the National Science Foundation's (NSF) Directorate for Education and Human Resources (EHR). In 2009 she served as Acting Executive Officer for EHR, and from January 2007 through December 2009 was Director of EHR's Division of Research on Learning in Formal and Informal Settings (DRL). While at NSF Dr. Ferrini-Mundy continues to hold appointments at Michigan State University (MSU) as a University Distinguished Professor of Mathematics Education in the Departments of Mathematics and Teacher Education. She served as Associate Dean for Science and Mathematics Education in the College of Natural Science at MSU from 1999–2006. Ferrini-Mundy was a Visiting Scientist in NSF's Teacher Enhancement Program from 1989–91, and served as Director of the Mathematical Sciences Education Board and Associate Executive Director of the Center for Science, Mathematics, and Engineering Education at the National Research Council from 1995–99. She directed the Michigan Department of Education Teacher Preparation Policy Study Group (2006–07) and chaired the MI Mathematics High School Content Expectations Development Committee. From 1983–99 Ferrini-Mundy was a member of the Mathematics Department at the University of New Hampshire, and in 1982–83 she was a mathematics faculty member at Mount Holyoke College, where she co-founded the SummerMath for Teachers Program. She has served on the Board of Directors of the National Council of Teachers of Mathematics (NCTM), chaired the Writing Group for NCTM's 2000 *Principles and Standards for School,* and served on the Board of Governors of the Mathematical Association of America. In 2007–08, representing NSF, she served as an ex officio member of the President's National Mathematics Advisory Panel, and co-chaired the Instructional Practices Task Group. Ferrini-Mundy holds a Ph.D. in mathematics education from the University of New Hampshire; her research interests include calculus teaching and learning, the development and assessment of teachers' mathematical knowledge for teaching, and mathematics and science education policy.

Chairman LIPINSKI. Thank you. I will recognize Mr. Stephens.

STATEMENT OF MR. RICK STEPHENS, SENIOR VICE PRESIDENT FOR HUMAN RESOURCES & ADMINISTRATION, THE BOEING COMPANY, AND CHAIR, AEROSPACE INDUSTRIES ASSOCIATION WORKFORCE STEERING COMMITTEE

Mr. STEPHENS. Thank you, Mr. Chairman, Dr. Ehlers and members of the Subcommittee. I am honored to speak on behalf of the Aerospace Industries Association, which represents this Nation's major aerospace and defense manufacturers with more than 630,000 high-paying, high-skilled jobs. I also chair AIA's Workforce Steering Committee to lead The Boeing Company's human resources function. One of my responsibilities is ensuring that our company and industry help develop the future workforce.

Today I would like to focus on what could be done at the undergraduate and graduate levels to strengthen the pipeline of students who enter and stay in STEM disciplines.

We in the aerospace industry are concerned about the United States' ability to sustain its leadership role in technology and innovation. As the need for complex problem solving accelerates globally, this country faces a competitive gap that we can close only if more of our young people pursue careers in STEM-related fields. Unless we close this gap, it will have grave implications for our Nation's competitiveness, security and defense industrial base.

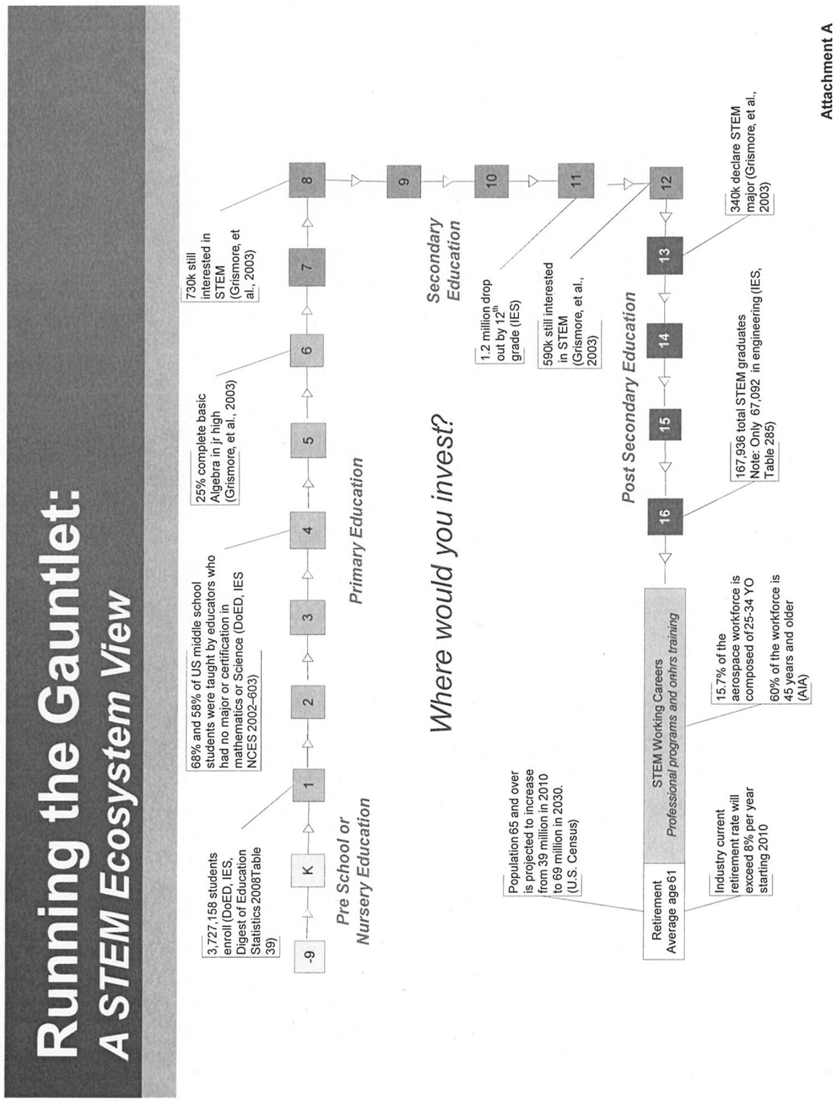
Today, the average age of the U.S. aerospace workforce is 45 and continues to increase. We expect that approximately 20 percent of our current technical talent will be eligible to retire within the next three years. In the very near future, our companies and our Nation's aerospace programs will need tens of thousands of engineers in addition to those joining the workforce today. These are already becoming difficult jobs to fill, not because there is a labor shortage but because there is a skill shortage. This is especially acute in the U.S. defense industry because many government programs can only employ U.S. citizens.

Of the positions open in the aerospace and defense industry in 2009, two thirds required U.S. citizenship. Yet, less than five percent of U.S. bachelor's degrees are in engineering compared with about 20 percent in Asia, for example.

Our pipeline of qualified U.S. STEM workers is too small. Of nearly four million children who start preschool in the United States each year, only about 25 percent of them will go on to complete basic algebra in junior high school, only nine percent declare a STEM major at the undergraduate level, only 4.5 percent actually graduate with a STEM-related degree and only 1.7 percent graduate with an engineering degree, and not all engineering degrees are applicable to the aerospace industry.

On a positive note, certain institutions of higher education have increased the retention rates of students who are in their engineering programs from 50 percent to greater than 80 percent. These successful programs typically feature similar key ingredients. From the time a student steps on campus, he or she is pulled into a group of students, or as part of this cohort has direct interaction with professors who wants to see his team succeed and also performs early on with hands-on projects as a freshman. When those things don't occur, we end up with costly attrition. The underlying problem with the STEM pipeline, though, starts much earlier. And I have a chart if it could be displayed now.

[The chart follows:]



Children whose imaginations are sparked by someone who reveals the possibilities of math and science tend to gravitate toward more related STEM interests, and if you look in the pipeline, this shows that we start with roughly four million at every preschool level and every grade year and ends up with the 1.7 percent at the end that get engineering degrees. And what you see is where the drop-off occurs each time. Hopefully this provides some insights to the Committee as a potential area to focus where resources be applied for the *America COMPETES Act.*

I think one of the most important elements is that today in the media about 10 percent of the characters are portrayed as scientists or engineers but of those, about 70 percent are negatively portrayed. This negatively influences children that spend 7 hours and 38 minutes every day engaged in media, according to the Kaiser Family Foundation. When this happens, we run into huge issues. The opportunity to turn it around comes, typically, from an inspiring teacher. However, all too often, we don't have enough inspiring teachers at the junior high school and high school level because some 58 percent of middle school teachers in math and 68 percent of middle school science teachers are neither proficient nor certified in these subjects.

The influence of parents and media is also profound. Let me just note here that AIA is in the process of tackling one of the biggest barriers, the perception of the STEM disciplines. We are collaborating with the Entertainment Industries Council, which has played a critical role in shaping people's perspective about smoking, seatbelts, and mental illness, just to name a few. We are now working together to support accurate depictions of how engineers and scientists are portrayed in the mainstream media.

The AIA and its members have developed the following recommendations to strengthen undergraduate and graduate education to support industry. First, encourage and expand scholarships and other forms of financial aid as well as retention programs for undergraduate STEM students. Number two, encourage and incentivize the preparation of STEM certified primary and secondary school teachers with the goal of ensuring that U.S. colleges and universities produce enough qualified secondary teachers of math and science. Third, help motivate our youth to pursue STEM-related careers by enhancing support for two- and four-year institutions. And fourth, motivate the media, parents and teachers to provide a positive view of STEM careers.

I also want to emphasize the importance of ensuring that we measure the impact of our investments in STEM education. Right now, the AIA is doing an inventory of our company programs to assess the impact of our investments, and we will have that complete by the first quarter of this year.

We are also working this process with other industries through a STEM coalition of coalitions. We encourage the Federal Government to also consider measuring the impact of its investments in STEM education programs and scaling up those that show positive outcomes.

Mr. Chairman, Dr. Ehlers and members of the Committee, thank you for the opportunity to testify before this important panel. I look forward to your questions.

[The prepared statement of Mr. Stephens follows:]

PREPARED STATEMENT OF RICK STEPHENS

Mr. Chairman and members of the subcommittee, thank you for inviting me today. I am honored to be speaking on behalf of the Aerospace Industries Association (AIA), the premier trade association representing the nation's major aerospace and defense manufacturers and their more than 631,000 high-wage, highly skilled employees; its Workforce Steering Committee, which I chair; and my employer—The Boeing Company. But I also come before the Committee with a background that spans more than a decade of engagement on education and science, technology, engineering, and math (or STEM initiatives). I have participated in shaping actions with the National Science Resource Center, National Association of Educators, the Business-Higher Education Forum, and the American Indian Science and Engineering

Society. Additionally, I have engaged researchers and scientists in brain research on what motivates students and am a regular speaker on this topic. I say this not to boast but to describe what I believe is a background necessary to integrate a number of issues and actions that impact the topics you are addressing today—Undergraduate and Graduate STEM education, and,,equally important, how to improve these areas and increase the number of students who choose STEM-related fields as majors and elect technology careers as their vocation.

Let me also provide a perspective that I believe is important to set a framework and context. In 1983, a blue-ribbon panel completed a seminal piece of work called "A Nation at Risk," which set the tone and framework for improving education in America. While it focused on primary and secondary education, I believe this work is directly related to today's topic. Today, nearly 27 years later, I contend that we are no longer a "Nation at Risk"; we are a "nation falling further behind"—this despite the fact that, as a nation, we spend more money on education at a total level and on a per-capita basis than any other country in the world. Hundreds of organizations are focused primarily on improving education in the United States and, more specifically, on STEM disciplines. These include the National Science Teachers Association, the Business-Higher Education Forum (BHEF), the Aerospace Industries Association (AIA), the American Institute of Aeronautics & Astronautics (AIAA), and the National Defense Industries Association (NDIA). In addition, every college and university is focused on increasing the number of graduates.

We are proud to be among those industries that have placed the United States in its leadership role in technology, innovation and the ability to solve highly complex problems. But as both the pace of innovation and the need for problem-solving accelerate globally, the United States faces a competitive gap that we can close only if more of our young people pursue careers in the growing fields of STEM disciplines.

In my industry, the *Aviation Week* 2009 Workforce Study (conducted in cooperation with the Aerospace Industries Association, American Institute of Aeronautics & Astronautics, and the National Defense Industries Association) indicates aerospace companies that are hiring need systems engineers, aerospace engineers, mechanical engineers, programming/software engineers and program managers. Today, across the aerospace industry, the average age of the workforce continues to increase, and expectations are that approximately 20 percent of our current technical talent will be eligible to retire within the next three years. As a result, in the very near future, our companies and our nation's aerospace programs will need tens of thousands of engineers—in addition to those joining the workforce today.

These are becoming difficult jobs to fill not because there is a *labor* shortage but because there is a *skills* shortage: Our industry needs more innovative young scientists, technologists, engineers, and mathematicians to replace our disproportionately large (compared to the total U.S. workforce) population of Baby Boomers as they retire. At the same time that retirements are increasing, the number of American workers with STEM degrees is declining, as the National Science Board pointed out in 2008.

This skills shortage is a global concern across the board in all high-tech sectors—public as well as private.

But it is especially acute in the U.S. defense industry because many government programs carry security requirements that can be fulfilled only by workers who are U.S. citizens. According to the *Aviation Week* 2009 Workforce Study, of the positions open in the aerospace and defense industry in 2009, 66.5 percent required U.S. citizenship. Yet only 5 percent of U.S. bachelor's degrees are in engineering, compared with 20 percent in Asia, for example. Meanwhile, in 2007, foreign students received 4 percent of science and engineering bachelor's degrees, 24 percent of science and engineering master's degrees, and 33 percent of science and engineering doctoral degrees awarded in the United States, according to the National Science Board. And most foreign students who earn undergraduate and graduate degrees from U.S. institutions are not eligible for U.S. security clearances.

Clearly, the throughput of our U.S. STEM pipeline carries serious implications for our national security, our competitiveness as a nation, and our defense industrial base.

Three key actions are necessary to ensure that we have enough scientists and engineers to meet future needs: 1) Successfully graduate all (or at least a lot more of) those who enter colleges and universities; 2) Ensure colleges and universities produce enough qualified secondary teachers for science, math and technology; and 3) Motivate our youth to pursue STEM-related careers that provide great pay, deliver on the promise of challenging and fun work, and create the future.

About that third point, let's face it: If you ask children what they want to be when they grow up, how often do you hear "I want to be an engineer"? First of all, many of them think engineers run trains. And those who do know what engineers are think they are like the nerds on the TV show, "The Big Bang Theory." We can fund all the public service announcements we want, but the sad truth is: If kids just don't see scientists and engineers as something they can and want to be (and if parents reinforce that perception), they simply won't go down that path.

Let me discuss what I think we can do to implement the three actions.

First: Successfully graduate all (or at least a lot more of) those who enter colleges and universities

At Boeing, we cultivate close relationships with 150 colleges and universities in the U.S. and around the world. We see the best students and hire the best talent possible. Two years ago, Boeing initiated a unique project to correlate work performance scores of engineers to the higher-education institutions from which our top-performing employees graduated. We have assigned a Boeing executive to partner with each institution to help us understand (1) general characteristics of programs that produce high-performing STEM workers and (2) how we can work together to further improve their students' readiness to enter the STEM workforce.

Although we hire graduates from many other institutions, we focus our active recruiting on our company portfolio of these high-potential institutions—many of which have increased their retention rates of students who enter engineering programs from 50 percent to greater than 80 percent. All of their successful programs feature the same key ingredients: From the time a student steps on campus, he or she is pulled into a group of students; as part of this cohort has direct interaction with a professor who wants to see this team succeed; and performs hands-on work, starting as a freshman.

Let me give you some good examples of these successes:

- At Columbia University, engineering students must do a hands-on community-service project; they must design and implement something of value to the community—a wireless network, for example.
- At the University of Southern California, engineering students attend core classes with the same group of 50 peer students and are assigned to an energetic professor who can relate to them and help them get through their critical first year.
- Many institutions today—including New Mexico State University, Northwestern University, the University of Southern California, and the University of Washington—offer bridge programs to freshmen minority or disadvantaged students. These programs help the students make a smooth transition to college-level academics, establish stable study and homework groups, attend academic workshops, take remedial or prerequisite classes that may not have been offered at their high schools, learn about STEM professions, gain work-study experiences, identify learning resources, and engage with the academic community. All of these activities significantly help with retention. Unfortunately, some of these programs have lost private funding from companies that are not faring well during the economic downturn.
- Most aerospace companies offer both internships (in which students—typically college juniors but sometimes sophomores—work at a company for 12 to 14 weeks during the summer months) or cooperative education programs (in which students typically work three industrial periods prior to their graduation). These programs enable students to demonstrate their skills, stretch their capabilities beyond their current level, increase their knowledge of their chosen fields, and experience what it's like to work in a company. Companies, in turn, are able to temporarily "hire" and evaluate talented students and later retain those with the right skills as full-time employees.

The U.S. has long been recognized as having many of the best colleges and universities in the world. By focusing on improving students' engagement in their freshman year with hands-on experiences and caring faculty, we can further improve even the best systems.

The second action: Ensure U.S. colleges and universities produce enough qualified secondary teachers for science, math, and technology

Our college and university system also prepares our teachers for primary and secondary education. But, by nearly every count, there are not enough qualified teachers to teach math and science in secondary schools. Many who teach STEM classes lack degrees in the fields they teach. According to the U.S. Department of Education, 58 percent of middle-school math teachers and 68 percent of middle-school science teachers are not proficient or certified in these subjects.

Math and science are hierarchical learning processes—meaning you have to learn them in stages, one step at a time, before you can move on successfully to the next step. When teachers anywhere along the way are neither proficient nor inspiring, too many of our young people miss foundational instruction, fall hopelessly behind and lose interest in science and math before they really have a chance to find out if they could be good at these subjects. What's more, the cost of remedial education (that is, trying to improve the skills of behind-the-curve students enough for them to grasp college-level STEM subjects) is very high compared to getting it right the first time.

Most colleges and universities that produce the lion's share of teachers have both education and engineering schools. The best higher-education institutions are finally beginning to focus on working together to ensure that teachers who graduate from college are in fact also wonderful scientists and engineers. "Rising Above the Gathering Storm," with its focus on 10,000 teachers and 10 million minds, did a great job laying out the actions needed to improve teacher quality and effectiveness at the primary and secondary school levels.

And finally, the third—and maybe most critical—action: Motivate our youth to pursue STEM-related careers

I know today's hearing focuses primarily on the undergraduate and graduate levels of STEM education. But if we cannot get enough students interested in going into the undergraduate STEM curriculums, we will fail in meeting the needs of business, government, and our economy. The underlying cause of the STEM-worker shortage starts way before college. What you learn *first* sticks with you; that is certainly true for how you think of math, engineering and science—and whether you're inclined to learn these subjects. Just as children whose parents read to them at a young age tend to do better as they progress through school and into adulthood, children whose imaginations are sparked by someone who reveals the possibilities of math or science tend to gravitate toward STEM-related interests. How can we expect that to happen more when so many *parents* are intimidated by math and science?

Unless and until we can show our young people that STEM specialties are important and fun—and pay well—the United States will continue to bleed human potential:

- According to the Department of Education: Of nearly 4 million children who start pre-school in the United States each year, only about 25 percent of them go on to complete basic Algebra in junior high, only about 20 percent are still interested in STEM subjects by the 8th grade, only 16 percent are still interested in STEM subjects by the 12th grade, only 9 percent declare a STEM major at the undergraduate level, only 4.5 percent actually graduate with a STEM-related degree, and only 1.7 percent graduate with an engineering degree. These figures are disproportionately worse for minority and female students. And, by the way—a topic for another day—1.2 million (or more than one-fourth) of those nearly 4 million children drop out of school altogether before they complete the. 12th grade, though a majority of these eventually return to obtain diplomas or equivalents such as the GED. These trends are consistent year over year. *[See Attachment A]*
- Meanwhile, U.S. students ages 15 to 17 rank 19th in the world in STEM critical-thinking skills, as measured by the Programme for International Student Assessment test. The number of engineering degrees awarded in this country is down 20 percent from 1985; that year, the percentage of undergraduates earning degrees in engineering fields peaked at 7.83 percent. It has declined most years since then. The United States graduates approximately 70,000 engineers each year, with only 44,000 eligible for aerospace careers, according to the AIA.

