Leveraging the NSF Broader-Impacts Criterion for Change in STEM Education

By Robert D. Mathieu, Christine Pfund, and Don Gillian-Daniel

The call for a more scientifically literate society is a constant drumbeat coming from the mainstream media and from reports of concerned organizations like the National Academy of Sciences. And they see improved education and outreach from institutions of higher learning as key to any proposed solution to this major national challenge. In higher education, the need to integrate research, teaching, and learning has been a theme woven through decades of calls for improvement. In reality, the weight of external research funding has tipped the scales at universities —and increasingly more often at colleges —toward research activities. Any associated gains in the teaching and learning of undergraduates are seen as collateral, albeit very real, benefits.

In an attempt to move, if not balance, the scales of activity toward increasing scientific capability across a diverse national population, U.S. federal funding agencies are purposefully linking research funding to broad national impact. Some U.S. federal funding agencies, such as the National Science Foundation (NSF) are now insisting that scientists describe how their proposed research will have "broader impacts." Activities of researchers must contribute not only to the growing fund of knowledge but to the more immediate national good.

This appeal for broader impact is an opportunity to truly integrate research, teaching, and learning in the culture of universities and their faculty. Indeed, through the training of graduate students and post-docs, programs that are working to improve STEM (science, technology, engineering, and mathematics) teaching and learning—such as the Center for the Integration of Research, Teaching, and Learning (CIRTL) at the University of Wisconsin-Madison—are poised to shape a future faculty whose members are both excellent researchers and superb teachers. Such programs are positioned to enhance both the research and teaching missions of U.S. research universities by providing principle investigators (PIs) applying for grants with the capacity to effectively address the broader-impacts funding criterion, which then becomes a leverage point 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.

A Lever for Change

Among United States federal agencies, the National Science Foundation (NSF) has led the way in the integra-

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tion of research, teaching, and learning. Since 1997, the NSF's proposal review process has had two major criteria: intellectual merit and broader impacts. The intellectual-merit criterion requires that proposal writers address how their work advances knowledge and understanding within their field of study or across disciplines. The broader-impacts criterion requires proposers to describe activities beyond their research that will benefit the nation, including teaching, training, learning, and outreach.

Arguing that their research has social relevance is not enough. The principal investigators must also broaden the impact of their work through one or more of a wide range of possible activities: sharing data; mentoring graduate students; engaging undergraduates in research; translating research results into instructional materials for classroom use; increasing the participation of groups that because of gender, ethnicity, disability, and/or geographic location are underrepresented in science; enhancing the research and educational infrastructures at their institutions; or working with the public. However done, the linkage of these broader-impact activities to research funding is a powerful leverage point for national change in STEM higher education.

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, which included the following 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 program 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 such 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.

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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 officers. Thus its impact was 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 PIs simply do not have the training and experience to adequately respond to it, even when they want to. Consider for example the CAREER awards. Graduate education in the STEM fields in the U.S. typically gives minimal attention to the development of teaching skills. In most cases, exposure to teaching in graduate school involves one or two semesters as a teaching assistant, an experience that is often largely unmentored. 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. Indeed, similar challenges face PIs at all career stages.

Importantly, these challenges often involve limits in capacity but not in ideas or commitment to broader impact. Centers such as the Center for the Integration of Research, Teaching, and Learning (CIRTL) view the NSF broader-impacts criterion as an opportunity to develop capacity for effectively integrating research, teaching, and learning.

CIRTL (www.cirtlcafe.net) is an NSF Center for Learning and Teaching. The CIRTL Network comprises six research universities: Howard University, Michigan State University, Texas A&M University, the University of Colorado at Boulder, the University of Wisconsin - Madison, and Vanderbilt University. This national network is developing model professional-development programs in teaching and learning for graduate students, post-doctoral scholars, and faculty in the STEM disciplines.

The ultimate goal of the CIRTL Network is to create a national STEM faculty with the knowledge and experience to forge successful professional careers that include implementing and advancing effective teaching and learning practices. Such knowledge and skills will help these faculty to address the broader-impact criteria effectively, but the longer-range impact will be to influence the culture of higher education in STEM.

