Constructive Alignment of Interdisciplinary Graduate Curriculum in Engineering and Science: An Analysis of Successful IGERT Proposals

MAURA BORREGO AND STEPHANIE CUTLER
Virginia Tech

BACKGROUND
Interdisciplinary approaches are critical to solving the most pressing technological challenges. Despite the proliferation of graduate programs to fill this need, there is little archival literature identifying learning outcomes, teaching experiences, or benchmarks for evaluating interdisciplinary graduate student learning.

PURPOSE (HYPOTHESIS)
The purpose of this study is to understand how engineering and science academics conceptualize interdisciplinary graduate education in order to identify common practices and recommend improvements. Questions generated by an instructional design framework guided the analysis: what desired outcomes, evidence, and learning experiences are currently associated with interdisciplinary graduate education? To what extent are these components constructively aligned with each other?

DESIGN/METHOD
Content analysis was performed on 130 funded proposals from the U.S. National Science Foundation’s Integrative Graduate Education and Research Traineeship (IGERT) program.

RESULTS
Four desired student learning outcomes were identified: contributions to the technical area, broad perspective, teamwork, and interdisciplinary communication skills. Student requirements (educational plans) addressed these outcomes to some extent, but assessment/evidence sections generally targeted program level goals—as opposed to student learning. This lack of constructive alignment between components is a major weakness of graduate curriculum.

CONCLUSIONS
Current practices are promising. Further clarification of interdisciplinary learning outcomes, coupled with closer alignment of outcomes, evidence, and learning experiences will continue to improve interdisciplinary graduate education in engineering and science. Specific recommendations for engineering and science faculty members are: define clear learning objectives, enlist assessment/evaluation expertise, and constructively align all aspects of the curriculum.

KEYWORDS
Curriculum design, graduate education, interdisciplinary

I. INTRODUCTION

Interdisciplinary approaches are necessary for addressing the most critical technological and socio-technological challenges facing the nation and the world today (National Institutes of Health, 2006; National Science Foundation, 2006). Students and their training programs are recognized as central to increasing interdisciplinary research capacity. The National Science Foundation’s (NSF) strategic plan states, “Future generations of the U.S. science and engineering workforce will need to collaborate across national boundaries and cultural backgrounds, as well as across disciplines” (NSF, 2006). The U.S. National Science Board has similarly concluded that graduate traineeships can provide ideal sites for interdisciplinary graduate education: they include work by the Carnegie Initiative on the Doctorate (Golde and Walker, 2006) and the Woodrow Wilson Foundation (2005), among others. Each of these prestigious groups has independently concluded that interdisciplinary training is an important new direction for graduate education.

Despite the proliferation of interdisciplinary graduate programs designed to fill the need for interdisciplinary Ph.D.s, there is little archival literature identifying learning outcomes, methods or benchmarks for assessing interdisciplinary graduate programs and associated student learning. Richards-Kortum, Dailey, and Harris (2003) describe an excellent example of an IGERT assessment plan. Other publications describe only the curriculum of a specific IGERT program, e.g., courses, seminars, and collaborations, similar to the proposals we analyzed (Cowan and Gogotsi, 2004; Martin and Umberger, 2003) describe an excellent example of an IGERT assessment plan. Other publications describe only the curriculum of a specific IGERT program, e.g., courses, seminars, and collaborations, similar to the proposals we analyzed (Cowan and Gogotsi, 2004; Martin and Umberger, 2003), while Thursby, Fuller, and Thursby (forthcoming) describe their curriculum and present assessment data.). A number of authors note that while engineering and science faculty members have little difficulty writing learning outcomes for technical work, the domains of teamwork, graduate education, and teaching and research universities (Nyquist and Woodford, 2000, p. 6). Weisbuch (2004) argues that interdisciplinary studies is a “new paradigm” for graduate education (p. 224). Furthermore, a series of studies compiled by Wulff, Austin, and Associates (2004) demonstrate a similar need for an increased focus on interdisciplinary training in graduate education: they include work by the Carnegie Initiative on the Doctorate (Golde and Walker, 2006) and the Woodrow Wilson Foundation (2005), among others. Each of these prestigious groups has independently concluded that interdisciplinary training is an important new direction for graduate education.

Despite the proliferation of interdisciplinary graduate programs designed to fill the need for interdisciplinary Ph.D.s, there is little archival literature identifying learning outcomes, methods or benchmarks for assessing interdisciplinary graduate programs and associated student learning. Richards-Kortum, Dailey, and Harris (2003) describe an excellent example of an IGERT assessment plan. Other publications describe only the curriculum of a specific IGERT program, e.g., courses, seminars, and collaborations, similar to the proposals we analyzed (Cowan and Gogotsi, 2004; Martin and Umberger, 2003), while Thursby, Fuller, and Thursby (forthcoming) describe their curriculum and present assessment data.). A number of authors note that while engineering and science faculty members have little difficulty writing learning outcomes for technical work, the domains of teamwork, graduate education, and
interdisciplinarity are challenging in their own rights and beyond the background or experience of most technical faculty members (Boix Mansilla and Dawes Durasingh, 2007; Felder and Brent, 2003; Hoey, 2008; Klein, 2008). To provide much-needed knowledge and recommendations, we present our analysis structured by a curriculum design framework. This framework emphasizes both the important components of curriculum and the necessity to align them to mutually support each other.