To reverse these abysmal trends, we first have to get more American children interested in math and science; then we have to keep them interested. And it must start with their perception of technology careers.

Where do children get their view of science and technology? A Kaiser Family Foundation study released January 20, 2010, indicates that young people ages 8 to 18 are directly engaged with the media (TV, movies and computers), mobile devices, and video games an average of 7 hours and 38 minutes a day—in other words, more time than they typically spend in school. And there's a correlation between media use and grades: While the study did not seek to establish a cause-and-effect relationship, it reports that about half of heavy media users (the 21 percent of young people who consume more than 16 hours of media a day) reported getting lower grades (mostly Cs or lower), while only about a quarter of light users (the 17 percent of young people who consume less than 3 hours of media a day) reported getting lower grades.

Who has young people's attention? It's clear that media in all its various new forms has a huge impact on the perspectives, attitudes and behavior of our youth. Take a look at the video "2 million minutes," and you'll see what we are up against when it comes to educating our children compared to other nations who want to be leaders in the marketplace.

In movies and on TV, 10 percent of characters are scientists and engineers. Unfortunately, of those, more than 70 percent kill others, are killed or are overcome by lay people. In the real world, however, scientists and engineers are the very people who create solutions for all that humans do in connecting people—whether by air, rail, car, or sea. They are the people who ensure that we have water, electricity, and gas. They are the people who create the devices that deliver the media that everyone clamors for. They are also the people who create artificial hearts and vaccines for H1N1. Scientists and engineers create the future. And they are *real* people. But if our media sends the wrong message, young people get the wrong view and don't want to be like most of the scientists and engineers they see on TV and in the movies.

In part to counter these misleading images, the Aerospace Industries Association has begun taking steps toward bringing together academia, government, industry, and media to strengthen the future workforce. Our Workforce Steering Committee, for example, is in the process of tackling one of the biggest barriers—the perception of the STEM disciplines. AIA and Boeing are collaborating with the Entertainment Industries Council (EIC), whose mission is to support accurate depictions of how engineers and scientists are portrayed in mainstream media. For the past 27 years, the ETC has played a critical role in shaping people's perspectives about smoking, seat belts (you remember the crash-dummy commercials) and mental illness, just to name a few. Boeing is providing scientific and technological expertise through a number of our engineers who are directly engaged with ETC to ensure that writers, directors and actors know what engineers and scientists do in real-world situations. These outstanding engineers have volunteered to help advance positive images of engineers and help develop creative storylines. Positive media influence will generate a huge impact on parents and children—and on those who would be our future teachers, scientists, and engineers.

Mr. Chairman and members of the subcommittee, I thank you for your attention to this important subject and appreciate your sense of urgency about it. If we in the United States hope to retain our nation's leadership in science, technology and innovation, we must immediately address the looming STEM skills gap.

At the recommendation of the Aerospace Industries Association and its members, please consider these actions to strengthen undergraduate and graduate education:

- First, encourage and expand scholarships and other forms of financial aid as well as retention programs for undergraduate STEM students.
- Second, encourage and incentivize the preparation of STEM-certified primary and secondary-school teachers.
- And third, help motivate our youth to pursue STEM-related careers by enhancing support for two- and four-year institutions that provide students with hands-on experience that is directly transferable to the. workplace.

We must cultivate and diligently attract talented young people who will become the scientists, engineers, and technical professionals that keep the United States economically competitive, our aerospace industry innovative and our national security strong.

Biography for Rick Stephens

Richard (Rick) Stephens is senior vice president, Human Resources and Administration, for The Boeing Company. Stephens, a 30-year Boeing veteran, also is a member of the Boeing Executive Council.

Named to this position in 2005, he oversees all leadership development, training, employee relations, compensation, benefits, Global Corporate Citizenship, and diversity initiatives at Boeing. The Chicago-based commercial airplane and defense company had revenues of $60.9 billion in 2008 and employs 159,000 people.

Prior to this assignment, Stephens, 57, served as senior vice president of Internal Services. During his career he has led a number of Boeing businesses, including

Homeland Security and Services, Space Shuttle, and Tactical Combat Systems, at sites across the United States and around the world.

Stephens serves on a number of nonprofit and business-focused boards and has been recognized for his longstanding leadership in local and national organizations. Passionate about improving education both inside and outside of the classroom, he works directly with community leaders to agree on common language, shared values, vision, and measures of success. This furthers industry's goal of ensuring a future workforce capable of the complex critical thinking necessary to succeed in an ever-changing competitive market.

Related to his efforts on education and the future workforce, Stephens currently serves on America's Promise Alliance Board of Directors; the National Science Resources Center Advisory Board; the Business-Higher Education Forum's Executive and Science, Technology, Education and Math (STEM) Committees; and the University of Southern California Engineering and Business School Corporate Advisory Boards. In addition, he is chair of the Aerospace Industries Association Workforce Steering Committee. These diverse but related experiences in education, along with his leadership in a major technology-based firm, give him unique insights into how education can prepare students to be successful in the job market.

Previously, Stephens served on the Department of Homeland Security Advisory Council; the Secretary of Education's Commission on the Future of Higher Education; the President's Board of Advisors on Tribal Colleges and Universities; the National Academy of Engineering Committee on Science, Engineering, and Public Policy; and

the Association of Public and Land-Grant Universities Science and Mathematics Teacher Imperative Commission.

Stephens is a member of the Department of Health and Human Services Health IT Standards Committee, Fellow of the American Institute of Aeronautics and Astronautics, and chairman of the Illinois Business Roundtable. Stephens also serves as the Boeing executive focal for the University of Southern California.

Stephens received his Bachelor of Science degree in mathematics in 1974 from the University of Southern California and his Master of Science degree in computer science in 1984 from California State University, Fullerton.

Stephens is an enrolled member of the Pala Band of Mission Indians and served as its chairman from 1988 to 1989. He is a former U.S. Marine Corps officer.

Chairman LIPINSKI. Thank you, Mr. Stephens. Now I will recognize Dr. Finkelstein.

STATEMENT OF DR. NOAH FINKELSTEIN, ASSOCIATE PROFESSOR OF PHYSICS, UNIVERSITY OF COLORAD, BOULDER

Dr. FINKELSTEIN. Thank you, Chairman Lipinski, Ranking Member Ehlers, and distinguished members of this Committee. My name is Noah Finkelstein. I am a professor in the Physics Department at the University of Colorado, one of the directors of the Physics Education Research Group there, and one of the directors of the Integrating STEM Education Initiative that is running across campus.

I am honored to be here today, and I applaud this Committee for holding these important hearings.

Education is society's fundamental form of investment in its future. This is the basic R&D for our society itself. And as a result, we are now deciding among a variety of possible futures. Will we depend on other countries for technological innovation, for basic technological infrastructure? Will our children grow up to be the leading scientists and innovators that we desire? Will students have access to college? The outlook is mildly pessimistic, despite my being an optimist.

While education is a fundamental form of investment in the future, a critical, perhaps the critical lynchpin in our educational system is higher education and STEM education within that. In addition to being the locus of where we educate our undergraduate and graduate students, this is where STEM disciplines are defined and practiced. This is the destination of our students in the pre-college system. This is where we educate our future teachers at all levels and current teachers return for professional development. This is where we produce materials, assessments, standards, and this is where we conduct leading research on student learning. It is also all too often an overlooked area in education in our national discourse on education.

So I make three brief points in my testimony. One, we know what to do, particularly in undergraduate STEM education, but we don't do it broadly. Second, the challenges in our STEM educational endeavors are complex and intertwined and so, too, should be our solutions. And third, given the scale of our educational challenges, key seed funding from the Federal Government through programs such as the NSF's can unlock hundreds of billions of dollars of latent infrastructure in the university system itself.

To the first point, through discipline-based education research over the last several decades, we have shifted our understanding of teaching and learning. We have shifted from a teacher-centered and information delivery model to that of a student-centered, inquiry oriented model. Those sorts of programs have been heralded by engineers for quite some time. Through the Colorado Learning Assistance program applications of these ideas and understanding, we have now doubled to tripled consistently our student performance in our introductory physics courses.

And yet, despite knowing what to do, these practices are not widespread. In short, we are not taking the same scholarly and scientific approach to promoting change in STEM education than we are to STEM education itself.

This leads us to the second point: the challenges in our STEM educational endeavors are complex and intertwined. We should be thinking about how we can couple undergraduate and graduate programs, teacher professional development programs, preparation and research on student learning. The Colorado Learning Assistant program is one such example where not only do we focus on course transformation to realize these enhanced learning gains, but we recruit talented undergraduates to serve as coaches for fellow undergrads, and they serve as a pool from which we recruit future teachers. We also focus on faculty development and education research. The results lead us to improved learning gains for all students. Our undergraduate learning assistants look more like their graduate student peers than they do their undergraduate peers. We see faculty developing along the way. We have tripled the number of physics majors going into K–12 teaching. There are plenty of other examples, such as the Science Education Initiative, Informal Science Education and graduate teaching programs such as CIRTL that are running and impacting our own campus.

So this is a key opportunity, and the Federal Government has served tremendously, historically, and has potential for the future for leveraging these opportunities and resources for seeding key individual action. We need to ensure that faculty practices are aligned with our understanding of student learning, and we need to support faculties' engagement and the scholarship of teaching and learning and discipline-based education research.

The National Science Foundation programs that were alluded to before are key. My own field has benefited from the Distinguished Teaching Scholars program, the Career Fellowships, the former PFSMETEs, or post-doc fellowships, and the GRFs themselves have been instrumental. And programmatic activities at the NSF have led to many of these findings such as CCLI, REESE, the DRK–12, and more recently education efforts within the directorates themselves. The STEM directorates are engaging in education. Noyce has also been instrumental in helping us transform our undergraduate programs.

Meanwhile, sustained federal support is essential, and scaling of federal support is essential. We can no longer operate just at the individual scale or just at the programmatic scale. We need to start thinking about departmental transformation, institutional transformation, and the role that professional organizations can play. The American Physical Society, the American Association of Physics Teachers, the Association of Public and Land Grant Universities have taken on the mantle of educational reform, teacher recruitment and preparation, and they have been instrumental in supporting our own efforts at the University of Colorado.

Through targeted federal funding on the order of billions of dollars we can engage university resources on the order of hundreds of billions of dollars. This Committee can catalyze and endorse both in name and in action these key stakeholders in making that education happen.

Thank you so much. I look forward to the discussions.

[The prepared statement of Dr. Finkelstein follows:]

Prepared Statement of Noah Finkelstein

Chairman Lipinski, Ranking Member Ehlers, and distinguished members of the Subcommittee on Research and Science Education,

Education is society's fundamental form of investment in its future.

As a result, we are now deciding among a variety of possible futures for our nation.

- Will we depend on other countries for technological innovation? Or for essential technological infrastructure, such as energy?
- Will our children grow up to be leading innovators and scientists?
- Will *all* students have access to college in a time when, more than ever before, a college degree is required for even entry-level positions? Will the *average* student?
- Will our school systems continue to mimic the educational systems that were designed for a different era, or will new models of education emerge?
- Will we have the basic human capital to ensure a quality of life for all, and to address our continued growth in consumption? Will our future be secure?

Current indicators are pessimistic for our country, on just about all accounts.

A critical, perhaps the critical linchpin in our educational system is in Higher Education, and STEM education in particular.

I applaud the Committee on holding these hearings and its continued investigation into the state of affairs in STEM education at all levels.

The focus of this testimony will be predominantly on the nature of undergraduate STEM education. My esteemed colleagues will be discussing the role of graduate education. However, much of what is stated here also applies to our graduate programs, and I explicitly address the linkages among our many educational levels.

I make 3 points in this testimony:

1) Through a scientific approach to science education, educational researchers in STEM have developed substantial research-based knowledge. Research has demonstrated that traditional models of classroom-based education are no longer appropriate and that new models that engage students in learning experiences are critical. Further, we now know what to do to improve individual learning, engagement, access, and retention of students in courses. We also know that these improved and effective educational experiences are not widespread. And we know that we are missing critical research on sustaining and scaling these educational reforms.
2) The challenges to our STEM educational endeavors are complex and intertwined, and so, too, should be our solutions. So far, higher education has been separated from national discussions regarding educational reform. It is time to focus on integrated approaches that reach across disciplines and across levels of our educational system to provide us with solutions that address our broad national challenge and do so in a scalable, sustainable, and cost-effective manner.
3) Given the magnitude of our educational challenges in STEM, we need far more resources than the Federal Government can supply—but we do need the Federal Government to become the catalyst for other kinds of investment. We need the investment of the American citizenry and the University system. We need to engage STEM faculty and researchers in educational innovation and change. Seed-funding from the Federal Government can stimulate the involvement of the populace and unlock $100s B in latent infrastructure of the higher educational system, thereby providing some hope of addressing the Grand Challenge that faces us.

1. We know which educational practices work, but they are not widely implemented.

In recent decades researchers within STEM disciplines, informed by research in the learning sciences, education, psychology and other social science arenas, have productively focused attention on how students learn, conditions that support (or inhibit) student learning, what defines meaningful learning, and how to authentically assess student learning in STEM disciplines. Numerous reports and testimonies document this shift in understanding of teaching and learning. We must move away from teacher-centered and passive-student pedagogy to a student-centered, inquiry oriented, discipline-based model of pedagogy that is research-based and research-validated. We have documented the failures of our traditional educational, system on: student mastery of foundational concepts, problem-solving skills, views about the nature of science, interest, engagement, and retention.

Through careful research, we have documented the sorts of educational practices that lead to substantial learning gains. For example, as part of the Colorado Learning Assistant model (described below), we have carefully implemented two key educational reforms in the introductory physics sequence at the University of Colorado: *Tutorials in Introductory Physics,* perhaps the most thoroughly researched educational reform at the introductory college level in our nation, and *Peer Instruction,* one of the most widespread educational reforms in introductory college physics. Both educational approaches shift from the instructor-centered to the student-centered, from dissemination of information to student construction of understanding, from rote algorithmic processing to student argumentation that is supported by and develops robust conceptual understanding. As a result of implementing these new educational practices, we now consistently document student learning gains that are two to three times what they used to be, and two to three times the national average for traditional educational experiences. Researchers within STEM departments are leading the way in similar, but isolated transformations around the country, and such results are found nationally in all STEM disciplines that make scholarly inquiry into the nature of student learning.

Because of a new scientific approach to education, STEM departments are establishing measurable learning goals for undergraduate education, tools for course transformation to address these goals, and evaluation instruments and metrics for assessing these achievements. Faculty are measuring not just rote algorithmic processing, but deep problem solving skills, conceptual mastery, beliefs about the nature of science, and beliefs about the nature of learning science. Researchers are identifying mechanisms for addressing the historical disparity in access, inclusion, and achievement between majority and minority students, and between male and female students. The involvement of researchers within STEM disciplines who focus on STEM education is critical in attending to disciplinary and departmental specifics. As a result of this scholarly approach, there are a variety of examples of educational practice that address the lack of achievement, poor retention and the gender and racial gaps in STEM education at the university level. Discussed below, we find that the most successful programs, and those that are likely to be sustained, are those that integrate across the many of the challenges that face us, those challenges identified in NRC's *Rising Above the Gathering Storm* report and those challenges that the America COMPETES Act seeks to address.

While effective practices of educational reform in undergraduate STEM have existed for decades, and data on their success have been widely accessible and cited, the reforms themselves are not widespread. This limited adoption is not because of a lack of effort on the part of the developers. For example, my colleagues at the University of Washington who authored the *Tutorials in Introductory Physics* have been running workshops on their curricula for the last decade. *Peer Instruction's* developer, Eric Mazur of Harvard, has given over 300 talks about *Peer Instruction* and 18,700 copies of his book *Peer Instruction* have been shipped—including 12,700 free copies. This represents approximately one free copy for each of the roughly 13,000 physics faculty employed in all four-year and two-year colleges in the U.S. Despite the best efforts of educational innovators across the country, practices have not changed dramatically. Current research studies from a variety of sources suggest that we lack a model of educational change that is sufficient. We cannot simply put good ideas out there and expect them to be used. We cannot simply mandate their adoption. We cannot expect these innovations to diffuse on their own. In recent reviews of over 400 studies of change in undergraduate STEM education, we have found that most change initiatives do not cite or build on prior approaches, most are not based on research, and most are not effective or sustained.[1] As a recent synthesis of a National Academies workshop on STEM education concludes, "the greatest gains in STEM education are likely to come from the development of strategies to encourage faculty and administrators to implement proven instructional strategies".[2] The conclusion calls for the development of "models for implementation, dissemination, and institutionalization for STEM reforms where the relative roles of evidence-based research on teaching, leadership, workloads, rewards, and so on are clearly delineated." In short, as of yet, our nation's universities are not taking a scholarly and scientific approach to promoting change in STEM education on a broad scale. These studies and others suggest that successful *change* efforts:

- identify a coherent vision of change and communication of that vision;
- attend to multiple scales of reform (focusing on individual faculty development and reward, along with departmental, institutional, and disciplinary community engagement);
- recognize that educational reforms must be adapted and transformed (at least modestly) to attend to local circumstances;
- focus on the university department as a key unit of change;
- and evaluate the change process and use evaluation to improve programmatic approaches.

Such findings provide us with tools and suggestions as we shape calls for reform and criteria for funding models of educational transformation. However, more research is needed, both on how educational innovations are locally adapted and models of scaling educational reform.

2. Education is a complex and integrated system: this structure is an opportunity for leveraging change.

The same features that challenge us to improve our educational system provide us opportunities to solve these challenges. Because components of our educational system are coupled with each other, we can effect change in the entire system by carefully seeding change at critical junctures. Higher education is a critical and often overlooked juncture. Policy makers, industry leaders, scientists and much of the broader populace are educated at universities. Universities are the institutions where we recruit and prepare our future teachers and where current teachers return for professional development. Universities are where disciplines are defined, modified, and practiced. Universities are (and should be) the destination for our nation's youth beyond high schools or community colleges.

Because universities serve such a broad constituency and possess such intellectual, social, and political capital, we can strategically leverage their roles to promote lasting, national-scale change in STEM education. Universities house the STEM re-

[1] Henderson, Beach, and Finkelstein. Facilitating Change in STEM Education. See: *http://www.stemreform.org* or *http://www.wmich.edu/science/facilitating-change/*.

[2] Fairweather (2008). P26. *http://www7.nationalacademies.org/bose/Fairweather_CommissionedPaper.pdf.*

searchers, STEM education researchers, and educators. Universities house and develop this knowledge and we can foster the necessary integration of these historically different areas of scholarship to promote educational transformation and institutional change. This approach requires that we implement change in which disciplinary content is brought together with educational research and educational practice. The model programs that are most successful—whether they are directed at increasing the number and quality of disciplinary majors or increasing access, at awareness and expertise in science among the general public, or at improving the number and quality of K20 STEM teachers—bring together stakeholders and expertise from disciplinary, pedagogical, and educational research domains. In addition to housing the resources necessary to improve undergraduate STEM, scalable, adaptable models of educational reform exist within universities that simultaneously address the multiple goals and challenges of the broader STEM education system.

Successful research-based programs at the University of Colorado at Boulder (and others across the nation) demonstrate that we can increase student learning and engagement, include more students, engage STEM faculty in educational change, recruit more and better STEM teachers, and do so in a sustainable, scaleable, and cost-effective manner.