The prototype CIRTL program was implemented at the University of Wisconsin-Madison as the Delta Program in Research, Teaching and Learning (www.delta.wisc.edu). The Delta Program is a curriculum of graduate courses, intergenerational small-group programs, and internships embedded within an interdisciplinary learning community. Here we describe the approach the Delta Program takes to help STEM researchers develop, implement, and evaluate broader-impacts initiatives.

Research with a Broader Impact

Delta's approach to helping researchers address the broader-impact criterion is based on the three core ideas of CIRTL (referred to as the "pillars"):

1. Using familiar systematic and reflective methods of disciplinary research to develop, implement, and advance learning experiences and outcomes ("Teaching as Research");
2. Cultivating communities of learners who generate new knowledge about teaching and learning though mutual support ("Learning Community"); and
3. Discerning and valuing diverse experiences that have the potential to enrich every learning environment ("Learning through Diversity").

These three foundational concepts have proven to be a powerful approach to developing and implementing broader-impact projects and, equally importantly, to engaging STEM faculty. At a practical level, they guide proposal writers toward a familiar research-based proposal design that specifies problems and goals, defines the audience, reviews existing literature, suggests hypotheses for enhanced learning, discusses issues relevant to diverse participants, evaluates outcomes, improves approaches, and plans for dissemination.

We typically engage with faculty and graduate students (e.g., those applying for NSF Graduate Fellowships) in a workshop setting within a month of proposal due dates, followed by individual consultations as requested or by individual consultations alone. The object is to work with current and future faculty to improve the design and presentation of their proposals and to connect the researchers with the wide range of existing campus programs and initiatives with which they might partner.

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At the initial stage of their interaction with Delta, PIs are seeking rather specific assistance with their proposals (in contrast, for example, to a broader professional development experience). We have found that the following sequence of thinking is effective both for the PIs and for the success of their proposals:

1. You must have an idea for broader impacts of your work.

Critically, Delta does not take ownership of the PI's broader-impacts challenge. To do so would not guide each PI toward a deep conceptual integration of research, teaching, and learning, which can only happen through their commitment, enthusiasm, and action. In fact, our experience shows that most PIs have excellent ideas for broadening the reach of their work through implementing new pedagogies, enhancing the success of underrepresented groups, providing informal education through outreach, and more. In some cases, the PIs propose working with several programs on campus to help develop their ideas, expand their capacity to implement and disseminate the work, and achieve the broadest impact possible.

2. Delta will provide you, your graduate students, and/or your post-docs with the ability to effectively implement your ideas.

What the PIs and their teams often lack is the knowledge and capacity to implement their ideas. Delta's role is to provide PIs and members of their research teams with the requisite skills and knowledge so that they can do so. This is a critical conceptual change for PIs. Typically, the PI of a project is expert in the disciplinary work being proposed; a lack of expertise is what makes the broader-impact aspect of a proposal uncomfortable. A partnership with Delta permits the PI to acknowledge that lack of expertise and yet still credibly propose to achieve the broader-impact goal. The existence of a program like Delta provides immediate credibility for those reviewing the proposal that the principal investigator can in fact develop the capacity to accomplish the scope of work being proposed.

This approach might be contrasted with an alternative strategy in which PIs hire teaching and learning centers or outreach collaborators to "take care of" their education and outreach activities for them. Arguably these strategies dif-

fer in their goals. Delta sees engaging STEM researchers in the broader-impact mission and providing them with the skills to succeed at it as outcomes of comparable long-term importance as accomplishing their specific broader-impact initiatives.

3. You need to request funding to support members of your research team as they develop the abilities to carry out the broader-impacts plan.

Perhaps surprisingly, it is important to explicitly encourage PIs to request funding for their outreach and educational work. Often this is an oversight of PIs who are inexperienced with education funding initiatives and don't recognize this work as legitimately fundable. At other times it derives in part from the reasoning that the budget for a given proposal is capped, so any funding that goes for broader-impacts work is that much less for the disciplinary research being proposed. While this is occasionally true, typically it is not. Furthermore, a proposal for activities without an associated budget lacks credibility, which can hurt in the review of a proposal.

