Statement On

STRENGTHENING UNDERGRADUATE AND GRADUATE STEM EDUCATION

before the

HOUSE SUBCOMMITTEE ON RESEARCH AND SCIENCE EDUCATION

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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 faculty[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

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

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 2-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 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**

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

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 US.

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 extra-curricular 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

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[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.

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 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 learning

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

in 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-docs 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 (SBE). 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-docs, 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

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

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 4-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

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[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.

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

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-docs, 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 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.

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

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-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

[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.

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

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 be 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 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 5 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 to this 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 non-research-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.