The Colorado Learning Assistant (LA) model,[3] directed by my colleague, Professor Otero, is a nationally replicated model for simultaneously improving undergraduate learning, recruiting talented STEM majors into careers in K–12 teaching, engaging STEM research faculty in educational transformation, and scientifically investigating these efforts. The model is designed to work in any discipline and currently runs in nine science, mathematics, and engineering departments at the University of Colorado at Boulder. The key to this approach is the experiential learning process, in which talented undergraduates (LAs) facilitate course transformation and thereby [earn themselves. LAs lead Learning teams of other undergraduate students, encouraging them to articulate and defend their ideas, engage with inquiry-based activities, and analyze real scientific data—activities that have been shown to improve student learning and retention. LAs also work with disciplinary faculty to refine course materials and instruction-based on student assessment data. To help LAs with this process, they take a pedagogical course, which encourages them to reflect on, evaluate, and investigate different teaching practices. Central to the Colorado LA model is its role in promoting institutional change. The LA model addresses the needs of multiple stakeholders including STEM and education faculty, undergraduate students, K–12 teachers, and university administrators and is flexible to accommodate small-scale to large-scale innovations.

These shifts have doubled and even tripled undergraduate learning gains for students in our introductory physics courses. At the same time Learning Assistants learn content (performing more similarly to our elite graduate students on measures of conceptual mastery), perform better in their upper division courses, and demonstrate more sophisticated views on the nature of education and teaching. As a result of the LA program, we have more than doubled the number of physics and chemistry majors getting certified in these hard-to-staff subject areas. The program also positively impacts graduate students (who are departmentally assigned Teaching Assistants) and future graduate students—the bulk of LAs go on to graduate school and carry their mastery of content and pedagogy with them. As such, the LA program directly addresses the concerns National Research Council's *Rising Above the Gathering Storm* recommendations: 1) more and better teachers and 3) educating our best and brightest in STEM education. Furthermore this program develops STEM departmental culture and promotes the positive and instrumental role that STEM faculty can play in education. Because it is a high impact, cost-effective, and easily adapted model of institutional transformation, the program has spread to institutions throughout the country with the support and the endorsement of professional organizations such as American Physical Society and the Association of Public and Land-grant Universities, discussed below.

The Science Education Initiative[4] (SEI) program led by Nobel Laureate Carl Wieman provides another model for simultaneously achieving two critical steps towards more effective STEM education. First, these programs are improving STEM courses at both the University of Colorado and the University of British Columbia. More importantly, however, this model focuses on shifting departmental culture. The program is designed to secure departmental-level commitment (and to provide substantial resources) to established, well-defined learning goals for students, rigorous assessment of learning, and implementation and testing of improved teaching

[3] Colorado Learning Assistant Program, see: *http://stem.colorado.edu.*
[4] Science Education Initiative, see *http://www.colorado.edu/sei.*

methods for each of its core undergraduate courses. Two key features of this approach include widespread discussion (and ultimate consensus) among the faculty of a department, and employment of department-based science education specialists, who bring expertise within the STEM discipline, knowledge of education research within the disciplines, and are familiar with proven educational approaches and evaluation techniques. The SEI partners faculty with each other, and with the educational specialist to draw on what is known in the field and make locally relevant and meaningful changes based on research. The goal of the SEI is to implement course- and department-level transformations that become a part of a department's institutionalized practice. Initial results demonstrate the potential of such a model: the bulk of faculty in several participating departments at two major research institutions have engaged in SEI activities; it has fostered a better understanding of practices that help students learn and has conducted fundamental research in STEM education; and the SEI has positively impacted tens of thousands of students in its four year history.

University-Community Partnership Models in Informal Science Education: Increasing attention is now being paid to the breadth of educational opportunities that exist for our students, to the great deal of learning that happens outside of formal school hours, and to the opportunities for partnerships between universities and local communities that can be leveraged inexpensively to be productive for all levels of education. The recent National Academy of Education study, *Time for Learning,*[5] recognizes the importance of out-of-school time for K–12. Meanwhile, professional societies and universities have been calling for more opportunities for undergraduate research, real-world internships, service learning, and experiential-based learning programs. Partnering universities with community-based K–12 programs provides a key opportunity for universities to educate undergraduates in innovative ways, while simultaneously addressing challenges of under-represented and under-supported students in STEM at all levels. We already have replicable models of university-community partnerships that bridge the historic divides between the university system and host communities, and the public broadly. A long-standing program, initiated at the University of California system, UC Links,[6] serves as a key model that has spread internationally with minimal funding or fanfare. As part of undergraduate education, students engage in a practicum course where they put their university, school-based learning into practice in local community center activities designed to improve the education, access, and identity of students in local areas, especially students from poor and under-represented populations. Project-based STEM activities are central to these activities, which have been shown to increase interest in teaching careers, increase children's performance, and increase college student performance and retention. Our own application of this program, Partnerships in Informal Science Education in the Community[7] has improved undergraduate and graduate students': mastery of content; interest, understanding, and acuity in teaching; awareness of the diversity and challenges in our local communities; and abilities to communicate with the public about science in everyday language. These programs are also shown to improve the communities in which they are embedded. They provide children with an increased understanding, interest, and ability in STEM; they, promote community agency and ability to engage in STEM educational programs; they support the development of community leaders and professional development of teachers. All partners benefit by leveraging local resources in a cost effective, sustainable, and scalable fashion.

These are a subset of the models of institutional support of STEM education that reach beyond the narrow vision of making improvements to specific courses. As a result of coordinating a broad-scale agenda, these programs address the integrated challenges in STEM education, and bring together supportive stakeholders at key levels. A variety of other models apply similar principles, which include but are certainly not limited to recent testimonies before this committee on the Center for Integration of Teaching and Learning (CIRTL) and K–12 Engineering education (programs at Tufts, Purdue, VaTech, and Clemson), and the NSF GK–12 and MSP programs (when well implemented, as per findings of recent studies),[8] and Peer Led Team Learning programs that are spreading from chemistry to other disciplines.

I do not advocate a one-size-fits-all model of institutional change, but rather emphasize the programmatic characteristics, and key features that emerge from these

[5] Time for Learning, *http://naeducation.org/Time_for_Learning_White_Paper.pdf.*
[6] UC Links, *http://uclinks.berkeley.edu.*
[7] Partnership in Informal Science Education in the Community, *http://spot.colorado.edu/~mayhew/PISEC/.*
[8] Change and Sustainability in Higher Education, *http://cashe.mspnet.org/.*

successful programs. These features are consistent with and build upon effective change models listed in section 1:

Establishment and Articulation of Goals for undergraduate STEM education. While broad goals have been established nationally (to provide access, inclusion, excellence in STEM disciplines), these must be realized in a localized fashion. Programs must clearly establish their goals, and mechanisms for achieving those goals. A significant, positive, and dramatic shift has been to focus on these goals and outcomes rather than on strictly mandating process (like seat-time or credit-hours for students). ABET[9] 2000 provides a key example of this successful shift, as does the European approach in the Bologna Process[10] to coordinate efforts in Higher Education.

Programs based on valued scholarship. Making a scholarship of our educational practices supports the use of effective research-based programs in locally meaningful ways. The explicit inclusion of disciplinary-based educational researchers (within university STEM departments), in partnership with educators and community members, is a particularly effective mode of bringing about scholarly change. The STEM fields, especially in departments at research institutions, should measure and value their educational pursuits to the same extent that they measure and value their research pursuits.

Participation and support of stakeholders at a variety of levels. Distributed expertise is needed to stimulate improved undergraduate instruction. Successful programs bring together students, faculty, administrators and often community members in creating sustained programs. Again, disciplinary-based education researchers provide a new model and instrumental resource for leading such change. At the same time, key reward structures are required to insure inclusion and enthusiasm of appropriate stakeholders at all levels.

Departments as are key levers of change. A variety of institutional structures can be employed in the transformation of undergraduate education. A key unit of change will be individual courses in STEM education, but to sustain these changes requires broader thinking. It is faculty, departmental and institutional culture, vision, policies, and structures that ultimately sustain the new practices in undergraduate STEM education.

Evaluation that provides formative (and corrective) assessment of programs will ensure relevance and evidence of success. These evaluations must be aligned with the identified goals at each level of the intended transformation (learning goals for the students, faculty engagement, sustained institutional transformation, and scaling of programs nationally).

3. Who is at the table and how do we act to improve undergraduate STEM Education?

Because our educational problems are not isolated, our solutions need to be integrated. We must act across scales of the educational system, from individual students and faculty to departments, institutions, and disciplinary societies, from K–12 teachers to districts and states. Again models of programs from the prior sections provide key insights into factors that enable quality transformation of undergraduate education in STEM, dramatically increase the number of majors, and significantly enlarge the pool and quality of STEM teachers.

National societies have played important roles in addressing these integrated problems and associated solutions. Physics provides a good example. With its internationally recognized Physics Teacher Education Coalition,[11] the American Physical Society (APS), in collaboration with the Am. Association of Physics Teachers (AAPT) and the Am. Institute of Physics, has acted on its main educational mission—increasing the number and quality of physics teachers. APS's second educational mission, doubling the number of physics majors, is intimately coupled with its mission to improve teacher education at all levels. The disciplinary societies also recognize the key role that discipline-based education research plays. Starting in the 1970s faculty in physics started offering Ph.D.'s to physicists for work in education research; in the 90s APS endorsed physics education research within departments, supporting the creation of this sub-discipline. APS and AAPT have been empowering departments to engage in the educational research and reform to simultaneously recruit and prepare more teachers and to recruit more students into the major. The University of Colorado at Boulder is a prime example of this approach; without the physics education research group our students would not be learning as much. APS

[9] ABET 2000, *http://www.abet.org/*.
[10] Bologna Process, *http://www.bologna2009benelux.org*.
[11] American Physical Society's, Physics Teacher Education Coalition, *http://www.ptec.org*.

and AAPT have been a key supporters in building this discipline-based education research group and the field more broadly.

More recently, and following APS model, the Association of Public and Land-grant Universities has launched it's Science and Mathematics Teacher Imperative.[12] Representing one of the largest coalitions of university presidents, chancellors, and provosts in the U.S., this organization brings together 121 institutions that are committed to doubling the number of high quality physics and chemistry teachers. They are part of the Educate to Innovate solution in K–12. They recognize the critical role that Universities play in national-scale educational change in both undergraduate education and teacher recruitment and preparation. This organization is moving universities to improve undergraduate STEM education by identifying effective models and practices, enacting and applying research on educational change, and creating value for institutional participation in these broad-scale challenges.

These are the seeds of change.

These are efforts that are beginning to *unlock the latent potential of universities to address the integrated challenges that face us in STEM education* at all levels. By leveraging significant and targeted Federal funding (in the $1Bs) we can engage the resources ($100Bs) that reside, largely inert, in our university system to improve STEM education. Universities are established as institutions of Higher Education; faculty are hired and given salary to simultaneously develop new knowledge and to share this knowledge with the public—through education. Recent studies demonstrate that faculty are committed to education—they spend tremendous time and resources on their teaching pursuits. We need to ensure that these faculty practices are aligned with our understanding of student learning. We need to establish institutional resources that support faculty engagement in meaningful educational experiences. And, we need to shift institutional reward structures, modestly, to support this scholarly approach to STEM education.

Long term and Federal support are critical.

The National Science Foundation (NSF) provides an excellent model in providing both funding and prestige (imprimatur) to effect change. NSF can allow scientists, engineers, mathematicians and educators alike to engage in STEM education research and reform.

How might NSF and other Federal agencies take steps to enhance the value (prestige) for the essential levers of change?

At a small but critical scale, programs that bring key individuals to the table, that engage scientists in the *scholarly* pursuit of education, are vital, in my own field, the story of success can be traced, in part, to key individuals who have received essential NSF support, which has provided needed prestige and funding. In the *NSF Distinguished Teaching Scholars* (DTS) program, faculty are recognized for their commitment to scholarship in traditional areas of science and science education. Other NSF programs achieve similar goals, *CAREER, PFSMETE, GRF's,* simultaneously provide a cache and financial resources for basic research and innovation in education. These award winners bring about change in education. My own work in education was started with a PFSMETE. Later, a CAREER award provided essential infrastructure to support our research group, now one of the largest of its kind. This type of funding has allowed me and other scholars to engage in fundamental education research and reform—that high risk, high reward research that is the hallmark of American innovation.

Because NSF applies a *scholarly review* to education funding, it emphasizes a scholarship of educational research, reform, and practice. NSF supports a scientific approach to conducting STEM education research and reform, and supports and rewards individual scholars with its high status reputation. Other agencies should adopt such review procedures. Key NSF programs, in addition to those listed above (DTS, CAREER, PFSMETE, GRFs), have supported individuals in the development of educational research in STEM and associated reforms. These include but are not limited to *CCLI, REESE, DR–K–12, education efforts within STEM directorates, and Noyce.* However, due to lack of funding high quality, innovative programs, some that review well and draw on and contribute to educational research are often not supported. With funding rates of ~10% in some areas, quality programs, those that contribute to our educational solution, are not getting funded. These programs, and others that allow for both research and reform at multiple levels (such as MSP, and potentially Noyce) should be supported more substantially. Further, excellent pro-

[12] Association of Public and Land-grant Universities, Science and Math Teacher Imperative, *http://teacher-imperative.org.*

grams like Noyce are too limited to allow for creativity in models for preparing and supporting teachers. While I recommend the continuation of such funding, I also recommend that flexibility be increased so that educational researchers can develop and test new models of teacher preparation and the intimately linked roles of undergraduate STEM education.

Meanwhile *sustained Federal support* is a characteristic of other Federal Departments that should be adopted by the NSF. As noted in *Gathering Storm,* U.S. infrastructure suffers from a "recurring pattern of abundant short-term thinking and insufficient long-term investment" (p. 25) A critical challenge of NSF is the intermittent funding. However other Federal programs, such as the Department of Energy, have recognized the essential role of sustained funding of innovation. This Committee can examine the potential for providing continuing funding for programs that are proving successful and still require external support. Another area of needed focus for NSF is to allow for *larger-scale programmatic efforts*—While individual faculty and researchers may seed change, larger units are essential to sustained and scaled transformation. Funding for larger scale programs such as departmental and institutional level transformation are needed. Small examples, such as NSF's Innovation through Institutional Integration, are a start. This funding is helping support the institutionalization of the educational reforms in STEM at the University of Colorado at Boulder.

Of course the scale of challenge that faces our nation demands a yet larger scale response, with more funding. What is needed is a cultural shift—within science, technology, engineering and math:

- for STEM departments to take up the mantle of educational reform and assume leading roles in STEM education challenges across all levels,
- for institutions to integrate efforts across STEM disciplines and teacher education programs,
- for professional organizations and societies to assume leadership in endorsing, enabling, and connecting efforts across the nation in reform,

and for *this Committee to catalyze and to endorse both in name and in action (funding) these key stakeholders* in improving STEM education at the undergraduate and at all levels. We know this approach can work; it has been demonstrated at a small number of institutions, such at my own, the University of Colorado.

This cultural shift in supporting STEM education may sound ephemeral, but it can be the result of a Grand Challenge, where all Americans realize their identity and agency in STEM education reform. As such, we can return to our roots as a Democracy based on an educated citizenry.

Thank you for your dedication to this critical issue.

Biography for Noah Finkelstein

Noah Finkelstein received a Bachelor's degree in mathematics from Yale University and his Ph.D. for work in applied physics from Princeton University. He is currently an Associate Professor of Physics at the University of Colorado at Boulder and conducts research is in physics education. He serves as a director of the Physics Education Research (PER) group at Colorado, one of the world's largest research groups in physics education. Finkelstein is PI or Co-PI many nationally funded research grants to create and study conditions that support students' interest and ability in physics. These research projects range from the specifics of student learning to the departmental and institutional scales, and have resulted in over 70 publications. Finkelstein is also a co-PI and a Director of the Integrating STEM Education initiative (iSTEM), an NSF-i3 funded program to establish a Center for STEM education. Finkelstein serves on five national boards in physics education, including: the Physics Education Research Leadership Organizing Council, and the Committee on Education of the American Physical Society. In 2007 he won the campus-wide teaching award and in 2009 he won the campus Diversity and Excellence award.

Chairman LIPINSKI. Thank you, Dr. Finkelstein. Now I will recognize Dr. Klomparens.

STATEMENT OF DR. KAREN KLOMPARENS, DEAN AND ASSOCIATE PROVOST FOR GRADUATE EDUCATION, MICHIGAN STATE UNIVERSITY

Dr. KLOMPARENS. Thank you. Congressmen Lipinski, Ehlers and members of the Subcommittee, thank you for the opportunity to discuss the importance of graduate education to the future success and competitiveness of the United States. I will focus my remarks on three areas, the first of which is the importance of graduate education to our Nation.

In the 21st century, knowledge-based economy, the clearest path for the country to remain competitive and secure is to produce a highly trained STEM workforce equipped with advanced and flexible skills across all the employment sectors. Our Nation's graduate programs are the major source of such a workforce. The number of doctorates awarded in the United States has grown an average of 2.5 percent annually for the last decade, and the proportion of those in STEM fields has also increased. However, this pales in comparison to the growth in China, as Chairman Lipinski pointed out earlier. Between 1985 and 2005, the number of science and engineering doctoral degrees awarded in China increased by 700 percent. While the actual numbers are not known yet, it is widely presumed that China is on a path to overtake the United States as the largest producer of Ph.D.'s in sciences, math and engineering. And it is not just with China with whom we are now competing. Other countries and regions of the world are investing in and enhancing their graduate education systems as part of their own national economic development strategies, in part by watching the success of the United States over the last 50 years.

Today's graduate students are the future innovators and creators of knowledge. They are also the future educators of the next generation. The United States will continue to need these individuals in a variety of fields not only to remain globally competitive but also to address the grand challenges we face in areas like energy independence, climate change and other environmental issues, food security—in Michigan the issue is water—other issues are healthcare, and areas that we can't even imagine today.

A major challenge for the entire U.S. educational system K through 12, undergraduate and graduate, is in recruiting and retaining a diverse cadre of talented students who are interested in and prepared to pursue STEM education.

The second area is a brief example of Michigan State University and what we are doing to try to help improve these issues. We enroll approximately 10,000 graduate and graduate professional students, including more than 2,000 in the STEM disciplines. Eight years ago we embarked on creating a professional development program for STEM and other disciplines that both complements both the academic curriculum and also equips students with additional essential skills such as collaboration, conflict resolution, responsible conduct of research, communication skills, all in order to be more effective leaders regardless of the employment sector.

Michigan State currently has five STEM education active grants, and our STEM faculty and students participate in these very actively. Best known of course is the NSF's Graduate Research Fellowship program, which provides vital support to our outstanding

Ph.D. students, and other programs such as the Alliances for Graduate Education in the Professoriate allow us to focus on developing a competitive and inclusive STEM workforce. These NSF programs are critically important for us to be able to promote and support continuous improvement in STEM graduate education.

The third area is the policy recommendations that I would like to make for the Committee to consider, and the question, of course, is how do we collectively enhance and improve STEM graduate education? One is by creating better alignment between K through 12, undergraduate and graduate education. This is a system, and it is a mistake to try to separate these and try to handle them differently. We also need to signal career pathways to students so that they understand the multitude of career options available with a STEM graduate degree. We need to continue to institutionalize interdisciplinary research and training, not for itself but to solve problems, and we need to increase the participation of the U.S. domestic population in graduate education, particularly members of underrepresented groups.

NSF is addressing each of these challenges, but Congress can further support the vital role of graduate education by recognizing and supporting graduate education as a key driver of our national competitiveness and innovation strategy; supporting the increases to NSF's Graduate Research Fellowship program, IGERT program and the Noyce program; reauthorizing provisions in the *America COMPETES Act* such as the Pace Fellowship program at the Department of Energy and the Professional Science Master's Degree Initiative; and enhancing the federal support for doctoral education, particularly through traineeships that may be focused on strategic national priorities.

Thus I recommend that Congress consider creating a traineeship for doctoral students to prepare future leaders to address the complex, interdisciplinary challenges I mentioned earlier. And finally, the Committee should consider upcoming recommendations from the Commission on the Future of Graduate Education, which is formed by the Council of Graduate Schools and the Educational Testing Service. These industry and academic leaders are exploring the connection between graduate education and competitiveness and will release their report on April 29.

In summary, a robust graduate education system is essential for our country to continue to prosper. Graduate education in STEM fields is particularly important if we are to have the future scientists, engineers, college faculty and researchers needed to respond to current and emerging national and global challenges.

Thank you very much for the opportunity to testify. I will be happy to answer and discuss questions.