4. See teaching-as-research assistantships as an opportunity to implement your ideas and to integrate them permanently into the institution.

The NSF is very concerned about the institutionalization of the innovations it funds. A graduate or post-doctoral "teaching-as-research assistantship"—with funding in the proposed budget—provides the means to implement and complete a proposed project and at the same time provide training to future faculty. This approach is analogous to the way disciplinary research is done and has equivalent credibility.

For example, at UW-Madison, graduate students and post-docs collaborate with PIs to develop innovative instructional materials for STEM courses. As part of their teaching-as-research assistantship, they then have the opportunity to implement the materials in a classroom, evaluate the student learning that results, revise the materials, and in some cases, publish their results.

5. Stress four outcomes:

- An evaluated product,
- Institutionalization (see #4, above),
- Dissemination, and
- The development of future faculty.

The need to evaluate educational and outreach activities may seem self-evident to those in the world of education reform, but it is a new idea for many STEM PIs–and a daunting one at that. Most research proposals do not include evaluation within their broader-impacts sections; those that do stand out as superior. The "teaching-as-research" concept casts evaluation within a model that is sensible to STEM researchers.

It is also critical for the PIs to describe how their projects and their outcomes will be disseminated for the benefit of the larger scientific community and society. For researchers with access to the CIRTL Network, this dissemination is straightforward. Broader-impacts projects developed, implemented, and evaluated on any of these campuses can be easily shared both among CIRTL Network institutions and more broadly.

Finally, by developing capacity throughout their research teams, the PIs are also developing the future STEM academic workforce–a priority goal of the NSF. Indeed, the hope is that these future faculty members will consider education and outreach activities as an inseparable component of their research programs and have the skills and abilities to create, implement, evaluate, and disseminate them.

Excerpt from a successful CAREER award proposal:

I propose a number of educational activities designed to foster new ways of thinking, to effectively communicate the discovery process, and to leverage the NSF-funded Center for the Integration of Teaching, Research and Learning (CIRTL) for designing and evaluating my courses and enhancing professional development of my graduate students. CIRTL [i.e., the Delta Program in Research, Teaching, and Learning] provides opportunities for graduate students to develop skills in classroom teaching, preparation of instructional materials, informal education, teaching to diverse student audiences, teaching with technology, and internships. The graduate students involved in this project will participate in the [Delta Program] to increase their effectiveness in formal and informal instruction and apply what they learn in the activities described below.

Course on Environmental Colloid Chemistry. Such a course would represent an expansion of a special topics course I co-taught during the 2003-2004 academic year with faculty from the Department of Geology and Geophysics. I intend to participate in CIRTL's Instructional Materials Development course to develop several problem-based learning modules for use in the class and involve my graduate students in the design, implementation, and evaluation of the PBL modules. I will evaluate teaching effectiveness and student learning by conducting formative and summative assessments. In addition, I will have the course peer-reviewed by other faculty in my program.

—CAREER Awardee, Department of Soil Sciences, University of Wisconsin - Madison

Outcomes of the Delta Approach

The short-term goal of Delta is to facilitate successful research proposals and their broader-impacts initiatives. Positive review-panel comments (see sidebars) persuade PIs (as well as campus administrators) about the value of compelling plans and capacities for broadening the impact of their research. Our more important longer-term goal is to help PIs and their research teams proceed on a path that deeply integrates their research, teaching, and learning missions.

Over the past four years, Delta has offered seven workshops at UW-Madison. Over 150 graduate students and 43 faculty from across the STEM disciplines have participated. Each workshop is designed to provide participants with the opportunity to 1) discuss strategies for writing a successful broader-impacts proposal, 2) hear from panelists about successful proposals and the review process, 3) learn about resources on campus focused on the effective integration of research and education, and 4) have time to work on their proposal drafts.

