By Christine Pfund, Robert Mathieu, Ann Austin, Mark Connolly, Brian Manske, and Katie Moore

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Graduate students and post-doctoral scholars at research universities will shape the future of undergraduate education in the natural and social sciences, technology, engineering, and mathematics (the STEM disciplines) in the United States. In 2009 alone, more than 41,000 doctorates were awarded in STEM fields, and if employment trends hold, roughly one in every three STEM PhDs will become faculty or instructional staff within six years of receiving their degree.

Since almost 80 percent of doctoral students are trained at only 100 research universities, the graduate schools of these institutions are a critical leverage point for improving undergraduate STEM education across the country. If a significant fraction of these universities were to intentionally prepare future STEM faculty as teachers of undergraduates, they would seed the diverse array of undergraduate institutions across the country with thousands of faculty and instructional staff who both teach effectively and continually improve the teaching-learning process.

Here we share the story of the Center for the Integration of Research, Teaching, and Learning (CIRTL), its conceptual framework for the preparation of future faculty, and one example of a high-impact implementation: the Delta Program in Research, Teaching and Learning (Delta) at the University of Wisconsin-Madison.

This story shows how institutions can provide aspiring academics with professional development opportunities in teaching and learning that are demonstrably effective and institutionally sustainable. In particular, it describes three core ideas that cultivate the knowledge, behaviors, and skills that future STEM faculty need in order to help generate undergraduate learning. Finally this story demonstrates that a combination of creative freedom, a sense of having a broader impact, and enhanced professional success will engage current faculty members, and thereby their universities, in this important national mission.
The Center for the Integration of Research, Teaching and Learning (CIRTL)

In 2002, the National Science Foundation (NSF) invited proposals for the creation of Centers for Learning and Teaching in higher education. These centers were expected to strengthen reform efforts in postsecondary teaching and learning by blending education research, instructional opportunities, and professional development for future and current faculty. The ultimate goal was to enable all undergraduates to experience effective teaching practices and exemplary educational materials.

In response to this call, a multi-institutional team of faculty, staff, and graduate students from across the STEM fields and the educational sciences designed a professional-development strategy for graduate students and post-doctoral researchers (post-docs) to improve STEM higher education. They were convinced that to prepare STEM future faculty at research universities for teaching and learning, they needed a new set of concepts that explicitly linked the improvement of teaching practice with scientific inquiry—an approach that would be congruent with the culture of research-extensive universities and thus be both viable and sustainable.

Ultimately the team proposed a model that integrated research, teaching, and learning — intellectual activities that graduate education has customarily kept asunder. In 2003, with funding from NSF, the University of Wisconsin-Madison (UW-Madison), Michigan State University, and the Pennsylvania State University founded CIRTL (www.cirtl.net) and began to develop a model for preparing future faculty in the STEM fields.

CIRTL’s conceptual framework consists of three core ideas: teaching-as-research (TAR), learning community (LC), and learning-through-diversity (LtD) (see Table 1).

These ideas help CIRTL participants build parallels between their approaches to research and to teaching and learning. Teaching-as-research describes the process of improving student learning in terms that are familiar from disciplinary research, while the core ideas of learning community and learning-through-diversity emphasize the rich and productive experiences researchers have working in diverse teams to achieve a common goal.

These ideas are rooted in the practice of STEM research teams, the educational literature, and past initiatives in faculty development such as the Preparing Future Faculty program (Pruitt-Logan & Gaff, 2004). CIRTL places them at the very foundation of preparation for STEM teaching and learning.

Current education research, such as that synthesized by Susan Ambrose and her colleagues (2010) in How Learning Works, supports the argument that advances in STEM undergraduate learning will be realized by faculty who engage in research-based, high-impact approaches to teaching. The CIRTL hypothesis is that future faculty will embrace these approaches by doing teaching-as-research, having learning-community experiences, and experiencing learning-through-diversity—and further, that their self-discovery will lead to deeper understanding of and engagement in high-impact teaching practices.