[The prepared statement of Dr. Klomparens follows:]

PREPARED STATEMENT OF KAREN KLOMPARENS

Chairman Lipinski, Congressman Ehlers and members of the subcommittee, I am pleased to be part of the panel to discuss the role of graduate education and its centrality to the future success and competitiveness of the United States. My remarks today will cover three interrelated areas: the importance of graduate education as a whole, the importance of graduate education in STEM fields focusing on our work at Michigan State University, and finally I will share some thoughts on policy issues related to the role of graduate education in ensuring our nation's continued competitiveness in the global economy.

National Perspective on Graduate Education

There is a strong link between economic growth and technological innovation. Looking ahead, America's prosperity and security in the 21st century depend upon innovation, scientific discovery and knowledge creation (Council on Competitiveness). In the knowledge-based economy, the clearest path for the country to remain competitive and secure is the production of a highly-trained workforce equipped with advanced and flexible skills, capable of operating at the frontier of knowledge creation. A major part of the responsibility for such a workforce rests on our nation's graduate programs. U.S. graduate schools are the jewel in the crown of our educational system attracting the top domestic and international students by creating dynamic graduate programs that foster research, scholarship and scientific discovery.

Currently, there are 2.3 million students pursuing graduate degrees at the Master's and doctoral levels in arts, humanities, social sciences, business, education, sciences and engineering. Approximately one-fourth of graduate students are enrolled in a doctoral program (Council of Graduate Schools, 2009). In 2007, U.S. graduate schools awarded 61,000 doctoral degrees across all fields, including 41,000 doctorates in STEM fields. At the Master's level, 610,000 degrees were awarded across all fields, including 120,000 masters in STEM fields (S&E Indictors, NSF, 2010).

Today's graduate students are the future knowledge creators, educators, leaders and experts in a variety of fields. We are going to need more of them particularly to address the grand challenges we face in areas of energy independence, climate change, health care, cyber security and others that we cannot even imagine today. The Bureau of Labor Statistics has estimated that one sixth of the fastest growing occupations from 2006–16 will require a Master's or Doctoral degree.

As we look to the future, it is clear that every industrialized nation and most developing nations are working to increase their research capability because investing in research and education is a key driver of economic growth in a knowledge economy. Other countries and regions of the world are enhancing their higher education systems and in particular their graduate education systems as part of their economic development strategies. For example, the Australian government has established research and education as a top priority, and backed up its commitment with a 25% increase in government expenditures from 2008 to 2009 (Nature, 2009). China increased its investment in research and development by 36 percent from 2002 to 2007 so that it has almost caught-up to the U.S. in the share of workers engaged in creating knowledge or products (UNESCO). In China between 1985 and 2005 the number of science and engineering doctoral degrees awarded increased by sevenfold, making China third in the world in terms of overall Ph.D. degree production. If trends last recorded in 2006 have continued, it is likely that China has now surpassed the United States in the annual production of doctorates in the natural sciences, mathematics, and engineering (S&E Indictors, NSF, 2010).

Here in the U.S. there is a great deal of discussion on ways to enhance higher education and graduate education in particular. As you know, the financial situation has taken a toll on all sectors of our economy including higher education. State budgets are particularly stressed and states have been disinvesting in graduate education for some time. At the same time, as noted above, leaders in many developing economies across the globe are investing in graduate education and in fellowships for their future STEM leaders. Watching the U.S. over the past 50 years convinced them that graduate education is a key factor in global economic competitiveness and raising their quality of life. This situation is not likely to change in the foreseeable future and creates the need for an enhanced role on the part of the federal government to ensure that the U.S. continues to have a world-class graduate education system.

A Commission on the Future of Graduate Education was formed by the Council of Graduate Schools and Educational Testing Service. The Commission consists of leaders from industry and higher education and is focused on developing an empirical foundation to support the connection between U.S. graduate education and competitiveness and innovation. Among other things, the Commission will examine projected trends for doctoral and master's degree holders, initiatives in other parts of the world focused on enhancing graduate education as part of an economic development strategy and suggest proposed actions to ensure our continued success. The Commission will release its report and recommendations on April 29.

The House Committee on Science and Technology is in the forefront of many efforts to enhance innovation and competitiveness. The upcoming reauthorization of the COMPETES Act is an important policy opportunity to develop and implement policies designed to ensure America will have the brain power we need in the future.

Graduate Education in Science, Technology, Engineering and Mathematics (STEM)

Graduate education is a comprehensive system that is inter-related with undergraduate education and, in STEM, with postdoctoral training, and should be deliberately developed and improved as a *system.* It is connected to undergraduate education through research experiences for undergraduates and the role of mentoring as well as through teaching experiences in classrooms and laboratories. It is also inextricably linked to the research enterprise by its dependence on faculty mentors and through connections to postdoctoral trainees.

Our successful STEM graduate education enterprise faces some current challenges. One major challenge is recruiting, retaining and developing a diverse cadre of talented students in STEM graduate education. We are now experiencing a brain drain as many students are capable of pursuing science, but turn to other disciplines for a variety of reasons. The "loss of talent" begins at the K–12 level. This is exacerbated by the failure of our educational system to attract STEM professionals into K–12 teaching, with the consequence that there is more emphasis on teaching students facts and vocabulary, than on the fun and fundamental processes of inquiry and discovery. STEM content knowledge and fundamental skills required for graduate education are built on the path from K–12 through undergraduate education, master's degree education, to doctoral education.

The "loss of talent" continues at the undergraduate level creating challenges to the recruitment of qualified graduate students. Engagement with "real-world" problem-solving and the approaches that scientists (broadly defined) use and apply to generate knowledge captivates undergraduates and encourages them to explore graduate education. MSU engages undergraduates in research through the NSF Research Experiences for Undergraduates (REU) program and also through our undergraduate research forum (*www.urca.msu.edu.*) The opportunity to engage in research at the undergraduate level is one important step in retaining these students, as it provides an opportunity to socialize them into the methods and cultures of a discipline. Students often find these experiences to be the first in which they can use the knowledge gained over years of coursework and apply them to real research problems and witness the impact of their work and practices.

The ultimate goal of graduate education is the metamorphosis from an undergraduate student who is the recipient of knowledge ("learning about"—Brown and Duguid, *The Social Life of Information,* 2000) to a STEM professional ("learning to be" IBID) who generates new knowledge. This is accomplished by defining and focusing on problems that need to be solved and guiding the graduate student in finding solutions independently. Quality mentoring is crucial. Research-active faculty members know the content areas important to their disciplines and share that content by engaging students through active learning in classrooms to the much more focused effort that is required for a dissertation—a substantial contribution to new knowledge.

Over the past decade, many national efforts have focused resources and time on the improvement of graduate education. For example, the Ph.D. Completion Project directed by the Council of Graduate Schools is examining bathers to completion of the doctoral degree and developing plans and strategies to increase doctoral degree completion in partnership with a number of leading universities across the country. Graduate education leaders have recognized that one of the most important issues to focus on is simply increasing degree completion.

At the Master's level, the Professional Science Master's (PSM) represents the development of an innovative new Master's degree designed to prepare future science professionals for careers in government, business or the non-profit sector. PSM degrees are designed in collaboration with employers and intended to be responsive to regional and local workforce needs.

A PSM initiative at NSF was authorized in the COMPETES Act and funds for it were included in the American Recovery and Reinvestment Act.

One of the most effective national initiatives for improving doctoral education was the Carnegie Initiative on the Doctorate (*http://gallery.carnegiefoundation.org/cid.*) No outside funding was provided, yet Michigan State University and a host of other institutions engaged faculty and graduate students in the improvement of their own programs. Two of the lessons learned in this endeavor were that: successful lifelong learners "have a keen sense of how they learn" (Walker, et. al, 2008, *The Formation of Scholars: Rethinking Doctoral Education in the 21st Century,* page 85) and that faculty and students need to work together as partners in order to foster change (ibid).

Graduate Education at Michigan State University

Michigan State University enrolls approximately 10,000 graduate and graduate professional students annually. This academic year, 2,185 of these students are in the STEM disciplines that cross 6 colleges (Natural Science, Engineering, Agriculture and Natural Resources, Human Medicine, Osteopathic Medicine, and Veterinary Medicine). In the 2008–09 academic year, MSU granted 501 graduate degrees in the STEM fields. MSU also has a living-learning environment in our Lyman Briggs College, a residential college focused on STEM undergraduate education that deliberately links the fundamental scientific and mathematical context of their individual disciplines with the societal context of science. Faculty members use the research-validated pedagogical techniques and technologies; students are active participants in the classroom. Students learn to analyze the way scientists think about research questions and also how scholars in other fields evaluate the methods and conclusions of scientists. This College is the longest running such entity on a research-extensive university campus and participates as a partner with the Graduate School to expose graduate students to teaching practices.

MSU is the only university in the U.S. with three medical schools on campus (Human Medicine (MD), Osteopathic Medicine (DO), Veterinary Medicine (DVM) that are connected to the basic life sciences and research (College of Natural Science) via jointly appointed faculty. Many of our College of Natural Science faculty members are also connected to the College of Agriculture and Natural Resources through joint appointments. This model, built on our land-grant tradition, contributes to our success in preparing a competent STEM workforce for the 21st century.

Preparing Graduate Students for 21st Century Careers

While many graduate students desire a career in academia and/or research, others pursue opportunities in government, large and small corporations, or the nonprofit sector. At MSU, we developed an approach to professional development that both complements the academic program of the students and provides faculty with the tools to adopt and adapt our approach to provide this "parallel" mentoring in close connection to their program curriculum. This professional development equips students with the knowledge and skills to be effective leaders across employment sectors for the global economy.

The Graduate School at MSU defines six broad areas of *essential skills* for graduate students and postdoctoral trainees (the Graduate School houses the MSU Postdoc Office—an indication of the importance of viewing STEM workforce development as a system). These are particularly important for the STEM workforce of the 21st century across all employment sectors:

1) **research, scholarship and creative activities** (synthesizing and integrating research, using relevant resources effectively, independent critical thinking, managing to completion, sustaining passion for the activity, being a steward of the discipline)
2) **leadership** (not administrators or titles, but rather idea and content leaders with influence, purposefully building learning communities, implement and evaluate solutions, manage people and resources effectively, encourage and support international connections)
3) **ethics and integrity** (including responsible conduct of research and scholarship, confidentiality where appropriate, adherence to professional principles)
4) **collaboration** (with other STEM researchers and with global communities in which research will be applied to solve problems, give and receive constructive feedback, partner with diverse groups, build and sustain networks)
5) **communication** (written and oral and for multiple audiences, apply principles of active and cooperative learning to diverse audiences, share your enthusiasm, practice active listening), and
6) **balance and resilience** (set goals, understand the multiple missions and expectations of your employer, understand your own expectations, negotiate and resolve conflicts effectively, take care of yourself).

Some of these, in fact, were explicitly defined as key skills by industrial boards of advisors for our Professional Science Master's degree programs, and apply equally well to doctoral programs. MSU was an early adopter of the PSMs, and was the first member of the Association of American Universities to develop a number of these programs. Others are defined by our faculty themselves when searching for new colleagues.

The Graduate School at MSU offers a variety of pathways for master's and doctoral students to gain and hone these skills, while simultaneously gaining expanded content knowledge in their respective disciplines and preparation to become effective researchers. The CAFFE (an NSF-funded initiative described in a later section) model now in development at MSU proposes effective "parallel" mentoring that continues the existing strong disciplinary preparation and provides individuals with the expanded skills necessary to meet the U.S. STEM workforce needs of the future (*http://grad.msu.edu/caffe/*).

To be globally competitive, the U.S. needs STEM graduate-degree holders across a variety of sectors: academia, government at all levels, business/industry, and nonprofits. The Graduate School developed a model to help students prepare themselves for these widely varying careers. Planning, Resilience, Engagement, and Professionalism, or PREP, has run for six years with evaluation data that supports calling this a success (*http://grad.msu.edu/prep/*).

The basic tenets are:

- **planning** throughout the graduate program to identify and successfully achieve career goals;
- developing **resilience** and tenacity to thrive through personal and professional stages;
- practicing active **engagement** in making important life decisions and in acquiring the skills necessary to attain career goals;
- and attaining high standards of **professionalism** in research and teaching.

A calendar of events *http://grad.msu.edu/prep/docs/prepskillsworkshops.pdf* helps graduate students, postdocs, and faculty plan the most effective use of their time.

One of the most useful aspects of the MSU model is that it is developmental, and is itself based on research on the factors affecting doctoral student attrition and completion, the personal and professional needs of students at different stages (from entry through graduation) of graduate education, and the key skills that employers say are crucial for career success. An interactive website for graduate students helps them assess where they are today in terms of their professional development and plan how to reach their goals in the future (*http://grad.msu.edu/prep/stages.aspx*). We are also engaging faculty in the use of PREP as a professional development planning tool. The goal of the website is to focus students on specific steps to take now and in the future for a successful career. An interactive website (publicly available) for graduate students helps them assess their current career and professional development, as well as what they might need in the future to reach their career goals. Postdoctoral trainees also find this site useful as they work with faculty on individual professional development plans.

The Post Doctoral Experience

Across the U.S., many Graduate Schools have an Office for Postdoctoral Trainees, often in partnership with the Vice President for Research. This is a reflection of the inter-related nature of graduate students' and post doctoral researchers' professional development needs. In the life sciences, a post doctoral experience is often required prior to assuming an academic position, and occasionally also for other employment sectors if the focus is exclusively research. These postdocs form a vital link in the development of a STEM workforce. The essential skills needed, in addition to the expanded research experience, is very similar to those described for graduate students. In fact, providing programming that mixes the two audiences is valuable, especially for the graduate students who may, in fact, be informally mentored by postdocs. Appropriate attention to this group of individuals on our campuses is an important responsibility.

NSF-Funded Graduate Education Initiatives at MSU

NSF's Education and Human Resources Directorate programs are critically important to universities' abilities to promote and support change and improvement in STEM graduate education. In addition, the NSF pre-doctoral fellowships are also of vital importance. These provide the students with a degree of flexibility that a research assistantship does not. They permit the *time* for students to pursue additional skills needed for the careers *they choose.*

The NSF-funded initiatives are also vitally important for the development of a more inclusive STEM workforce. The AGEP and LS–AMP programs (see below) provide needed funding and, as importantly, a clear signal from NSF about the value of diverse students. Increasing inclusiveness in the STEM population at the highest levels of education is fundamental to ensuring the stewardship of the disciplines and their impact on U.S. competitiveness and innovation.

Similarly, the IGERT training grants also provide flexibility and the required program components that help the student with additional skills development that are important for career success. Internship opportunities, graduate level study abroad programs, and interactions with external (non-academic) boards of advisors are key activities for graduate student skill and knowledge development. IGERT and other fellowship programs provide some of the needed guidance and time/flexibility for students to develop these additional skills.

As an example of the power of these collective programs, MSU is now *connecting five NSF-funded initiatives,* all of which are focused on creating a competitive and diverse STEM workforce for the future. Our recently funded Innovation through Institutional Integration grant from NSF, Center for Academic and Future Faculty Excellence (CAFFE), brings together the NSF-funded human resource initiatives at MSU (*http://grad.msu.edu/caffe/*).

The CAFFE initiative brings pedagogical research for effective teaching and learning across employment sectors to our STEM faculty, graduate students, and postdoctoral trainees. Future faculty members must have an opportunity to develop as effective teachers, as well as researchers, in order to most effectively prepare the diverse STEM workforce of the future. Graduate students on research assistantships for most (or all) of their graduate careers do not always have the opportunity to develop these skills. CAFFE provides a menu of professional development opportunities for use in parallel (to the research activities) mentoring of students for success and for multiple career options. The NSF initiatives included in CAFFE are:

Alliance for Graduate Education and the Professoriate: http://grad.msu.edu/agep/. AGEP supports recruitment, retention, and graduation of U.S. students in doctoral programs to promote changes that transform U.S. universities to embrace the responsibility of substantially increasing the number of students from under-represented U.S. populations who will pursue academic careers in STEM and SBES (social, behavioral, and economic sciences) disciplines. Our Michigan Alliance (Michigan State University, University of Michigan, Wayne State University, and Western Michigan University) developed an active collaboration that works well to engage students in a supportive learning community with opportunities for professional development and socialization into doctoral education, along with national network connections

FIRST IV (for postdoctoral trainees): Faculty Institutes for Reforming Science Teaching: *https://www.msu.edu/~first4/*. FIRST is a national dissemination project designed to reform undergraduate science education through professional development of postdoctoral trainees as competent instructors with an understanding of science-based pedagogy and how that influences student learning. International postdoctoral trainees in particular, bring excellent research skills to our laboratories, but often have had no opportunity to engage in teaching or to think about how students learn and how teaching influences learning. This program is an innovative and effective way to bridge that gap.

Center for the Integration of Research, Teaching and Learning (CIRTL) (UW-Madison, lead): *http://www.cirtl.net/*. CIRTL is a growing national network of institutions seeking to improve the learning of students at every college and university, and thereby increase the diversity in STEM fields and STEM literacy of the nation. CIRTL uses graduate education as the leverage point to develop a national STEM faculty committed to implementing and advancing effective teaching practices. (see Professor Bob Mathieu's testimony).

ADVANCE (recruitment and retention of women faculty in STEM): *http://www.adapp-advance.msu.edu/*. The goal of ADVANCE is to strengthen the scientific workforce through increased inclusion of women in STEM.

LS–AMP: Louis Stokes Alliance for Minority Participation: *http://www.egr.msu.edu/egr/departments/dpo/programs/milsamp/*. With the same alliance partners as AGEP, the goal of this program is to significantly increase the number of under-represented minority students earning baccalaureate degrees in STEM fields and prepare them for entry into graduate programs.

In addition, MSU operates an NSF-funded GK–12 grant (at our Kellogg Biological Station, *http://www.kbs.msu.edu/education/k-12-partnership/gk-12-program*) that provides funding for graduate students in NSF-supported STEM disciplines to bring their leading research practice and findings into K–12 learning settings. The graduate education community is interested in learning more about how graduate students, K–12 teachers and K–12 students benefit from this program.

Lessons Learned Through NSF Funded Graduate Education Programs

There are two important lessons-learned from these NSF-funded initiatives at MSU: first, education research on effective environments and processes for STEM undergraduate and graduate education are likely to be believed *and adopted* by STEM faculty only when the research is either done by those STEM faculty members themselves or in close collaboration with them. STEM faculty members expect and respect a high level of rigor in research. Education research must be shared, explored, reviewed, and vetted in the science and engineering disciplinary communities to have an impact. Lack of the connection between the research generation and those who would need to implement it represents a major barrier to implementing improvements. On our campus, a few active research scientists also conduct research on scientific teaching methods and use these in their undergraduate classrooms. *Those faculty members* are changing their colleagues methods and practices, as well as sharing with postdocs and graduate students (collectively, our future faculty), who are open to learning.

Second, the key barrier to implementing an effective learning environment and activities for STEM graduates across the employment sectors is most often, simply, *time*. The graduate education system, as described above, is inextricably connected to faculty research programs. Learning to be an effective STEM researcher which is the goal of a doctoral program, requires intense, focused time. It is not simply additive to the coursework. It is not something students have had enough opportunity to learn through K–12 or undergraduate education. The competition for research grants is intense and based in large measure on the prior productivity and generation of data. It is often easier, and less time-consuming, for faculty to stick to the traditional models, of educating graduate students, than to invest the time to learn and adapt a new method. That level of time and creativity is invested in the research enterprise.

The Importance of Interdisciplinary Training

Interdisciplinary training is a key component of graduate education and in the preparation of the future highly skilled workforce the U.S. needs to remain competitive in the global economy. This is a mantra that many individuals discuss, but the implementation is clearly not trivial.