> A strength of the proposal is the broad impact that will result from the synergistic involvement of three graduate students simultaneously, all of whom are involved in the Center for Integration of Research, Teaching and Learning. These students are being trained in outreach skills and will participate in the application of Digital Data Maps, which will have wide use in teaching and research.
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> *—Panel review for successful NSF individual investigator proposal. Department of Geology and Geophysics, University of Wisconsin-Madison*

Over half of the 2006-2008 CAREER recipients at UW consulted individually with Delta while writing their proposals. Table 1 provides a summary of types and numbers of grants for which the Delta staff has provided individual consultation over the past three years. Typically such consultations include assistance in developing ideas into proposal-ready plans of work, providing feedback on proposal texts, and providing letters of support when the PIs intend to make participation in Delta programming part of their plan of action (as is typical).

> **"Being able to leverage off an NSF-funded program gave my proposal more weight."**

Evaluation of these workshops indicates that participants find them beneficial; this is also demonstrated by the attendance numbers. When we asked new faculty applying for CAREER awards about these consultations, 65 percent of respondents indicted that writing their proposal in collaboration with Delta was either "better" or "much better" than their previous grant-writing experiences.

Participants made comments such as the following:

- "My proposal was greatly improved by having collaborated with people with the education expertise that I lack."
- "Being able to leverage off an NSF-funded program gave my proposal more weight."
- "It was very helpful to get immediate feedback and suggestions for improving the broader-impact section. I also learned a lot about the programs available on campus, which I found very helpful."
- "I thought it was very useful to understand the history of the 'broader impact statement' so that we know how it relates to NSF's goals and how we can speak to those goals. I also liked hearing from actual recipients of the fellow-

Table 1: Individual Consultations by Grant Type (2004-2007)

Grant Type	# of consultations	# of STEM departments
NSF Graduate Research Fellowships	22	16
CAREER Award	29	19
NSF Research Grant, Individual Investigator	18	13
Other NSF Research Grants	10	16

ships, who gave very helpful advice and made the award seem more attainable with the right preparation."

Other workshop participants have commented on the value of new links to potential campus collaborators and organizations.

Participants also indicated that they did several things differently in their proposals as a result of the consultation: seeking out more formal support letters for their broader-impacts objectives, improving the education component of their proposals, providing more specific details regarding their education objectives, writing broader-impacts statements that more accurately reflected their educational goals, writing with a more university-wide perspective, investing time in reading about active-learning approaches (including more emphasis on diversity) and providing more details about implementation and assessment.

> [This proposal] describes a systematic program that will involve both graduate students learning to teach and undergraduate students learning organic chemistry, within a strong infrastructure at Wisconsin (... CIRTL, a NSF Center) dedicated to similar educational objectives... .
>
> Possibly the most important impact of the work will be the preparation of faculty-to-be for teaching at the university level. American faculty receive outstanding training in research, but ... often never understand fundamental issues related to quality learning. Any project addressing these problems is significant.
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> *—Panel review for successful NSF CAREER proposal, Department of Chemistry, UW-Madison*

Present and Future Gains

The success rate for UW proposals that result from the support of the Delta program benefits the PIs and their research programs and increases the flow of federal funds to the university. The implemented and evaluated broader-impact initiatives benefit future students at UW, in nearby colleges, and in local schools.

The proposal consultations they have with the Delta staff are the first interactions most PIs have with Delta, but they are seldom the last. For example, all seven of the UW CAREER recipients from 2006 and 2007 who consulted with Delta are now active contributors to the learning community as program facilitators, course instructors, and teaching-as-research mentors. Such faculty and their graduate students and post-docs sustain the Delta learning community and help it grow by bringing in new ideas, providing funding and mentoring for teaching-as-research assistants, bringing Delta ideas into their departments, and becoming campus leaders for both Delta and other new initiatives. Ultimately, these successful research-active faculty become strong and visible advocates for the integration of research, teaching, and learning at UW.

These benefits to both the research and teaching missions of UW have led to the Delta Program's now being institutionalized. Thus Delta has leveraged the NSF broader-impacts criterion into a sustainable approach to institutional change via the integration of research, teaching, and learning. Equally important, through the integral involvement of graduate students and post-docs in broader-impacts initiatives, each of the six CIRTL Network campuses are poised to shape a future STEM faculty that is integrating research, teaching, and learning at colleges and universities throughout the nation. ◻

Resources

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