Table 1
The CIRTL Conceptual Framework

<table>
<thead>
<tr>
<th>Teaching-as-research (TAR)</th>
<th>Learning communities (LC)</th>
<th>Learning-through-diversity (LtD)</th>
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<tbody>
<tr>
<td>is the deliberate, systematic and reflective use of research methods by STEM instructors to develop and implement teaching practices that advance the learning experiences and outcomes of both students and teachers.</td>
<td>bring together groups of people for shared learning and the discovery and generation of knowledge. To achieve common learning goals, a learning community nurtures functional relationships among its members. In this project, learning communities serve as both formal and informal spaces that encourage and support transformation of the teaching–learning process.</td>
<td>recognizes that excellence and diversity are necessarily intertwined. True learning-through-diversity capitalizes on the rich array of experiences, backgrounds, and skills among STEM undergraduates, graduates, and faculty to enhance the learning of all.</td>
</tr>
</tbody>
</table>

Full descriptions can be found at www.cirtl.net
By engaging graduate students and post-docs in professional development, CIRTL is producing a national cohort of STEM faculty (a term that includes all those providing instruction in both college classrooms and informal contexts) who can implement effective teaching practices for diverse learners as part of a multi-faceted professional career.

**The Delta Program in Research, Teaching and Learning**

In 2003, CIRTL launched its prototype learning community at UW-Madison: the Delta Program in Research, Teaching and Learning (Delta; www.delta.wisc.edu, Figure 1). The objective was to develop an effective and sustainable professional-development program based on the CIRTL conceptual framework. The vision was of a multi-disciplinary, intergenerational learning community created by and for the future and current faculty of UW-Madison.

Establishing a shared sense of ownership among Delta learning-community members is critical to its vitality and sustainability. After nearly a decade, Delta has developed into a dynamic learning community with a diverse array of offerings, including graduate courses and small-group programs embedded within an interdisciplinary learning community of STEM graduate students, post-docs, faculty, and staff.

The creativity and expertise of learning-community members has nurtured extensive growth of Delta offerings. For example, in the 2010-11 academic year, the learning community provided

- fifteen courses,
- three small-group facilitated programs,
- eleven internships,
- six supplemental workshops, and
- six monthly roundtable dinners.

Although most of these offerings were created specifically for Delta, several are long-standing campus programs that have been integrated into Delta; others are new opportunities developed by campus groups in partnership with Delta. The offerings continue to evolve and new ones emerge. The course and program instructors change over time, with some carrying forward instructional materials and resources with little change and others introducing novel components.

For example, the Effective Teaching with Technology course (Figure 2) has been taught seven times by six different instructors. While the emphases of certain sessions and

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**Figure 1**

**Delta Program in Research, Teaching and Learning in 2011**

Five core graduate courses are shown in red, small-group discussion programs are shown in yellow, and low-engagement events are shown in green.

Basing Delta on a conceptual framework rather than on a specific curriculum was a critical design feature that distinguishes it from other professional-development programs, many of which feature an established curriculum taught by faculty and staff who maintain high fidelity to that curriculum. Other models include programs that offer a series of workshops, each with its own learning objectives but with few conceptual linkages between them.

The developers and instructors of each Delta offering, in contrast, have been free to design its learning objectives, activities, and projects based on their expertise, interests, and goals for the future faculty. The only requirements are that they integrate the three core ideas of TAR, LC, and LtD into the course design and content and that they give participants an opportunity to apply what they learn. This allows instructors to explore a variety of approaches to teaching future STEM faculty and enables those ideas and that expertise to contribute to the evolution of both the Delta learning community and the national movement to improve the preparation of future STEM faculty.

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**Figure 2**

**Delta’s Effective Teaching Course Syllabus (Fall 2009)**

<table>
<thead>
<tr>
<th>Session</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>Learning-Community Building</td>
</tr>
<tr>
<td>Week 2</td>
<td>What is Teaching-as-Research (TAR)?</td>
</tr>
<tr>
<td>Week 5</td>
<td>Assessment/Clickers</td>
</tr>
<tr>
<td>Week 6</td>
<td>TAR Case Study</td>
</tr>
<tr>
<td>Week 8</td>
<td>Universal Design and Learning-through-Diversity</td>
</tr>
<tr>
<td>Week 13</td>
<td>Project Presentations</td>
</tr>
<tr>
<td>Week 14</td>
<td>Project Revisions</td>
</tr>
</tbody>
</table>

This shows only the weeks in which the core ideas of CIRTL are the central topic. Complete course guidebooks for all 5 core graduate courses are available at www.cirtl.net/course_guidebooks. The most recent syllabi are available upon request.
the examples shared have changed based on the instructor’s area of expertise, the overarching goals of this course have remained stable:

- to provide participants with a foundation for choosing appropriate technological tools based on learning needs;
- to give participants hands-on experience with learning technologies such as interactive web applications, video/audio lectures, clickers, and course-management tools;
- and
- to provide participants with teaching-as-research skills for the ongoing evaluation of instructional technology’s efficacy.