"Global changes have created an important transitional moment for higher education, one that is redefining the nature and the context for teaching and learning; for research, scholarly, and creative activities; and for the outreach and engagement missions of our universities and colleges. The challenges now confronting the nation and the world underscore the need for higher education institutions to engage, with passion, intention, and innovation, as engines of societal growth and transformation. There is a need for a continued research and educational focus on problems that span the boundaries of disciplines, nations, and cultures. Because higher education institutions are intimately linked to societal growth and transformation, they can help create and instill both the basic and applied knowledge that provides opportunities for all peoples and nations to achieve a heightened state of social and economic well-being and sustainable prosperity." (Michigan State University President Lou Anna K. Simon; *http://worldgrant.msu.edu/*).

One of the strengths of STEM disciplines at Michigan State University is the openness to integration with the social, behavioral, and economic science disciplines in both training and research. Faculty and leaders acknowledge that the social sciences are a catalyst for the adoption and implementation of important STEM advances. The current grand challenges facing the U.S. (e.g., energy independence, climate change, the bioeconomy, health care, etc.) depend on the contributions of social, behavioral, and economic scientists to maximize the impact of new discoveries in the STEM disciplines. The most effective investments in STEM education and research focused on solving real-world problems will include social science disciplines as partners. In addition, research from the social sciences on how the human mind interprets, stores, organizes, and retrieves information should be connected to the development of effective pedagogical practices in STEM. Again, to be effective and outcomes-oriented this requires considerable time and focused attention by faculty and their graduate students and postdocs to work across disciplinary boundaries and to focus on the nexus between research and initiatives in both STEM and policy arenas.

Importantly, interdisciplinary study and approaches, especially those that span very different disciplinary approaches, require more time investment by individuals and over a longer period for success. Institutional support and recognition of this is requisite for faculty and graduate students to engage for the long term. Funding agencies must also recognize and reward this fundamental difference between a narrowly-focused research topic and one that is interdisciplinary in nature.

Summary

In summary, U.S. graduate education is a strategic national asset. A robust graduate education system across all fields is essential if our country is to continue to prosper in the future. Graduate education in STEM fields is particularly important if we are to have the future scientists, engineers, educators in higher education, and knowledge creators we need to respond to current and emerging global grand challenges in energy independence, climate change, health care, cyber security and others.

Some of the major challenges we face in improving graduate education include:

- ○ recognizing and supporting graduate education as a key driver of competitiveness and innovation
- ○ creating better alignment between K–12, undergraduate and graduate education and signaling career pathways to students to achieve a better understanding on their part about the multitude of career options associated with a graduate degree
- ○ recognizing the importance of interdisciplinary research and training and adequate support for successful outcomes by funding agencies
- ○ continuing to provide opportunities for success for an inclusive population of students so that their representation in graduate education begins to approach their percentage in the U.S. population.

Graduate programs at NSF including the IGERT and GRF programs are critical. I strongly encourage continued support for these programs as proposed by the Administration and supported by this Committee. Additionally, I encourage the Committee to consider the need for an additional federal graduate traineeship program as described in the recommendations below.

Recommendations:

As the Subcommittee prepares for reauthorization of the COMPETES Act, I ask that you address the vital role of graduate education as a key driver in developing the intellectual leadership necessary to compete effectively in the global economy:

- ○ **Retain current provisions in the COMPETES Act that support graduate education.**

The current statute supports a number of graduate education programs including the Protecting Americas Competitive Edge (PACE) Fellowship program at the U.S. Department of Energy, the Professional Science Master's degree (PSM) at NSF and increased in funding levels for the NSF IGERT and GRF programs. I ask that all of these provisions be retained and supported in the upcoming reauthorization.

- ○ **Consider the need for a new traineeship program for doctoral students to prepare future leaders to address grand challenges in health care, energy independence, climate change, cyber security and other areas.**

State government budgets are not likely to rebound anytime in the foreseeable future and there is a pressing need to enhance the federal role in supporting graduate education, particularly at the doctoral level. While all forms of support are important, traineeship programs offer several advantages. Traineeship funds are awarded on a competitive basis to institutions which in turn award fellowships to doctoral students. Funds may be targeted toward strategic national priorities and mission objectives rather than dispersed across a variety of research paths chosen by individual students or individual Project Investigators (Pis). Given the fiscal constraints facing the country, the opportunity to target funding for the preparation of new talent to areas of known national need offers a clear advantage.

- ○ **Review and consider the forthcoming recommendations from the Commission on the Future of Graduate Education.**

Particular attention should be paid to those that relate to enhancing traineeship opportunities for doctoral students and enhancing support for Professional Master's programs building off the success of the Professional Science Masters (PSM) degree.

Recommendation on IGERT grants

NSF should convene an annual meeting of graduate deans and interested STEM faculty and administrators to share best practices and challenges related to the institutionalization of IGERT-supported professional development and approaches to interdisciplinary research. Attendees for this meeting should include IGERT Principal Investigators, interested STEM faculty and administrators across higher education, IGERT and non-IGERT graduate student representatives, and postdoc representatives. The transformational promise of IGERT grants for interdisciplinary research and workforce development should be made transparent in order to encourage successful dissemination. The intended outcome of the meetings is the explicit sharing of "lessons learned" from IGERT institutions in order to identify possible programmatic changes to enhance graduate student support and to encourage change in approaches to interdisciplinary research.

Thank you for the opportunity to share my views about central role of graduate education in supporting our national innovation enterprise.

BIOGRAPHY FOR KAREN KLOMPARENS

I serve as Dean of the Graduate School and Associate Provost for Graduate Education at Michigan State University and have done so since 1997. As a Professor of Plant Biology (specifically mycology) and especially as past Director of Michigan State University's Center for Advanced Microscopy—the core facility for electron, confocal, and scanning probe microscopy—I worked with graduate students across the STEM disciplines during my 32 years as a faculty member at MSU. Prior to becoming Assistant Dean for Graduate Student Welfare in 1994, I was a Fulbright-supported fellow during a sabbatical at the University of Cambridge, England where I worked with two of the foremost electron microscopists at the time. In 1998, with the important intellectual contributions of my Graduate School colleagues, we developed a program on "Setting Expectations and Resolving Conflicts in Graduate Education." A monograph, published by the Council of Graduate Schools in 2008, plus current training sessions around the U.S. and Canada widely disseminate the key concepts and training methods for this important skill for career success. To contribute ideas and energy to the national discussions and actions related to graduate education, I served a two-year term as the Chair of the Big Ten (CIC) graduate deans group, three years on the Executive Committee and five years on the Board of Directors for the Council of Graduate Schools, two years on the Professional Science Master's Board of Directors, two years of service on the GRE Board, two years on the Executive Committee of the Association of Graduate Schools (AAU).

Chairman LIPINSKI. Thank you, Dr. Klomparens. I now recognize Dr. Mathieu.

STATEMENT OF DR. ROBERT MATHIEU, PROFESSOR AND CHAIR OF ASTRONOMY, DIRECTOR, CENTER FOR THE INTEGRATION OF RESEARCH, TECHNOLOGY AND LEARNING, UNIVERSITY OF WISCONSIN, MADISON

Dr. MATHIEU. Chairman Lipinski, Ranking Member Ehlers, and distinguished members of the Committee, thank you for inviting me to present this statement on the importance of preparing our future STEM faculty so that American college graduates have the skills to lead a high-technology, globally competitive diverse workforce.

Currently there is little teacher preparation in higher education. Those who can do research well receive Ph.D.'s and then teach. To the credit of deeply committed higher education faculty and students everywhere, much learning does occur, but we can do much better, especially to advance the STEM knowledge and skills of the Nation broadly.

Currently we waste national investments in education research. I agree with Dr. Finkelstein; we have learned a tremendous amount about how to improve STEM learning and retention, and no small part is a result of NSF funding. Our challenge is how to broadly implement these practices. Much of the answer lies in introducing this knowledge early to the future national STEM faculty. As we both went to Berkeley, Dr. Ehlers, I look forward to sharing opinions on our preparation for teaching.

Furthermore, we are not retaining students in STEM and especially women and minorities. Research findings are clear; classroom experiences are central to attrition from STEM fields in higher education. Ninety percent of those who switch out of STEM cite poor teaching as their primary concern, as do in fact three quarters of those who stay in STEM. Again, change in retention lies in the preparation of the future STEM faculty.

The critical leverage point for change in STEM higher education is the training in teaching and learning of graduate students at research universities. They are the future STEM faculty of the United States.

Furthermore, only 100 research universities produce 80 percent of all doctoral degrees. As such, they produce the faculty members of our 4,000 colleges and universities. This is a 40-to-1 leverage point for investment of federal funds.

Research universities are the lever toward a STEM faculty at all colleges and universities across the Nation to have the ability to enhance the learning of every student.

Fortunately, the improvement of teaching rests upon answering a research question, and that question is simply, what have my students learned? This idea enables the Center for the Integration of Research, Teaching and Learning to place improving undergraduate education in a research context in which the STEM faculty are already comfortable and skilled and thereby able to foster their active engagement in advancing their own students' learning.

This idea works. The prototype of CIRTL is the Delta Program in Research Teaching and Learning at the University of Wisconsin-Madison. Since opening in fall 2003, over 1,900 STEM graduate students, post-docs and faculty have advanced their students' learning via the Delta program. To get back to Dr. Finkelstein's point, the recognized impact of this program on both future and current faculty at UW Madison is demonstrated by the fact that now, the Delta program, which was begun with NSF funding, is entirely supported by the UW Madison.

We need similar outcomes at all of the highest producing 100 universities. As a first step, we have created a prototype CIRTL Network of six major research universities: Howard University, Michigan State University, which was the founder of CIRTL, Texas A&M University, Vanderbilt University, the University of Colorado at Boulder, and the University of Wisconsin at Madison.

Based on these experiences, these are, respectfully, my three policy recommendations for how this Committee might launch a national mission to prepare the STEM faculty of the United States. First, fund a federal/university partnership. Ultimately CIRTL's success at UW Madison spoke for itself, but at the beginning, it was the NSF funding that provided the resources and equally importantly, the legitimacy to change the status quo. The imprimatur of NSF remains key as we recruit each new university into the CIRTL network. A federal investment on the order of $100 million over five years would establish, for example, CIRTL programs at

100 universities. Once established, their integration into graduate education will yield a sustained investment in preparation of the STEM faculty.

Second, modify reward structures by integrating research and teaching and learning funding. In 1996, the Shaping the Future Report wrote research directorates—this was the key—research directorates should expand resources for educational activities that integrate education and research. This counsel still rings true. The call for broader impacts at NSF has been an absolutely critical lever to integrate research, teaching and learning into the culture of universities and their faculty, to adjust the reward systems of universities and to shape faculty whose members are both excellent researchers and superb teachers. The major impacts of the CAREER awards, of the REU programs, of the Howard Hughes Medical Professorships, all show that our strategic goals in higher education can be achieved through programs that are integrated with research funding, and by this I mean STEM disciplinary research funding.

And finally, leadership. I urge this Committee to charge and fund the entire NSF, not just EHR, the entire NSF to explicitly and proactively take on federal leadership and responsibility for a new national mission of improving undergraduate STEM education through preparation of our future faculty.

The *America COMPETES Act* is one of the most important pieces of recent legislation with respect to developing the STEM competency of the United States. You are to be congratulated for its success and for your wise consideration of its reauthorization. Now is the time to build a new national program—indeed, a mission—to prepare the Nation's future faculty to be both superb researchers and excellent teachers. In these tight fiscal conditions, the 40-to-1 leverage point of graduate education for preparing the teachers of our college students has never been more compelling.

Thank you for the opportunity to share these thoughts about improving the quality and effectiveness of STEM higher education through advances in graduate education. Thank you.

[The prepared statement of Dr. Mathieu follows:]

PREPARED STATEMENT OF ROBERT MATHIEU

Thank you Chairman Lipinski, Ranking Member Ehlers, and members of the Committee, for inviting me to present this statement on the importance of STEM faculty preparation in teaching and learning so that American college graduates will have the skills to lead a high-technology, globally competitive, diverse workforce.

I. Opening Thoughts

The call for a more scientifically literate society is a constant drumbeat coming from industry leaders, from reports of concerned organizations like the National Academy of Sciences, from the mainstream media, and from Congress and the White House. I commend the members of this committee for urging the National Academies to examine the key actions that federal policymakers could take to enhance the science and technology enterprise. The *Rising Above the Gathering Storm* report of the National Academy brought this issue to the front of our discussions about global competitiveness. In this report, the challenge is seen properly as a pipeline issue, with substantial improvement needed every step of the way from K–12 through higher education through life-long learning.

Currently, we—quite rightly—invest many billions of dollars into improved K–12 teacher preparation. We then send many of the students from that pipeline into college classrooms with faculty1[1] who are dedicated to their students' learning but who often have little or no preparation in teaching. There is virtually no "teacher preparation" model in higher education. Those who can do research well receive Ph.D.'s, and then teach. To the credit of deeply committed higher education faculty and students everywhere, much learning has occurred. But I do not believe that we can continue in this way if we want to truly advance the STEM knowledge and skills of the nation broadly.

Furthermore, this model is inefficient and wastes national investments in education research. We have learned a tremendous amount in the past decade about how to improve STEM learning and retention, in no small part as a result of National Science Foundation (NSF) funding. Our challenge is how to scale up best practices, and clearly a major component of the answer lies in our preparation of the future national STEM faculty.

Research shows that currently very few STEM faculty are aware of or employ findings of research about teaching in their classroom instruction. This is not stubbornness or lack of interest—the reality is that our higher education system does not adequately promote or reward either pre-service or in-service faculty development. In fact, the weight of external research funding has tipped the scales of reward at universities—and increasingly more often at colleges—strongly toward funded research activities. Any associated gains in the teaching and learning of undergraduates are seen as collateral, albeit very real, benefits. Without a change in both message and rewards we are assured of replicating the current system, which has been extraordinarily successful in producing an invaluable scientific elite but much less successful in developing STEM skills broadly.

Equally important, it stretches credibility to think that an unprepared faculty will succeed in teaching our ever more diverse student population, and especially those who may be at risk to leaving STEM. No matter how well K–12 preparation of diverse students may be, we then place them in university classes and research environments with faculty who often have no preparation to enable them to continue to succeed. In this regard I am sure that we have a great deal to learn from our K–12 and two-yr/technical college colleagues. I say this both because of their greater experience and knowledge in teaching diverse student populations, but also because we must align the diversity efforts in K–12 with those in higher education.

Finally, without changing faculty preparation I think it is unlikely that STEM higher education will have as much impact on growing our STEM workforce as could be possible. Broadly speaking, faculty are little aware of their impact on student career choices outside academia. I am a firm believer in a liberal education, and I do not think that STEM education at the university level should be primarily vocational in nature. But too often current faculty diminish interest in non-university STEM vocations by our role modeling.

As one example, we know that the nation is desperately in need of more STEM teachers at the 5–8 level, and physical science teachers at the 9–12 level. Research is showing that students—and often the very strongest students—enter college with an interest in STEM teaching, but soon lose that interest for many reasons. Some of those reasons are in the college classroom. The value of K–12 teaching as a noble and valuable endeavor is not reinforced in STEM classes; the clear message is the preeminence of great discoveries. Research shows that this has a significant impact on moving the strongest students out of the STEM teacher pipeline. What an impact we can have if we were intentional about recognizing the potential pre-service teachers in our classes, in both their learning opportunities and in our actions. (See testimony and the Learning Assistant program of CIRTL colleague Prof. Noah Finkelstein.)

To summarize, successes in national STEM literacy, in diversity, in K–12 teacher preparation, and in development of the STEM workforce will only happen intermittently if left to chance. We must be intentional in our faculty development, and especially in the preparation of our future faculty, to achieve these national goals.

A critical leverage point for change in STEM higher education is the training of doctoral students at research universities. In the United States, roughly 100 research universities produce 80% of all doctoral degrees, and the vast majority of the faculty members in the nearly 4000 colleges and universities of the U.S. pass through these research universities. Thus graduate education represents a 40:1 leverage for improving higher education, and research universities are the lever toward a STEM faculty at all institutions of higher education with the skills to enhance the learning of each student. The time to address this challenge is now. With large numbers

[1] Throughout this statement, "faculty" is intended to broadly comprise all teachers in higher education.

of faculty retirements, universities and colleges will soon be hiring young STEM scientists to replace their ranks.

II. Importance of High-Quality Instruction in Enhancing Engagement in STEM

Research findings are clear—classroom experiences are central to attrition from STEM fields at the higher education level. In the last page of this testimony I provide a table taken from Elaine Seymour and Nancy Hewitt's book *Talking About Leaving.*[2] Put simply, this book reports the findings of interviews of a large sample of undergraduates who entered college interested in careers in STEM, too many of whom ultimately left STEM majors. The table ranks the primary reasons for leaving. The highest concern of all students—those who stayed and those who left—is "poor teaching by [STEM] faculty". **90% (!) of those who switched out of STEM cited poor teaching as a concern, as did 73% of those who did not leave STEM.** Roughly half of those who left STEM also cited "Non-[STEM] major offers better education/more interest" and "Curriculum overloaded, fast pace overwhelming". There is little doubt that the nature and quality of instruction plays a central role in the high attrition rates from STEM fields in the U.S.

A critical finding of Seymour and Hewitt is that there is little difference in the innate capabilities, prior preparation, or initial interests of those who left STEM and those who stayed. "We posit that problems which arise from the structure of the educational experience and the culture of the discipline . . . make a much greater contribution to [STEM] attrition." Many scientists and engineers still hold to the ideas that 'science is hard' and attrition is a consequence of insufficient ability, commitment and 'toughness'. In truth, too much attrition is a consequence of those who hold these ideas.

Furthermore, attrition is not gender- or race-blind. Carol Colbeck, Alberto Cabrera and colleagues have studied extensively the causes of attrition among women and minority students. They write:

> The effects of pre-college science programs for girls, recruitment efforts, and extracurricular support programs will be limited if students continue to leave engineering programs because of poor classroom instruction. Ineffective teaching and competitive climates understandably constitute barriers to participation in engineering and science for many students, including women. This study shows that the effects of such barriers are reduced when faculty use collaborative and active learning practices, provide feedback and interact with students, are organized and clear, and treat all students equally and fairly. *Therefore, policy and funding efforts must involve the academic core of science and engineering and not just extra-curricular support programs [italics mine].*[3]

III. The Landscape of Faculty Preparation in Teaching and Learning

Research universities are the "normal schools" for teachers in higher education. Ironically, a research university is also the one institution of higher education most divided with respect to its investments in teaching and research. Put in a positive light, faculty at research universities are contributing an important good to society through their generation of forefront knowledge. From the perspective of this goal, diversion of effort from research is perceived as not being strategic or efficient. Put in a more worldly light, institutional, disciplinary, and Federal reward systems—tenure, promotion, grant funding, awards, salaries—greatly reinforce the primacy of superb research over superb teaching.[4]

At the same time, research universities contribute to society in a major way through their mission to teach undergraduates and to train the next generation of scholars and citizens. It would be a serious error to think that the faculties of research universities are not deeply committed to their roles as teachers, and to the learning of their undergraduate and graduate students. This life purpose is why we *are* faculty—many of us could pursue research-only positions outside of the university, often with much higher compensation.

Thus graduate faculties are conflicted with respect to the amount of time to invest in their teaching relative to their research, particularly when most reward systems

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[2] Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving: Why undergraduates leave the sciences.* Westview.

[3] Colbeck, C., Cabrera, A., & Terenzini, P.T. (2001). Learning professional confidence: Linking teaching practices, students' self-perceptions, and gender. *Review of Higher Education, 24,* 173–191.

[4] It is notable that funding as a component of the reward system is moving into even our liberal arts colleges.

point toward the latter. Furthermore, they often see research and teaching as fundamentally orthogonal. This tension is directly imprinted upon graduate students, who look to their faculty as role models, as their paths to successful careers, and as their employers via research grants. The message sent to graduate students is clear: "teaching is a good thing—research is the path to success—don't let teaching get in the way of [your/my] success."

It thus is no surprise that currently STEM graduate students—the future STEM faculty of American undergraduates—receive little or no pedagogical training. A typical STEM graduate student may have one, perhaps two, semesters as a teaching assistant, usually unmentored and almost certainly untrained (beyond perhaps a day of workshops on class management issues). The teaching assistant experiences may be similar to future classroom teaching (e.g., teaching small discussion sections), or they may be little more than grading, tutoring, or lab management. Many graduate students, especially those in well-funded research programs, will have no teaching experience at all. On this experience, they enter their first college classroom as faculty and begin to teach.