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**Table 2: Courses and Programs Offered Annually through Delta**

<table>
<thead>
<tr>
<th>Course Title</th>
<th>Description</th>
<th>References</th>
</tr>
</thead>
</table>
| **THE COLLEGE CLASSROOM (6)**                                                | Participants explore their philosophy of teaching, design a course curriculum, and learn how to assess the effectiveness of their classroom learning environment. They engage in micro-teaching and receive feedback from peers.  
| **EFFECTIVE TEACHING WITH TECHNOLOGY (1)**                                  | Participants develop new approaches to using instructional technology in their teaching. They design technology-based instructional materials aimed at helping students learn a concept in their discipline.  
| **INFORMAL SCIENCE EDUCATION FOR SCIENTISTS (2)**                           | Participants learn to communicate their work to a wide array of audiences using informal communication strategies. They work in groups to design an activity for children and assess its effectiveness at an annual science outreach event.  
| **INSTRUCTIONAL MATERIALS DEVELOPMENT (3)**                                 | Participants analyze student learning problems and find resources to address them. They work in teams with faculty/staff to develop instructional materials aimed at helping students overcome learning challenges.  
| **INTERNATIONAL STUDENTS, INTERNATIONAL FACULTY (3)**                       | Participants explore global perspectives on culture, communication, and learning and how these pertain to effective and inclusive teaching. They develop relevant skills and habits of mind, along with the knowledge base associated with international cultures and high-quality teaching, learning, and assessment. |                                                                                                                                                        |
| **DIVERSITY IN THE COLLEGE CLASSROOM (5)**                                  | Participants consider the complex issues of diversity and how to address them effectively in their classroom practices. They develop an action plan to make their future classrooms more inclusive and to enhance the learning of all students.  
| **EXPEDITIONS IN LEARNING (9)**                                             | Participants engage in facilitated small-group discussions about the diverse campus learning environment and discover new ways to connect their experience of it to their own teaching practices.  
| **CREATING A COLLABORATIVE LEARNING ENVIRONMENT (2)**                       | Participants explore the learning process and its implications for their teaching with a small group of colleagues.  
| **RESEARCH MENTOR TRAINING (0)**                                            | Participants engage in facilitated small-group discussions of case studies on the relationship between research mentors and their mentees. They develop a mentor philosophy and learn strategies for effective mentoring.  
| **INTERNSHIP PROGRAM (7)**                                                  | Graduate students and post-docs partner with a faculty or instructional staff member on or off campus to use teaching-as-research to define a problem in teaching and learning, implement a solution, and assess its effectiveness.  
| **CERTIFICATE PROGRAM (0)**                                                 | Graduate students and post-docs achieve a Delta Certificate in Research, Teaching and Learning by participating in two courses and one small-group program, completing a teaching-as-research internship, and defending their teaching-and-learning portfolio. |                                                                                                                                                        |

The number of semesters for which participant data from the indicated course or program were collected is shown in parentheses. Publications and presentations that highlight student learning in these offerings are included after each description.
Graduate-student participants can follow project-based courses with a Delta internship, in which they engage in teaching-as-research projects with a faculty partner, gaining practical experience applying the concepts they have learned and assessing the learning outcomes. Often the internship projects build directly from instructional materials designed in a Delta course.

Since fall 2003, over 1600 UW-Madison graduate students and post-docs and 650 faculty and staff members from a wide range of STEM and social-science disciplines have participated in Delta. Almost 40 percent of the future faculty have participated in high-engagement programs and courses (at least one semester long). Fourteen percent have participated in multiple courses, which is required of those who complete the capstone Delta certificate.

As with their course designs, the instructors of each Delta offering create and administer their own evaluations and interpret the data they collect. This approach fosters TAR among the learning community of instructors and demonstrates TAR to the students. Delta staff, in turn, use data gathered from these efforts in changing future offerings. These data show that students achieve the intended learning outcomes in the courses and are highly satisfied with their experiences (as reported in the references noted in Table 2; Austin et al., 2009).

**LEARNING FROM DELTA**

If a Delta participant were asked about her approach to teaching, what would she say, and would her responses incorporate the core ideas of the CIRTL framework upon which Delta was built? Would her answers demonstrate achievement of the learning goals for CIRTL program participants (Table 3)?

And finally, do students who select experiences across the range of offerings adopt research-based high-impact approaches to teaching and learning STEM?

To find out, we asked Delta instructors to include two questions in their end-of-semester evaluation forms:

1. What major concepts are you taking away from this Delta course, program, or activity that will affect your practice as an educator? If possible, please give two to three specific examples.
2. Suppose that you are preparing to teach some scientific concept from your discipline (e.g., the nitrogen cycle, amplitude, redox reactions). Describe the steps that you will take, based on what you’ve learned in this course, program, or activity.

These two questions were included on participant surveys for 39 instances of nine different Delta courses and programs across 12 terms (spring, summer, and fall; n = 312) between fall 2005 and fall 2009.

We analyzed the participants’ answers and derived 23 distinct learning outcome categories from their responses, not from preconceived notions of what they “should have” learned through their participation in Delta. The resulting categories were organized using the CIRTL conceptual framework (Table 1); those that did not fit within the framework were organized separately.

The frequencies of participants whose responses included each of the 23 identified learning outcome categories are shown in Figure 3. Participants most frequently mentioned outcomes pertaining to assessment and evaluation, with 230 respondents (73 percent) mentioning the need or intention to assess student learning or teaching effectiveness. Participants also discussed learning goals and outcomes for the students (46 percent) and mentioned aspects of student learning (38 percent). In addition, participants noted the need to acknowledge diverse learners (27 percent) and highlighted their intentions to use a variety of instructional strategies (21 percent). These and the entire catalog of participant

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**TABLE 3**

**CIRTL LEARNING GOALS FOR FUTURE FACULTY PARTICIPANTS**

<table>
<thead>
<tr>
<th>When asked about teaching, a CIRTL participant’s answer would include:</th>
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<tbody>
<tr>
<td>1. Discussion of learning goals for the students, the nature of learning and effective teaching strategies that can support specific learning goals</td>
</tr>
<tr>
<td>2. Discussion of student learning and ideas about how to assess what students have learned</td>
</tr>
<tr>
<td>3. Awareness of literature related to teaching and learning and of research findings about high-impact teaching</td>
</tr>
<tr>
<td>4. Introductory knowledge of learning theory</td>
</tr>
<tr>
<td>5. Reference to the meaning of a learning community in terms of functional relationships and goals</td>
</tr>
<tr>
<td>6. A broad definition of diversity</td>
</tr>
<tr>
<td>7. Discussion of at least one way that a teacher might leverage the diversity of the students to enhance the learning of all</td>
</tr>
<tr>
<td>8. Discussion of the role the scholarship of teaching and learning plays within the larger nature of a faculty’s work life</td>
</tr>
<tr>
<td>9. Ability to see themselves and their teaching process as part of larger communities, including their classrooms, their colleagues, their departments, their institutions, and the nation</td>
</tr>
</tbody>
</table>
The participant responses are well aligned with the high-impact practices that research shows correlate with enhanced student learning.

Responses listed in Figure 3 are well aligned with the high-impact practices that research shows correlate with enhanced student learning (Froyd, 2008).

The learning outcomes identified by participants across the Delta learning community align closely with CIRTL’s intended outcomes (Table 3).

Responses are organized into subcategories within each major conceptual category. N = 312 respondents; overall response rate was 68%. Because course data were collected anonymously, it is not possible to link specific answers to individual participants. The responses came from a wide range of participants with different career stages, varied levels of participation in Delta, and diverse disciplines. Descriptions of each category can be found online at www.cirtl.net
The frequencies with which at least one concept within the CIRTL framework was included in participant responses from across the range of experiences in the Delta learning community are shown in Figure 4: 45 percent conveyed a LC-related concept, 57 percent noted a LtD-related concept, and just over 90 percent of respondents included mention of at least one TAR-related concept in their responses.

These data suggest that the core CIRTL ideas provide a functional framework for participants to organize the concepts and approaches they learn.