IV. The Center for the Integration of Research, Teaching and Learning

a. The Ideas

The *Center for the Integration of Research, Teaching, and Learning* (CIRTL) is one of two NSF Centers for Learning and Teaching focused on enhancing STEM teaching and learningin higher education. CIRTL uses graduate education as the leverage point to develop a national STEM faculty committed to implementing and advancing effective teaching practices for diverse student audiences as part of successful professional careers. **The near-term goal is to produce a national cohort of graduate students and postdoctoral researchers who are launching new faculty careers at diverse institutions, demonstrably succeeding in promoting STEM learning for all students, and actively engaging in improving teaching and learning practice. Ultimately, by preparing the next national STEM faculty CIRTL seeks to improve the learning of students at every college and university, and thereby to enhance the diversity in STEM fields and the STEM literacy of the nation.** Finally, I stress that graduate students who become both skilled researchers *and* superb teachers benefit the nation broadly, whether they go into academia, industry, or government.

The success of CIRTL rests on aligning and integrating research, teaching and learning. CIRTL cuts through the Gordian Knot created by the perception of research and teaching as orthogonal. In fact, the improvement of teaching is itself a research problem, one that rests upon each teacher answering the question "What have my students learned?". The enhancement of student learning is a question subject to the experimental method of hypothesis, experiment, observation, analysis, and improvement. Thus my colleagues and I have suggested, and now established, that the concept of **Teaching-as-Research** can play a powerful role in engaging STEM graduate students and faculty in the improvement of their teaching practice. Our hypothesis is that the Teaching-as-Research idea places teaching in a context within which STEM researchers are comfortable and skilled (albeit in different methods), and thereby fosters their active engagement in advancing their own teaching. Importantly, this perspective naturally leads to self-sustained, ongoing improvement of STEM education. Like STEM disciplinary research, teaching becomes a dynamic, progressive and intellectually stimulating activity rather than a static task. **Our ultimate goal is to develop STEM faculties who themselves continuously inquire into, and thereby enhance, their students' learning throughout their careers.**

Equally importantly, CIRTL recognizes the reality that existing social and educational practices do not always promote equal success for all learners. Thus, creating equitable learning experiences and environments requires intentional, deliberate and skilled efforts on the part of current and future faculty. CIRTL is committed to developing a national STEM faculty who model and promote the equitable and respectful teaching and learning environments necessary for the success of all students and for the reduction of attrition.

CIRTL actually sets the bar even higher for future STEM faculty. Students and faculty all bring an array of valuable experiences, backgrounds, and skills to the teaching and learning process. Effective teaching capitalizes on these rich resources to the benefit of all, a core idea of CIRTL that we call **Learning-through-Diversity.** Not only does this approach benefit the learning of all, it also demonstrably enhances the self-perception of value and capability of each student with respect to STEM. This is a critical factor in reducing attrition from STEM fields.

b. The CIRTL Prototype

The prototype CIRTL implementation is the ***Delta Program in Research, Teaching, and Learning*** at the University of Wisconsin-Madison (www.delta.wisc.edu). Since opening in Fall 2003, over 1900 STEM graduate students, post-dots and faculty have participated in the Delta Program. The disciplinary affiliations of participants are 26% physical and mathematical sciences, 44% biological sciences, 20% engineering sciences, and 10% social, behavioral, and economic sciences (SSE). These frequencies mimic the overall UW-Madison graduate populations in these disciplines, except SBE is under-represented. The gender distribution among graduate students is nearly equal, which is an overrepresentation of women relative to the broader STEM graduate student population.

One of our early findings was the depth of the felt need for a program like Delta among the graduate students.[5] These future faculty enter graduate school recognizing the importance of high-quality teaching to success in their future careers. Despite the array of current cultural and programmatic barriers described above (III), large numbers of graduate students insist on finding paths that permit their engagement in the Delta Program. Moreover, the percentage of graduate student participants who have taken part in more than 30 credit-hours of Delta programming has increased from 15% to 34%, arguably the most significant measure of their commitment and of the success of the CIRTL idea.

The programmatic component of Delta comprises interdisciplinary graduate courses, intergenerational (graduate students, post-does, faculty) learning groups, and Teaching-as-Research internships. The program design emphasizes semester-long intervals of engagement, building on research showing that such longer-term involvement is more transformational. Every facet of Delta is designed around research models familiar to STEM graduate students and faculty. The courses are project-based, requiring students to define a learning problem; understand the student audience; explore the literature for prior knowledge in research on teaching; hypothesize, design, and implement a solution; and acquire and analyze data to measure learning outcomes. Delta internships are research assistantships in teaching, in which a graduate student partners with a faculty member to address a learning problem, much as they do in their disciplinary research assistantships. The Delta activities are designed to provide each graduate student participant with a teaching and learning portfolio, letters of recommendation, and presentations/publications in teaching and learning analogous to those in their disciplinary research *curriculum vitae.* And finally, courses are team-taught by research-active STEM and social science faculty and staff. These pairings of STEM faculty with education researchers provide powerful combinations of experience, theoretical foundation, and—crucially—role modeling for the STEM future faculty.

Recently, the Delta Program has introduced research mentor training into its curriculum. Research experiences represent an essential component of learning STEM skills and ways of knowing; evidence shows that undergraduates who participate in research benefit from engaging in experiential learning and report gains in many areas, including research skills, writing skills, self-confidence, and intellectual maturity. Furthermore, undergraduate research experiences have been shown to successfully recruit students, especially minorities, to graduate school thereby diversifying the workforce and benefiting the entire scientific community. Today almost every four-yr college and university points to research experiences (STEM and non-STEM) as a central element of their curriculum.

The success of an undergraduate research experience depends largely on a positive relationship between the student and the research mentor. Therefore, it is vital that current and future faculty be effective mentors. Again, future faculty preparation in mentoring has been absent, other than through experiences with their own mentors. Based on the *Entering Mentoring*[6] curriculum for biology developed with funding from the Howard Hughes Medical Institute and supported by NSF, we have adapted and implemented purposeful research mentor training across STEM. Published data on this training indicate that trained mentors are more likely to discuss expectations with their mentees, to consider issues of diversity, to use a reflective approach to their mentoring, and to seek advice of their peers than their untrained colleagues. At UW-Madison, over 350 future and current faculty mentors have been trained, and proposals have been submitted to expand this program nationally.

c. The Impact on Future Faculty

[5] For simplicity, 'graduate students' will be intended to include post-doctoral fellows. In practice, graduate student participants in CIRTL far outnumber post-does.

[6] Handelsman, J., Pfund, C., Miller Lauffer, S., and Pribbenow, CM. 2005. *Entering Mentoring: A Seminar to Train a New Generation of Scientists.* Madison, WI: University of Wisconsin Press.

Delta is measurably enhancing participants' attitudes and understandings about teaching and learning, and their plans or practice in teaching. Detailed evaluation and research results show that Delta graduate students and post-docs learn how to effectively teach STEM courses and to think intentionally about the diversity of their students in their teaching. Delta participants are then able to move beyond teaching practice to improving the learning of all students. A general—and distinctive property—of Delta participants is their dynamic conceptualization of teaching practice. When asked to describe steps that they would take in future teaching, 56% of single-dosage (one-semester) participants incorporate the ideas and actions of teaching-as-research and learning-through-diversity, while 80% of multiple-dosage participants do so. Furthermore, Delta participants are able to use their disciplinary research skills in investigating their own students' learning. As one cohort, 85 Delta interns designed, implemented, and analyzed projects to address student learning challenges at UW-Madison and at nearby colleges. Each obtained data on prior student knowledge or attitudes, mined education research literature, designed an intervention that built on research-based strategies, collected and analyzed outcome data, and presented findings to the Delta learning community, and in many cases in publications or disciplinary presentations. These and other evaluation evidence triangulates toward showing that the Delta Program has increased participants' awareness of research-based effective teaching practices, and has uniquely developed their abilities to improve undergraduate student learning in an ongoing way.

The ultimate measure of Delta's impact must be the future teaching practices of participants, and the learning of their students. To this end, an interview-based longitudinal study, launched in 2005; is following graduate students and post-does, both Delta participants and non-participants, as they finish and move into their first professional positions in diverse settings. Analyses to date of these interviews show that Delta participation resulted in (a) attainment of implemented knowledge and skills about teaching, (b) positive changes in attitudes toward teaching, and (c) expanded views of the types of academic roles they might play and types of institutions of interest. Those Delta graduate students and post-docs who have already transitioned into first positions report that their experiences in Delta helped them adjust effectively and creatively to the teaching-related demands of their new positions. This longitudinal study is now funded by an NSF grant as part of an expanded study to inform future faculty preparation programs.

The committee asked, "What skills do CIRTL graduate students gain that their typical peers in graduate school do not?" We have data that address this question directly, and show that Delta students have significantly higher knowledge in, among other things: setting learning goals, establishing clear standards for assessment of student learning, aligning course design with learning goals, incorporating active learning activities into teaching, encouraging peer learning, creating an inclusive learning environment, teaching students of varying academic backgrounds, improving their teaching through research methods, discussing teaching with colleagues, and motivating students to learn. Extensive education research—and indeed, common sense—find that these skills in a teacher lead to enhanced learning. and retention of students. CIRTL is too young to be able to prove that CIRTL graduate students in fact enhance student learning as faculty . . . but we have established that they are on the right path.

Amidst all the data, perhaps the voices of two Delta participants themselves are in order. Both have now become faculty members. The write:

> I'll be starting in the Biology Department at Lawrence University in Appleton next month. Put simply, the Delta Program and the internship in particular were instrumental in placing my on my current career path. Through the Delta Program, I was inspired to believe that I could become an effective teacher. The Delta Internship and classes also gave me the tools I needed to accomplish this goal. On an even more self-serving note, the Delta Program was also very useful in getting a job. In my job interviews, people seemed to be very impressed that I could talk about approaches to teaching and learning. They were also impressed that I was participating in a study to assess student learning. In fact, one interviewer even began going over some data she had on student learning and asking me about how to do other assessments!

and, much shorter, but no less compelling to me:

For an experimental physicist I have rare training in recognizing the diversity in my classroom and addressing it in order to both enrich the learning for and ensure the learning environment is inclusive to all students.

d. The Impact on Undergraduate Education at UW-Madison

CIRTL and its prototype Delta Program are about preparing future faculty for the entire nation. A collateral benefit is the impact of graduate student work on *current* undergraduate STEM learning at UW-Madison. Delta graduate student-faculty partnerships design and implement new teaching approaches grounded in research-based practices, and then assess the consequent student learning. The instructional materials and approaches developed by these Delta partnerships that are successful continue to be used to enhance undergraduate learning at UW-Madison; currently more than 2000 students with each offering of the improved courses. And of course the new teaching approaches travel with the graduate students to their next college, university or other job.

We call one of the unexpected outcomes the 'trickle up' effect; faculty often begin working with the graduate students for the students' sakes, and as a consequence go through major changes in their own teaching practices and philosophies of teaching. Through these partnerships, faculty themselves gain new knowledge in how to assess student learning and investigate the effectiveness of their teaching. For example, 76% of Delta internship partners (faculty) indicated that their teaching was positively altered by their experience with a Delta intern. One participant noted:

> The experience allowed me to reflect on my own teaching, to share things that I have learned and to toy with new ideas and approaches that the interns bring to the classroom. It has added to my curriculum, and invigorated my passion for the profession.

e. Impact on Research University Cultures

The recognized impact of the Delta Program on UW-Madison is perhaps best demonstrated by its successful institutionalization. CIRTL launched the Delta Program under NSF funding in August 2003. Since August 2007, the Delta Program has been entirely supported by internal funding at UW-Madison. This institutional funding was garnered by providing evidence that Delta was preparing well large numbers of future faculty, *and* that the current goals and missions of many key stakeholders in the university were being furthered by Delta.

I have just discussed the impact of Delta on current education at UW-Madison. Equally critical to its institutionalization, Delta also enhances the *research* mission of UW-Madison. For example, Delta provides faculty with the capacity to effectively address the broader impact criteria of research funding agencies like NSF and NIH. UW-Madison faculty more successfully secure research funding by partnering with Delta. NSF's broader impacts criterion requires that proposers describe ways in which they will advance discovery and understanding while promoting teaching, training, and learning, broaden the participation of underrepresented groups, and contribute to society. Linking their research teams (graduate students, post-docs and faculty) with Delta allows faculty to compellingly establish in funding proposals their ability to carry out their proposed plans, as well as their ability to leverage both NSF and university investments.[7] Once funded, participation in Delta provides faculty and their research teams with the skills to carry out their plans, thus leaving a legacy of implemented and evaluated broader impact products. Faculty members also are leveraging Delta to complement Federal research training grants. For example, the UW-Madison Neuroscience Department recently received an NIH training grant in which they created a new Teaching Fellows track. The grant partners with Delta to provide trainees with opportunities and resources to gain experience in teaching to improve undergraduate student learning across the department.

Finally, Delta is also enhancing the recruitment of the very best graduate students to UW-Madison. As one recent recruit wrote:

> Although I was initially drawn to UW-Madison for graduate study due to the strength of the Chemical Engineering Department, the Delta Program was one of the main reasons I ultimately chose to come here. Since I knew that I wanted to be a professor someday, I was excited about the opportunity to develop myself as both a researcher and an educator during my graduate program. But more importantly, the existence of a program such as this one demonstrated the university's commitment to education, and I wanted to pursue my graduate work at an institution that truly valued teaching. [Note: This student also received an NSF Graduate Research Fellowship.]

Thus the CIRTL ideas—especially Teaching-as-Research—naturally yield future faculty preparation programs that also allow participants to satisfy the current reward and legitimacy structures of research universities. Ultimately, this integration

[7] Mathieu, R.D.,1Pfund, C., & Gillian-Daniel, D. (2009). Leveraging the NSF Broader Impacts Criterion for Change in STEM Education. *Change, 41,* 50–55.

of research, teaching and learning will become an integral part of standard operating procedure . . . if the Federal government continues to demand the broader impact of research funding.

f. Impact for the Nation

Nationally, Delta serves as the prototype CIRTL learning community, but it is not alone. For example, Michigan State University was a founding member of CIRTL, and has itself created a broad and successful faculty preparation program called *PREP* that incorporates CIRTL ideas in their teaching and learning component. (See testimony of Dean Karen Klomparens.) The successes of Delta and PREP demonstrate that major research universities can and will commit to the preparation of STEM graduate students to be both forefront researchers and excellent teachers. In addition, they confirm the strong felt need for such preparation. Finally, Delta and PREP demonstrate that a learning community built on the CIRTL ideas is an effective approach to improving teaching and learning and to promote institutional change.

To prepare the future national STEM faculty, CIRTL seeks to similarly influence future faculty preparation in teaching and learning at research universities across the nation. A clear lesson of recent decades is the power of institutional networks to adjust priorities and academic cultures. Through networks, institutions can try new approaches together, share diverse successes, benchmark against their peers, and indeed challenge each other to "keep up".

Thus in 2006 CIRTL created the *CIRTL Network* of six major research universities—Howard University, Michigan State University, Texas A&M University, Vanderbilt University, the University of Colorado at Boulder, and the University of Wisconsin-Madison. In a superb example of sequential leveraging of best practice, the NSF has provided $5.1M to move from the prototype Delta Program to the CIRTL Network, itself a prototype for an ultimately much larger national network.

The CIRTL Network will enhance the preparation in teaching and learning of future STEM faculty in at least three ways. First, through the development and enhancement of learning communities on each campus, building on successes in Delta and throughout the Network. In fact, each of these institutions are using CIRTL ideas and CIRTL Network connections to expand and improve existing faculty preparation programs. Together the Network comprises and leverages an important diversity of programmatic experience and ideas. Second, building on this diversity, cross-Network programs such as on-line courses expands each local program into a national learning community. And finally, this electronically connected community will naturally continue beyond graduate school into the faculty experience, and thereby will build a national community for building and sustaining strong undergraduate faculties in STEM.

Ultimately, as the CIRTL Network matures, the current universities will become nodes of many unique, and highly connected, campus-based learning communities at research universities across the nation. We also see the CIRTL Network as the means to engage the employing institutions—liberal arts colleges, comprehensive universities, and two-year/technical colleges—in the national enterprise of preparing the future national faculty. While these institutions do not themselves teach large numbers of graduate students, they represent a tremendous national resource in preparing their future faculty about teaching and learning. The earlier Preparing Future Faculty programs [8] showed the promise of networks of diverse institutional types, and CIRTL has embraced their model.[9]

V. Leadership of the National Science Foundation

In an attempt to move, if not balance, the scales of activity toward increasing scientific capability across a diverse national population, Federal funding agencies have purposefully linked research funding to broad national impact. **This call for broader impact has been an absolutely critical lever to integrate research, teaching, and learning in the culture of universities and their faculty, to adjust the rewards system at research universities, and to shape a future faculty whose members are *both*** excellent researchers and superb teachers.

Among United States federal agencies, the NSF has led the way in the integration of research, teaching, and learning. Over the past decade the NSF's proposal review process has emphasized both intellectual merit and broader impact. The *intellectual-*

[8] Launched in 1993 as a partnership between the Council of Graduate Schools and the Association of American Colleges and Universities, this program associated more than 45 doctoral degree-granting institutions and nearly 300 "partner" institutions across the United States.

[9] Gillian-Daniel, D.L. (2008). National Research Council Workshop on Linking Evidence and Promising Practices in STEM Undergraduate Education.

merit criterion requires that proposal writers address how their work advances knowledge within their field of study or across disciplines. The *broader-impacts* criterion requires proposers to describe associated activities that will benefit the nation, including teaching, training, learning, and outreach.

While increasing the impact of science was part of the original NSF charter, this recent emphasis on broader impacts began with the *Shaping the Future* report,[10] which included the following key statement: "Research directorates should expand resources for educational activities that integrate education and research." **Significantly, this call to action was targeted directly at the NSF STEM research directorates** rather than being assigned only to the Education and Human Resources Directorate, the traditional locus of STEM-education funding.

The policy spawned an array of programs-most notably NSF CAREER Awards for junior STEM faculty, which requires proposers to develop innovative plans of work in *both* research and education. This CAREER Awards replaced the former NSF Presidential Young Investigator program, which honored only research; the shift was a very strong policy signal on the part of NSF. Other integrative programs include the NSF Distinguished Teaching Fellows for senior STEM researchers, CAREER-like programs for post-doctoral fellows, and incorporation of the broader-impacts criterion into the prestigious NSF Graduate Fellows Program.

Even so, when it came to the review of mainstream research proposals from individual investigators, the weight given to the broader-impact criterion depended heavily on each review panel and its NSF program officer. Thus its influence has been highly varied and too often minimal. So in 2002 NSF Director Rita Colwell delivered *Important Notice 127* (2), which said: "Effective October 1, 2002, NSF will return without review proposals that do not separately address both merit review criteria within the Project Summary. We believe that these changes to NSF proposal preparation and processing guidelines will more clearly articulate the importance of broader impacts to NSF funded projects." While the tension with review panels continues to this day, this proclamation again signaled NSF's strong commitment to the criterion.

Resistance to the broader-impacts criterion is not solely the result of disagreement with the principle of linking its aims to funding for disciplinary research. Many principal investigators simply do not have the training and experience to adequately respond to it. Consider for example the CAREER awards. As previously discussed, graduate education in STEM fields in the U.S. typically gives minimal attention to the development of teaching skills. And post-doctoral positions generally represent an extended hiatus from teaching. Thus, many new faculty members find themselves unprepared to write a well-conceived and innovative proposal for a five-year scope of work in STEM education, as required for a CAREER award. Indeed, similar challenges face principal investigators at all career stages.