At the same time, one-third of the learning outcomes extended beyond the CIRTL categories and pertained either to “learners and learning” or “teaching identity.” Over 72 percent of the participants mentioned the need to understand how students learn, to get to know their students’ academic backgrounds, or to actively engage students in learning. An integral component of TAR is exploration of the literature and existing knowledge, where concepts of learning theory and active learning are commonly found. These are also topics integrated within many learning-community discussions.

Identity as a teacher is not a concept linked tightly to the CIRTL framework but it was mentioned as a learning outcome by over a quarter of respondents. Given how early graduate school and post-doc positions occur in an academic career, this is a frequent subject of discussions and supplementary programs within Delta. These findings suggest that CIRTL should incorporate these ideas into its working framework.

**Discussion and Next Steps**

Since 2007, the Delta Program in Research, Teaching and Learning has operated independently of CIRTL’s NSF funding. UW-Madison supports three full-time staff to administer the program. The learning community brings together tens of UW faculty and staff each year to advance the teaching of hundreds of future faculty, who in turn will teach thousands of undergraduates.

For example, in the 2010–11 academic year, 22 faculty and staff were instructors in Delta courses or facilitators in Delta semester-long programs, serving 213 participants. The faculty and staff contributed through the support of their own departments or colleges or as volunteers on overload. Such wide faculty and staff participation ensures an array of creative ideas and builds on the shared development and ownership that has characterized the creation and expansion of the Delta Program.

It is noteworthy that the future faculty participants are not funded by Delta; support for their engagement in the learning community spans the usual array of mechanisms within a research university. The vast majority participate while being supported by disciplinary grants. In this regard, the NSF emphasis on “broader impact” has critically changed the landscape; now, professional development is aligned with the proposed outcomes of research grants (Mathieu, Pfund, & Gillian-Daniel, 2009). For example, NSF CAREER awardees often fund Delta interns who help carry out their educational initiatives.

The research presented here highlights the concepts and practices that Delta participants plan to incorporate into their future teaching positions. Longitudinal studies of former doctoral students are investigating the extent to which these ideas are actually integrated into the practice of these participants.

In one longitudinal study, we have found that a majority of study respondents (76 percent) applied the knowledge and skills they gained from their teaching development to their subsequent undergraduate teaching. Respondents most frequently cited delivering instruction that increases student engagement (e.g., through active learning, inquiry-based learning, or the creation of learning communities within the classroom). They also frequently cited what they had learned in assessment and course preparation and planning, especially backward design, which starts with learning goals.

**Over 72 percent of the participants mentioned the need to understand how students learn, to get to know their students’ academic backgrounds, or to actively engage students in learning.**
(Benbow, Byrd and Connolly, 2011). Of course the ultimate proof of concept will be in the impact of Delta future faculty on undergraduate student learning.

In 2008, CIRTL welcomed the University of Colorado-Boulder, Howard University, Texas A&M University, and Vanderbilt University and created the CIRTL Network. In fall 2011, the CIRTL Network added 19 new research universities, for a total of 25. These institutions will be expanding local and national efforts focused on the preparation of future STEM faculty. While the CIRTL framework will link the 25 institutions, each will develop its own local learning community based on its institutional needs, strengths, and culture.

For example, one Network campus plans to integrate the CIRTL concepts into preparing faculty for community colleges. Another is helping future faculty learn how to incorporate service learning into STEM classes. Several are focusing on the success of minority and women future faculty. And others will bring future faculty more closely in touch with discipline-based education research through journal clubs (group meetings researchers typically have with their teams to discuss newly published results relevant to their work), which are familiar to STEM researchers. Participating graduate students and post-docs will also have opportunities to connect in a cross-Network learning community, in which the diversity of campuses will better prepare them for faculty positions across the spectrum of higher education institutions.

Graduate students and post-docs at research universities will shape the future of undergraduate STEM education in the United States; CIRTL is designed to improve their teaching practices so that diverse learners in the STEM disciplines will benefit. CIRTL is not the only initiative aimed at improving the preparation of STEM faculty, but it is distinctive in its conceptual framework and in its national scope.

The three core ideas of CIRTL—teaching-as-research, learning community, and learning-through-diversity—and the evidence of their impact on future faculty in the Delta Program may help others who are designing, implementing, and evaluating professional-development programs focused on teaching and learning. We hope that the success of CIRTL and its Delta learning community inspires others to provide aspiring academics with development opportunities that are demonstrably effective; are institutionally sustainable; and what is most important, advance STEM undergraduate learning.

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**Resources**