Importantly, these challenges often involve limits in capacity, not in innovative ideas or commitment to broader impact. Programs such as CIRTL provide that capacity to current faculty through the provision of the requisite skills to the future faculty in their research teams. Thus our programs are positioned to enhance both the research and teaching missions of U.S. research universities, and thereby be a foundation for institutional change. **A decade from now we envision that present graduate students will he leaders of a national faculty for whom the broader impact of their research programs is taken as a given, *and that they will have the skills and abilities to make it happen.***

VI. Recommendations

Enhancing the preparation in teaching and learning of the future national STEM faculty is a challenge of changing current culture more than will. My experience has been that current faculty care deeply about the success of both their undergraduate and graduate students. Furthermore, CIRTL has clearly established that there is a strong felt need among future faculty for preparation to become effective teachers as part of their careers.

As such, these are my recommendations for how NSF—and indeed all Federal STEM funding agencies—can play a more impactful role in preparing the future STEM faculty of the United States:

i) **Increased funding of faculty preparation programs.** I am sure that "increased funding" is the recommendation that this committee hears most

[10] National Science Foundation. (1996). *Shaping the future: New expectations for undergraduate education in science, mathematics, engineering, and technology.* Washington, DC: Author.

often. I want to emphasize that my recommendation has two equally important purposes.

The first purpose is the usual—current funding is nowhere near sufficient to establish, for example, CIRTL programs at those 100 universities that produce most STEM faculty. I emphasize here the goal of 'establishing' programs rather than operating them. We have found that funding to initiate programs is crucial to establish a foothold within a university, and to open doors by proving both demand and success. Ultimately, as with the Delta Program and with many of the earlier Preparing Future Faculty programs, the goal must be complete institutionalization across the system of research universities. A Federal investment of order $100M over five years in the nation's highest producing research universities will yield an ongoing investment in future faculty preparation from those universities.

The second purpose is equally important. In the research university culture as it currently stands, and as it has been created in part by the Federal government over the last 60 years, external funding plays a major role in defining importance and legitimacy. Ultimately CIRTL's success at UW-Madison spoke for itself. But at the beginning it was the imprimatur of NSF funding that opened the door to that success, and continues to do so as we recruit more universities into the CIRTL Network.

ii) **Change reward structures by integrating research, teaching and learning.** "Research directorates should expand resources for educational activities that integrate education and research."—*Shaping the Future.* If this committee wishes to influence the preparation of the nation's faculty through graduate education, then it still need be true tothis counsel. Integrating research and teaching is not only key to improving undergraduate STEM learning; it is also the lever for change in research universities. The demonstrated successes of the broader impact criterion, of the CAREER awards, of the REU program, of the Howard Hughes Medical Institute Professorships, all show that our strategic goals in higher education can be achieved through programs that are coupled to the research funding infrastructure.

To provide some specificity without intending to be prescriptive, we might further strengthen the response to the call for broader impact of Federal research funds by requiring that proposals request and delineate funding for such initiatives. Remarkably, proposed broader impact activities are often not included in proposal budgets. At the institutional level, total Federal research funding could be linked with a proportional institutional investment in advancing STEM undergraduate education (including future faculty preparation). A Teaching-as-Research for Graduate Students (TARGS) program could build on the REU model, and indeed reverse it by sending graduate students to nonresearch-universities for summer work in advancing student learning. Many more innovative ideas are possible, and likely will arise in the Commission on Graduate Education report. The key idea is to link, align and integrate advancing STEM education with advancing STEM disciplinary research, and thereby adjust current reward structures.

iii) **Leadership by NSF.** I urge this committee to charge and fund the NSF to proactively take on Federal *leadership and responsibility* for a national mission of improving undergraduate STEM education, including future faculty preparation.

I note that this charge will require some conceptual broadening within NSF regarding their role and mode of operation. In accord with its charter to foster new knowledge, the NSF philosophy is to respond to directions set by the knowledge-generating communities. This approach has served the scientific research progress of the nation very well. However, this philosophy is not optimal for implementing and replicating knowledge that exists. I am suggesting here a more proactive, mission-oriented approach to advancing STEM higher education.

The NSF has proven successes in broad implementation, especially in education. To my mind, the Research Experiences for Undergraduates (REU) program is the exemplar—today there is hardly a STEM graduate who does not cite one or more experiences at an NSF REU site as central to leading them to consider a career in STEM research.

The Course, Curriculum and Laboratory Improvement (CCLI) program of the Division for Undergraduate Education (DUE) is a specific example of an implementation program of best practices in teaching, and indeed CIRTL derives

> from DUE's leadership and investment of flexible CCLI funds in preparing future faculty.
>
> Again, the Education and Human Resources Directorate (EHR) of NSF cannot, by itself, change graduate education and faculty preparation. EHR and its excellent programs such as CCLI, IGERT, and GK–12 simply do not have the attention of most graduate faculty. To be broadly successful, the mission of preparing the future national STEM faculty must engage the STEM research directorates and EHR collaboratively, both in terms of funding and programs. A broad, collaborative implementation across all STEM of the training grant idea, as currently used by NIH and by NSF Engineering, may be an effective approach.
>
> Finally, this leadership role for NSF should not be limited to only its own programs. NIH, DOE, USDA, and other Federal agencies are major players in research funding and graduate student research training, and all should be aligned with this national mission. This committee quite rightly expects faculty to make use of the nation's investment in education research. In the same spirit, the committee should expect all Federal STEM funding agencies to make collaborative use of the existing national investments in integrating research, teaching and learning.

The America COMPETES Act is one of the most important pieces of recent legislation with respect to developing the STEM competency of the United States. You are to be congratulated for its success, and for your wise consideration of its reauthorization. Please remember as you envision the scope of its reauthorization that STEM literacy is a journey for each American, and a key to their successful journeys are effective teachers each step of the way—from K–12 through higher education through life-long learning.

Now is the time to build a national program to prepare the nation's future faculty to be both superb researchers and excellent teachers. In these tight fiscal conditions, the strong leverage of graduate education for preparing the teachers of the nation's college students has never been more compelling.

Thank you for the opportunity to share my thoughts and experiences about improving the quality and effectiveness of STEM higher education through advances in graduate education.

Table 1: Factors contributing to switching decisions; and all concerns of switchers and non-switchers, by rank and percent of switchers, of non-switchers, and of all students. (Seymour and Hewitt 1997)

ISSUE	Contributed to switching decisions		All switchers' concerns		Non-switchers' concerns		All students' concerns	
	rank	%	rank	%	rank	%	rank	%
Lack of\loss of interest in SME: "turned off science"	01	43.2	04	59.6	06	35.5	04	48.6
Non-SME major offers better education\more interest	02	40.4	05	58.5	07	31.6	05	46.3
Poor teaching by SME faculty	03	36.1	01	90.2	01	73.7	01	82.7
Curriculum overloaded, fast pace overwhelming	04	34.9	06	45.4	03	41.4	06	43.6
Feel SME career options\rewards are not worth effort to get degree	05	31.1	07	43.1	12	20.4	09	32.8
Rejection of SME careers\ associated lifestyles	06	29.0	07	43.1	11	21.1	08	33.1
Shift to more appealing non-SME career option	07	26.8	11	32.8	14	16.5*	12	25.4
Inadequate advising or help with academic problems	08	24.0	03	75.4	02	52.0	02	64.8
Discouraged\lost confidence due to low grades in early years	09	23.0	10	33.9	16	12.5	14	24.2
Financial problems of completing SME majors	10	16.9	12	29.5	10	23.0	10	26.6
Inadequate high school preparation in basic subjects\study skills	11	14.8	09	40.4	05	37.5	07	39.1
Morale undermined by competitive SME culture	11	14.8	14	28.4	19	9.2	17	19.7
Reasons for choice of SME major prove inappropriate	13	14.2	02	82.5	04	39.5	03	63.0
Conceptual difficulties with one or more SME subject(s)	14	12.6	15	26.8	09	25.0	11	26.0
Lack of peer study group support	15	11.5	20	16.9	20	7.2	20	12.5
Discovery of aptitude for non-SME subject	16	9.8	21	11.5	21	4.6	21	8.4
Prefer teaching approach in non-SME courses	17	8.7	16	24.0	15	15.1	16	20.0
Unexpected length of SME degree: more than four years required	17	8.7	17	20.2	08	27.6	15	23.6

Switching as means to career goal: system playing	19	7.1	22	8.7	23	2.6	22	6.0
Language difficulties with foreign faculty or TAs	20	3.3	12	29.5	12	20.4	12	25.4
Problems related to class size	21	0.0	18	19.7	17	11.2	18	15.8
Poor teaching, lab, or recitation support by (non-foreign) TAs	21	0.0	18	19.7	18	10.5	19	15.5
Poor lab\computer lab facilities	21	0.0	23	4.4	22	4.0	23	4.2

*Issue raised by non-switchers intending to move into non-SME field following graduation.

BIOGRAPHY FOR ROBERT MATHIEU

Department of Astronomy, University of Wisconsin-Madison

Bob Mathieu has been on the faculty of the University of Wisconsin-Madison since 1987, and currently chairs the Department of Astronomy. He was educated at Princeton University and the University of California at Berkeley, after which he became a fellow of the Harvard-Smithsonian Center for Astrophysics. His work has been recognized by a Presidential Young Investigator Award, a Guggenheim Fellowship, and a Kellett Mid-Career Award. He has served as President of the Board of Directors of the WIYN Observatory, and recently chaired the University Committee of UW-Madison. His research involves the formation and evolution of stars and the dynamics of star clusters.

While associate director of the National Institute for Science Education, Mathieu led the development of the Field-tested Learning Assessment Guide (FLAG) and research-based resources in collaborative learning and teaching with technology, all designed for science, engineering, and mathematics faculty.

Mathieu presently directs the NSF Center for the Integration of Research, Teaching, and Learning (CIRTL), whose mission is to prepare STEM graduate students to be both forefront researchers *and* excellent teachers. CIRTL is a national network of 6 major research universities. He also is the principal investigator of the Student Assessment of Learning Gains (SALG) instrument for evaluation use by individual instructors, entire departments, and developers of new teaching and learning approaches.

Chairman LIPINSKI. Thank you, Dr. Mathieu. At this point, we will begin our first round of questions, and I will begin by recognizing Ms. Johnson for five minutes.

Ms. JOHNSON. Thank you very much, Mr. Chairman and Ranking Member. As you know, this is an area where I have been very, very keenly interested in, and practically every piece of legislation that has come through this Committee I have put an amendment on to involve especially minorities, knowing that that is the growing population in this country.

And my first question goes to Dr. Mundy. There are several programs, many of which were mandated by law at the National Science Foundation within the Human Resource Directorate that had the goal of broadening participation in the sciences. Out of these programs, have any studies been conducted to measure their individual effectiveness, and if so, what are the results?

Dr. FERRINI-MUNDY. Thank you very much, Ms. Johnson, for the question. As you know, the Directorate for Education and Human Resources has as one of its six fundamental themes the notion of broadening participation in the STEM workforce. And we are very proud of our portfolio of programs in this area. The Alliances for Graduate Education and the Professoriate Program (AGEP), the Tribal Colleges and Universities Program, the Historically Black Colleges and Universities Programs—all of our programs have ongoing evaluations which are beginning to tell us about the types of strategies that are proving to be most effective. And a couple of these include very strong involvement of faculty in both the recruitment and in active engagement with students as they come into programs. So opportunities to work in labs, opportunities to have mentoring by faculty and to have career advice by faculty in a personalized way that works toward retention of promising students in our programs. We can provide more detail about the kinds of evaluation findings. But we are learning a lot about what can be done, and we are also learning that these strategies can apply broadly across types of institutions and can help us with the general questions of recruitment and retention as well.

Ms. JOHNSON. Okay. Have any of the programs that have the goal of broadening participation in the sciences received Recovery Act funding?

Dr. FERRINI-MUNDY. I don't believe so.

Ms. JOHNSON. Okay. So that is no comparison then. Can you please explain the reasoning behind the recent decision of the National Science Foundation to merge all of the broadening participation programs to compete for funding, and has this been done with any group of programs of the National Science Foundation?

Dr. FERRINI-MUNDY. Yes, I can speak to this. We, in the 2011 budget request, propose a comprehensive broadening participation in undergraduate STEM program that will be a new effort to build upon the excellent work that has been done in the separate programs thus far but will draw upon much of what has been learned there and that will, we hope by consolidation in a sense, enable the Nation to learn from the very best practices that have been available across programs and to try to leverage those for more involvement across a wide range of programs. So for example, Hispanic serving institutions will also be eligible at this point.

We are very early on in our design and planning of this program and are very keen on making sure that we understand and can synthesize what we have learned and where the most effective practices are happening, and which of those are particular to types of institutions and which of those can be generalized across institutions, so that we make all of that knowledge very clearly available for the field. We will be working in close consultation with all of the communities involved as we design the initiative moving forward.

Ms. JOHNSON. Thank you. Could I get a report from you as to where you are on each of these programs? Of course not right now.

Dr. FERRINI-MUNDY. Okay. Yes, of course.

Ms. JOHNSON. Thank you very much, Mr. Chairman

Chairman LIPINSKI. Thank you, Ms. Johnson. The Chair now recognizes Dr. Ehlers for five minutes.

Mr. EHLERS. Thank you, Mr. Chairman, and I apologize for dashing out earlier. This is one of those horrible days we have. I have four committees meeting simultaneously now, and one of them was marking up a bill and I had to dash out to vote, but I am going to have to leave immediately after I ask my questions to cover some other areas.

Dr. Mathieu, you referred to this in your testimony, and I wanted to follow up on it, that with regard to NSF's STEM programs, I am just interested in what your comments are about the role of

STEM education goals within the research and related activities, so-called RRA Division, and what should remain completely within the Education and Human Resources—that are known as EHR Directorate? I would appreciate any comments you might have on that.

Dr. MATHIEU. You bring up a very good point there, Dr. Ehlers.

Mr. EHLERS. Also a very sensitive point for some people here.

Dr. MATHIEU. I have, I suppose, the good fortune in terms of the question to be an astronomer, and so I spend a lot of time on two different floors of NSF.

You spoke about the chasm, as I often call it, between schools of education and the scientific departments. That seriously exists. It has to be crossed. I would say that much of the academic chasm has also shown up at the National Science Foundation, and they are doing their very, very best to cross the chasm as well. They have the same challenges. And so as someone who sits on the astronomy side, I know how few of my colleagues are connected or knowledgeable about what goes on in the EHR division, and they need to be. The broader impact criteria which is just so critical, the CAREER awards, the REU programs, all of which require our young faculty to both be great researchers and superb teachers. Those faculty need the NSF to talk to each other. In astronomy, they need the astronomy division to know what is going on in CCLI, to know what is going on in the STEP programs.

One of the challenges that NSF faces in this regard is that NSF has a longstanding tradition of reacting to its communities rather than being proactive to its communities. I once went into the astronomy department education officer's office and I asked him, that I knew about this superb instrument for assessment, classroom assessment, would he be interested in letting astronomers know about it? His response was very firm, in fact, rather harsh, and he said, "We do not state what is good". We respond to the community's assessment of what is good. That has been extremely effective for developing new knowledge, as I said in my testimony. However, it is not the most effective approach if you want to implement successes across the Nation. And as such, and I say this in my testimony, if you charge NSF to take leadership in creating the future faculty, part of that needs to be to charge the NSF to be willing to be proactive as compared to reactive and actually lead in a mission-oriented sense. I, for example, deal with NASA. I see the difference between NASA's mission-oriented approach and NSF's response-oriented approach. I am not criticizing NSF here, I mean this sincerely. It has been extremely effective for developing research. It has protected academic freedom. But the mission of preparing our future faculty is going to require someone in the Federal Government to say, "We think this is good. We think the evidence supports this. We want this to happen across the Nation, and this is how we are going to do it". That is what I mean by a mission-oriented approach. And that is going to require the entire NSF to do it, because as I said in my testimony, if you want the research faculty to respond, you need to tie these initiatives to the research funding.

Mr. EHLERS. Thank you very much, and I would like to turn to Dr. Ferrini-Mundy at this point. First of all, I just want to mention, in the fiscal year 2011 budget request, NSF is proposing to change the name of the Course Curriculum Laboratory Improvement program, CCLI, and change it to Transforming Undergraduate Education in STEM, TUES, I think we are running out of good acronyms here. But I am concerned that this may not be simply a name change. I am just wondering what this is going to involve and also I would like your response to Dr. Mathieu's comments just now, so if could enlighten us, please?

Dr. FERRINI-MUNDY. Yes. Thank you for the question. First on TUES, I think we mean to signal our seriousness about the importance of transforming undergraduate education. We have heard from our other panelists that part of the issue is the scaling up of practices that show promise, that have been effective in particular settings and that are being widely tested in lots of places. And so the next big challenge is there—and in a sense, Dr. Mathieu, this is a little bit of a direction that I think is evident in this new solicitation. We now want to tackle the challenge of scale-up and learn about what it takes to help faculty be inclined to engage with these sorts of strategies, to be willing to take a look at the wonderful assessment tools that are there that can help inform their teaching and their practice, to even think about the shape of materials and the sort of translation and facilitation that might be provided with promising practices that may help with their spread. Old fashioned dissemination models aren't working. The scale-up is a major challenge. And so we see that as an important direction in the new solicitation.

And then as to the matter of how directive or prescriptive NSF might be in its education activities, I actually think our solicitations in key ways do identify—by identifying areas which we often say are areas of emphasis or you know, where we hope to see proposals in this area. Certainly at the K–12 level, we have been able to generate specific activity, say around assessment or around instructional materials in particular areas.

So our staff are certainly always eager to work with the field, to understand what the coming issues and challenging problems of tomorrow might be and then in ways that are appropriate to the NSF situation, to sort of weave those into solicitations as we can.

I should also add that internally, our collaborations with the R&RAs actually I think are quite strong. They often happen at the program officer level, but we have a number of projects across the directorate that are co-funded with the R&RAs and increasing collaboration in trying to imagine what the overall education mission of NSF looks like, and the different parts the different entities within the organization can play.

Mr. EHLERS. Thank you very much. I apologize that I will have to leave. I may be able to make it back before you finish, but in the meantime, my thoughts and my spirit will be here with you, and I give permission to the majority to continue without a member of the minority being here.

Chairman LIPINSKI. Thank you, Dr. Ehlers. The Chair now recognizes Mr. Tonko for five minutes.

Mr. TONKO. Thank you, Chairman. The success stories that we know across the country at different universities were sparking a better response in the STEM area. How are those shared with the overall culture of higher education? Is there a sharing in terms of those successful efforts? Can anyone on the panel speak to that? Sure, Dr. Finkelstein.

Dr. FINKELSTEIN. Sure. Yes, I mean, in many regards, there is tremendous effort to get the success stories out there. This is one area where the disciplinary societies play a tremendously important role. They serve as establishing the culture of the disciplines themselves. So in my field in physics, the American Physical Society, the American Association of Physics Teachers, is tremendous. There are pan-society organizations that I mentioned, the Association of Public and Land Grant Universities are starting to sort of share those networks broadly. So that is one way that we go about doing that.

At the next scale-down you might say that there are programs that are spreading from campus to campus, and that is what is happening. This Learning Assistant program is now running sort of partly by word of mouth in a viral way but also purposefully seeded and posed along the way so that we are running at well over a dozen institutions around the United States, based on the promotion of these professional societies. CIRTL is another example where this is purposefully built into the structure of that so that these good ideas get out there. And I would make sort of two points about this. One is that we have to have a particular model of change for how to push this out there. I am engaged in a large-scale research study that looks at how particular implementations are successful or not, and what we find overwhelmingly here is that programs don't have grounded scholarly models of change in STEM education in the published literature. And I am pleased to provide references around that. But the bottom line is that we need work on how to do that. That doesn't mean that things can't scale sort of along the way.

And the other thing that we found is that you have to work across multiple levels of the system here. It is really important that you have faculty within the department who are recognized and valued and vetted for doing this. So I am housed in a physics department. But meanwhile, of course, I can't do that alone. I need institutional support, and I have to think about the institutional structures of the programs that I'm seated within and similarly, you can scale all the way to the disciplinary society and the national scale level.

So I think that the way we can get these things to scale is by working across multiple levels of the system and identifying the key levers of change, and I do some of that in my written testimony.

Mr. TONKO. Yes, Doctor?

Dr. KLOMPARENS. Yes. Just two other comments. I agree with Dr. Finkelstein's points. The other good disseminator is NSF itself. NSF hosts meetings of project investigators. We have a chance to talk across our institutions and share best practices, and the other group would be the Council of Graduate Schools for anything that is occurring at the graduate level. That is a group of graduate deans who have a role to play in terms of disseminating information across their campuses, because most of the graduate deans work with all the departments or most of the colleges on their campus. So it is another place for the information to get shared and to be supported.

Mr. TONKO. And in terms of the numbers that we know to be far better outcomes in other cultures, other countries, is there any exchange there? Do we know what they may be doing that we are not doing or not doing enough of? Dr. Klomparens.

Dr. KLOMPARENS. Yes, there is some information that is shared back and forth across cultures largely through faculty but also through graduate deans because the students that we recruit, the international students that we recruit to campus, there are often dialogues set up between faculty and between administrators on exactly how they are preparing their students for STEM education, what kinds of curriculum they are actually using in their classrooms because we get to see transcripts, we get to see descriptions of what those educational processes are.

Mr. TONKO. Is there something different there that——

Dr. KLOMPARENS. Some of it is a very strong support of math and science education all the way from grade school on through high school. It is supported by the parents, strongly supported by the parents, as a way for those students to be able to move forward in their own economies. So again, it is part of——

Mr. TONKO. So, hearing that said, what is the role? Does there need to be a stronger incentive provided by private/public sector? Should the Federal Government be inspiring these careers by its action? Is it holding back the thirst for STEM education? I would think if we are not being progressive and aggressive about encouraging the transformation, the innovation economy, the energy, clean energy example as one. If students don't hear that, are we holding back their thirst for STEM education? Dr. Mathieu, did you have your hand up or no?

Dr. MATHIEU. I think that I would like to reinforce in answering with something that I said before, and that is that the key to the change is in the linkages to research funding, because that is where the faculty respond.

We go to these meetings, I have been to them, but I have the advantage of also being an active researcher right now in astronomy, and I want to emphasize the disconnect between those two worlds. Dr. Ferrini-Mundy is absolutely correct. If there is any directorate of the National Science Foundation that knows how to disseminate, it is EHR. But I am assuring you that the vast majority of my colleagues and my faculty in both physics and astronomy at the University of Wisconsin at Madison do not show up at those meetings and are not connected to those worlds. And I think the real transformation will happen when this panel, with all due respect to Dr. Ferrini-Mundy, has her but also has the Assistant Director of Math and Physical Sciences or one of the others. And that person can speak compellingly, intelligently and connectedly to the need to change graduate education.

And so I guess what I am really trying to say again is, in my opinion, the most effective change agent in the last decade for the things that you wish to accomplish has been the CAREER awards, because those CAREER awards require young faculty who are still in their formative stage to hear from the NSF that we want you to be superb researchers, and we also demand that you be excellent teachers, and show us how to do it. And understand that that carrot, when it first started, was very difficult for those graduate students because our system did not prepare them to respond to that carrot. I was on the early panels, and the CAREER awards were 14-1/2 pages of research and a half-page of very poor education. I am happy to say I was on the panel a year ago, and not only are the pages becoming more equal in length, but they are becoming more integrated. And that is because the prestigious research funding award at the NSF requires it. When I was young, I got a Presidential Young Investigator Award. It had nothing in it about teaching. That change in this decade has been huge, and I would suggest that if you really want the change you are looking for, the model is to connect the education funding, and call, with the research funding. That is where the reward system is in universities and even colleges now.

Mr. TONKO. Thank you for the insight. Thank you. Oh, I'm sorry. Mr. Stephens?

Mr. STEPHENS. Congressman, from an industry perspective, I agree with my colleagues on the panel here that certainly funding for graduate and undergraduate education is important, but I do believe we have a fundamental issue in this Nation and that is most people don't view engineering and technology careers are the ones to go pursue. And that starts with the media, it deals with parents and it deals with this sense about who wants to be a nerd and is not putting it on the table. All one has to do is watch the TV show the Big Bang Theory, and there are four characters on there. I don't know any child in America who wants to be one of those four individuals. Yet, they represent the perception of what engineering and technology is about. So I believe, like my colleagues, we have to work on this notion about what goes under 'education'. But I think we have to change this perception about the real jobs that are available, who creates space shuttles, space stations, green technologies, opportunities for the future. I don't think our society values those technology degrees as it should, like other nations do today.

Mr. TONKO. As an engineer, I appreciate the answer. Yes, Dr. Finkelstein?

Dr. FINKELSTEIN. I am happy to briefly comment on that. I think that is right. We need a cultural shift here, and the question is, how do we effect, how do we bring that cultural shift about? And I think it is tremendously important.

One lever that we have is our school system itself, and if we engage children—I mean, this Committee a few weeks ago heard about K–12 engineering education. I think that is critically important. And a key lever for that, for engaging and allowing for that, is having disciplinary faculty within engineering and physics and even astronomy start taking up the mantle and saying, my job is to recruit and prepare the next generation of teachers. These are going to be our best and brightest students, and we are going to shift so that the departmental cultures themselves transform and they see the value of putting out the next generation of teachers who transmit that value, enthusiasm and excitement to their students. This is why many programs such as the Noyce Fellows program are tremendously valued and important. It also helps improve our faculty at the university, and I think that is an underutilized lever.

Dr. MATHIEU. Even astronomy?

Dr. FINKELSTEIN. Even astronomy, Bob.

Mr. TONKO. Dr. Ferrini-Mundy?

Dr. FERRINI-MUNDY. Thank you. Just a brief comment on this point. I think another kind of avenue to imagine using in recruiting people and engaging them in interest is the increased focus and commitment by young people to the importance of issues around energy, sustainability, other interdisciplinary issues that are attractive and appealing to the Nation's youth. That may be a way to draw them in.

And NSF is working with a variety of mechanisms for trying to foster continued education activity around these sorts of areas as a way to continue the recruitment.

Mr. TONKO. Thank you, Mr. Chair. I went way past my time, so I thank you.

Chairman LIPINSKI. That was very interesting, I think. When it comes to me, I might follow on some of those. But right now, I want to recognize Mr. Inglis for five minutes.

Mr. INGLIS. Thank you, Mr. Chairman. And Mr. Stephens, am I happy to see you. You know, I am from South Carolina, and so you can imagine how happy I am to see you. We are very excited about making Dreamliners in Charleston. And so to get the opportunity to talk to the Vice President of Human Resources at Boeing and to say thank you for coming to South Carolina is a wonderful opportunity for me. And it is a huge thing for our State obviously and the jobs, statewide, not just in Charleston. I represent the upper part of the State, but I know of folks who were putting up the steel and the hangers that are from the upstate. We got a drill company that is hopefully going to sell you drill bits. They are already selling you drill bits.

Mr. STEPHENS. Terrific.

Mr. INGLIS. They are going to sell you a lot more drill bits. And so you have made our year. You have made our decade, so we are very grateful to you and very excited about what is happening at Boeing.

Mr. STEPHENS. Congressman, thanks very much. We are happy to be there.

Mr. INGLIS. And you are going to love Charleston. And you know, I mean, it is sort of one of those places where you can get to go visit and wow, can you imagine, having a manufacturing operation in Charleston, South Carolina, where you can get to go see Charleston and enjoy all of that, wow.

End of the commercial, Mr. Chairman, or what is it?

Mr. STEPHENS. I appreciate it.

Mr. INGLIS. Smiling faces, beautiful places. That is what South Carolina is. What else can I say about South Carolina, Mele? Mele is from South Carolina. So anyhow, very excited and obviously we are just giddy about the tremendous opportunity for us. And it is exciting that the Dreamliner has an energy connection in that it saves on energy and is a very efficient system, and what a great thing for our future, national security as well as the environment. So very excited about all that.

And also, I agree with you completely in what you were just saying about the presentation in STEM education. We really do need to show people that it is exciting and fun. I had an opportunity to go with this Committee to Antarctica, and when I got back actually from Antarctica, I dialed into some high school classes, science classes. And from Antarctica, we were able to tell them what we are doing and they were so excited about it. And when I got back, I had some opportunities to do some big presentations to some high schools. And two of my favorite slides were a very good-looking scientist. I mean, one of them was this blonde knockout. I mean, she was just amazing. And then another one was this handsome fellow who had graduated from Dartmouth. And so I put those slides up on the screen. I said, that is what scientists look like. Anybody want to be a scientist? And so it was pretty exciting. I mean, people in the class were saying, yeah, see you get to do cool things and they are cool people. I mean, they were obviously by the pictures of the way they were engaged with each other, very fun and engaged, you know, enjoying life and also doing interesting things.

And so it is very important I think to present science that way. It is also I think very important for us to present it as a key to our national future, and I am taking all the time to make statements here rather than ask questions, but Dave Bodde is at Clemson University's International Center of Automotive Research. He says that when he was traveling across the country on a family vacation, Sputnik was launched. His mother turned around to him in the back seat and said, "Son, it is your patriotic duty to become a scientist and to help us win the race to the moon". He did it. He participated in all of that. And he took it as a patriotic duty. When I go around to people saying to people, it is your patriotic duty to figure out how to break this addiction to oil and how to repower our lives, and if you do that, you can improve the national security of the United States and your friends won't be boots on the ground in some very dangerous places in the Middle East. And we will be able to say to those folks, we just don't need you like we used to. Part of that is the Dreamliner getting there with more efficiency.

By the way, also Mr. Chairman, I should note that I have been told that Dr. Arden Bement announced his retirement this morning at NSF, and what a guy that really believes in STEM education, and he will be missed. A great contribution he made to us.

Anybody want to pick up on any of those lines of statements and commercials? Dr. Finkelstein might have something that he wants to bring to South Carolina. If you do, I will give you a commercial.

Mr. STEPHENS. Congressman, I appreciate the comments and certainly the Dreamliner in South Carolina is very important to us. But on the comments about education as I made in my remarks, we are doing some work with the Entertainment Industry's Council, who is all about shaping the minds and hearts of the American people. They have been very successful in seatbelts with the crash dummy campaign, smoking cessation, elimination of smoking, the issue of mental illness. We are now using them to influence directors, writers and actors and how they portray engineers and scientists in a very positive and pro-active way. You talk about the good-looking scientists in Antarctica; there is an organization called Nerd Girls out of Tufts University who did exactly that. They were on the Today Show about year and half ago. A couple of our engineers are actually Nerd Girls, and our communications folks came and he says, Rick, you know, they were on national TV and we were a little concerned it was about looks. And I said, I want more of that because if we can get more people about what really scientists and engineers look like, act and do, they are like the rest of us and they really make a tremendous contribution to society. I don't think enough people really understand in America what our engineers and scientists really do. So I solidly support it, and we are putting our money behind it to support that.

Mr. INGLIS. Dr. Finkelstein?

Dr. FINKELSTEIN. Congressman Inglis, thank you. Yes, I always have something to say, and I am more than happy to bring several programs to South Carolina. I think that would be——

Mr. INGLIS. Okay, good.

Dr. FINKELSTEIN. And I think that this is a fundamental form of investment in our future. As I mentioned before, I think that this is the great R&D for a future society.

A couple of threads to pick up on what you said. One is, I think there is a tremendous role for informal science education. This isn't something that we've touched on quite yet. NSF has been instrumental in pushing this, but we have sort of danced around the edges of that. I think programs that couple university systems and the public, I think bringing industry together with the university systems and the public, I think is tremendously valuable because it provides opportunity, access and inclusion to children who have been historically taught, no, you can't do that or shouldn't do that or don't even know how to ask the question that way.

We also know that it improves our undergraduate and graduate students from participating in those sorts of programs. So the point is we leverage value throughout this entire system.

The other thread that you talked about was this notion of a grand challenge, the space race. I think that is where we are at in STEM education. I think STEM education should be a grand challenge in and of itself. I don't know if that is a sales thing. We can talk about, you know, what the opportunity is for that. But certainly I know some of the impetus behind the Rising Above the Gathering Storm or outcomes of that was to provide a grand challenge, really, around this question of energy and using education as a key tool to address the challenges of our energy future here. I think that would be a great way for us to play and start pushing.

Mr. INGLIS. And I am way over time, but I might just add this if I can, Mr. Chairman. The grand challenge, I am a little bit concerned about the cancellation of the Constellation program as losing a grant challenge. I think it is something to be concerned about. If we lose something like that, we lose the focus on—now of course, I think the reality is, we are somewhere out on the curve of diminishing marginal returns, so that the early space program created enormous opportunities for all of us in plastics and all kinds of things. So we are somewhere out on that curve of diminished marginal returns because we have been there and done that. But I have got to believe there is a lot more to be discovered as we continue in exploration. And losing that grant challenge is something to be concerned about.

Thank you, Mr. Chairman.

Chairman LIPINSKI. Thank you, Mr. Inglis. I think you were trying to take Henry Brown's place as the lead ambassador for Charleston here.

The Chair will now recognize himself for five minutes. I am looking here. I think we are about to start voting here, but we do have a little bit of time. There are so many things I want to explore. One sort of coming out of what we were all talking about, about the incentive for teaching and research, but I want to leave that because I want to make sure I hit this other question first. Mr. Stephens, in your testimony you describe a project at Boeing that compares the various university engineering programs that produce the company's highest performing workers. So I am interested if you could highlight the common characteristics of these departments and institutions. This is not something when I was a student that I thought a whole lot about, but it was after I left that I better understood different schools do things differently. So I am wondering, Mr. Stephens, what are some of those characteristics that really did produce good, the highest-performing workers?

Mr. STEPHENS. Mr. Chairman, I appreciate the opportunity. As you are aware, we looked at—since we have a relationship with 150 colleges and universities around the United States, we were able to take a look at our employee performance based upon the schools they went to, and we looked at employee performance over a 10-year period. What we found is engineering schools do a great job getting across the technical disciplines. We found very little difference in terms of their technical competency and ability. What we did find is those who were involved early on in projects starting their freshman year did better at The Boeing Company because we work as teams.

Second, we found out that it was those who supported internship programs and got them engaged with industry early on in their career, went a long ways as well. We also found those who were forced to work in teams as opposed to independent projects also did very well.

And so it is those soft skills and those engagements in real projects early on in their curriculum that were the ones that did best for us at The Boeing Company.

Chairman LIPINSKI. Thank you. One other thing. Dr. Mathieu——

Dr. MATHIEU. I was just going to add very quickly, the good fortune is that we found that the best way for students to learn is also in teams and actively working with each other. So there is a beautiful confluence here if we can change the way we do things.

Chairman LIPINSKI. The question of if we bring people in or they come in thinking that they are going to be an engineer or scientist. The whole question then of retention I think is an important question, but on the other side, you also have the question of the preparation before they get there, who is really ready to move on. And for some people, it may not be what they want to do and decide it is not what they want to do. But it is certainly a very important issue, and it is interesting to hear. It makes a lot of sense to me, Mr. Stephens, what you said, what parts of programs would be good. And that resonates with me.

I want to move back to the question of what we can do to encourage better teaching. I look at it, even though I have got master's and bachelor's in engineering, and then I went on to graduate school in social science and got my Ph.D. in political science, I look at it and I say I got to graduate school and was essentially told at Duke, we are a top department in producing top political scientists. You are not going to be rewarded for your teaching. And I learned some individuals personally felt that it was part of their mission to be a good teacher, some of the faculty. But that was more personal than incentive structures.

I like a lot of what I heard about setting up these, changing some of the incentives. But they seem very small, how much can we do. And Dr. Mathieu, I think leadership is critical. But how do we really change that? I just see this as such a huge problem. And there is a tradeoff. Everyone only has so much time, and if you are going to be rewarded and if what makes you a top person in your field is where you have published and how much you have published, how do we reward teaching? How do we really change that? I am just a little pessimistic about doing that. How do we really get this turned? To me it seems like it is going to take a long time to get it turned. Is there anything else that—you know, is there a reason for optimism, a reason I should be more optimistic about this? I just want to throw that out there. Dr. Mathieu?

Dr. MATHIEU. Well, I think you should be very optimistic, because if you aren't, then we aren't going anywhere.

Chairman LIPINSKI. Well, besides that.

Dr. MATHIEU. More concretely, I mean, you have to appreciate and I am sure you do, that the current system evolved over 40 years, and we are now in a place where the external reward systems at research universities are primarily based on research funding at the university level.

And so I don't think it is going to take 40 years, but it is going to take a little time in order to change that reward system. And fundamentally, I think the heart of it, and I apologize for repeating myself, I think the heart of it is linking the reward system currently, which is research funding, with the requirement to have broader impact. And the requirement and—especially for the young faculty—the recognition that if they are going to succeed in their research, they are going to have to be able to do teaching well. And the reason that I can say that that works is because I think one of the main reasons that CIRTL was actually institutionalized in Wisconsin, the main reason that they are actually supporting us is not so much the fact that we are preparing the current future faculty, although that is a wonderful thing. It is because research programs in our campus are being funded at a higher rate now because they can associate with our programs to show that they have the capacity and the ability to satisfy the requirements that you put on the Nation with the broader impact requirement.

It especially happens with CAREER awards. You end up with a situation where a professor comes from—I shouldn't name any given school—but they come from a psychology like you were describing. Suddenly, in order to achieve the most prestigious award at the National Science Foundation, they need to be able to speak intelligently about education and about teaching. Well, how do they do that? They do that by collaborating with us, and as they do, they get CAREER awards and they get research rewards, and that process happens for NSF Centers on our campus, and I am sure on yours to Dr. Klomparens with the Prep Program, it happens on the individual investigator level who now have to actually have a broader impact component to the research proposal, and we find the draw on our resources and the ability to change the reward system is profound because of your decision to link the broader impact and teaching to the research funding model. I truly believe that 10 years from now we will have a future faculty, which will be the current faculty, who not only are skilled in doing this because of our programs but actually won't even think twice. It is the way it is done.

Chairman LIPINSKI. We have a vote going on right now, and so we have about two more minutes I would say. So Dr. Finkelstein?

Dr. FINKELSTEIN. Thank you. Very briefly then. I mean, one thing is, I think excellence is a habit of mind, and so those same research scholars who are committed to excellence in journal publication and foundational science research are at universities because they want to engage in education and reaching future people. We have to provide them the resources for doing so. There is a reason they are at a university rather than say a National Lab. I think there is an opportunity there, and we have got to provide that. We can model opportunities for faculty, and there are many sorts of models and resources by which we can support our faculty for engaging in this. We can have education researchers and reformers housed within departments that help these faculty do that. That is the nature of our research group. We do foundational research in education, but we also help other faculty transform what they do. We enable them. The culture in our physics department right now is that of educational excellence. We are committed to that, and that is something that we do in addition to our scholarly excellence.

It is also because we have as, Dr. Ehlers had pointed out, we have strong partnerships between our School of Education, where they have expertise and excellence in undergraduate level education and our disciplinary departments. We think we can support faculty for engaging in doing this and valuing that NSF and having sort of a national dialogue imprimatur behind these sorts of activities through career awards and others is also extremely helpful.

Chairman LIPINSKI. Thank you. Mr. Stephens, very quickly.

Mr. STEPHENS. Yes, sir. I don't know enough about the university system, but we run into similar issues about engineers wanting to move into management. We have a dual track. Engineers can make same compensation the management does. It certainly would be nice to see that at the university level. I think those incentives may drive those who have excellence in teaching if they are recognized for that at the same level they are recognized for research.

Chairman LIPINSKI. Thank you. It is a very critical issue and something that I thought a lot about certainly when I was in graduate school, when I was an assistant professor. It is going to take time and lot of effort to turn this around. But I thank all of you for your testimony today. The record will remain open for two weeks for additional statements from Members and for answers to any follow-up questions the Committee may ask of the witnesses. And with that, the witnesses are excused, and the hearing is now adjourned.

[Whereupon, at 1:05 p.m., the Subcommittee was adjourned.]

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