The purpose of this study is to understand how engineering and science academics conceptualize interdisciplinary graduate education in order to identify common practices and recommend improvements. The research questions guiding this study follow from a simple curriculum design framework (Wiggins and McTighe, 2005), which is described in detail in section II. Background and Literature Review.

1. What desired outcomes are currently associated with interdisciplinary learning in graduate engineering and science?
2. What evidence is currently used to assess interdisciplinary learning in graduate engineering and science?
3. What learning experiences are being designed for interdisciplinary learning in graduate engineering and science?
4. To what extent are these three components constructively aligned with each other to communicate expectations to students and reinforce learning?

To address these questions, we collected and analyzed funded proposals from a long-running interdisciplinary graduate education NSF program (beginning in 1998). The results of this study indicate that many interdisciplinary graduate program proposals lack strong connections between desired outcomes, evidence, and learning experiences, and suggest that more thorough integration of each of these goals may better support new and continuing interdisciplinary programs.

II. BACKGROUND AND LITERATURE REVIEW

A. Defining Interdisciplinarity, Multidisciplinarity, and Transdisciplinarity

Before exploring what engineering and science faculty members mean by interdisciplinary learning, we offer some definitions. Generally agreed upon definitions of interdisciplinarity, multidisciplinarity, and transdisciplinarity are summarized in Table 1. Noted interdisciplinarian Julie Thompson Klein offers a general and often cited definition of interdisciplinarity: “Interdisciplinarity is a means of solving problems and answering questions that cannot be satisfactorily addressed using single methods or approaches” (Klein, 1990, p. 196). To those who distinguish multidisciplinarity from interdisciplinarity, multidisciplinarity is less integrative, often a temporary or weak combination of contributions from multiple disciplines (Berger, 1972; Chubin et al., 1986; Committee on Facilitating Interdisciplinary Research, 2004). Stokols et al. make the distinction in more process-oriented terms:

Multidisciplinarity is a process in which scholars from disparate fields work independently or sequentially, periodically coming together to share their individual perspectives for purposes of achieving broader-gauged analyses of common research problems. Participants in multidisciplinary teams remain firmly anchored in the concepts and methods of their respective fields.

Interdisciplinarity is a more robust approach to scientific integration in the sense that team members not only combine or juxtapose concepts and methods drawn from their different fields, but also work more intensively to integrate their divergent perspectives, even while remaining anchored in their own respective fields. (Stokols et al., 2008, pp. S78-S79)

While earlier definitions of transdisciplinarity focused on overarching theories that transcended traditional disciplines (Berger, 1972; Lattuca, 2001), the term has more recently taken on a meaning that includes a broader range of stakeholders—including practitioners and the public—in its focus on solving authentic problems (Gibbons et al., 1994; Klein, 2005).

However, many academics that practice research that crosses or combines disciplines do not draw these distinctions. For the purposes of this paper, we will use the term “interdisciplinary” (because it is the most common) to refer collectively to activities which may be strictly multidisciplinary, interdisciplinary, or transdisciplinary. One of the major aims of this analysis is to understand what engineering and science academics mean when they describe interdisciplinary grade education and its variants, rather than to impose our own definitions.

It is well-documented in the literature that engineers and scientists tend to define interdisciplinary as teamwork (Hagstrom, 1964), and accordingly, discussions of interdisciplinary learning take the perspective of representing one’s own discipline when working with others. Emphasis is on understanding and respecting

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interdisciplinarity</td>
<td>“[A] means of solving problems and answering questions that cannot be satisfactorily addressed using single methods or approaches” (Klein, 1990, p. 196).</td>
</tr>
<tr>
<td>Multidisciplinarity</td>
<td>Less integrative than interdisciplinarity, often a temporary or weak combination of contributions from multiple disciplines (Berger, 1972; Chubin et al., 1986; Committee on Facilitating Interdisciplinary Research, 2004).</td>
</tr>
<tr>
<td>Transdisciplinarity</td>
<td>Combines traditional academic disciplines and includes a broader range of stakeholders including practitioners and the public in its focus on solving authentic problems (Gibbons et al., 1994; Klein, 2005).</td>
</tr>
</tbody>
</table>

Table 1. Definitions.
the contributions of other disciplines well enough to coordinate team projects (Richter and Paretti, 2009). However, an extensive review of undergraduate-level interdisciplinary learning outcomes is beyond the scope of this paper, which focuses on overall curriculum design. For a more extensive discussion of interdisciplinary learning outcomes, see Borrego and Newswander, in press; Richter and Paretti, 2009.

B. Learning Outcomes and Assessment in Graduate Education

Due to the widespread influence of outcomes-based assessment systems (e.g., ABET, Engineers Australia), many engineering academics are aware that a critical first step is to define the long-term goals and objectives that will create “enduring understanding beyond the classroom” (Wiggins and McTighe, 2005). Without these, professors and program directors risk gathering only the data that are easy to measure or quantify, rather than the direct evidence that will help to evaluate and improve student learning. Specific to graduate engineering education, Hoey explains:

A common pitfall when beginning the assessment of graduate programs in engineering is the conflation of managerial objectives for the program with student learning outcomes. Managerial objectives for a graduate program might include things like increasing the number of quality applicants to the program, increasing yield rates, decreasing program time-to-degree, increasing the number of research proposals, or increasing faculty salaries relative to peers. While these operational objectives are all of clear importance to the vitality of a graduate engineering program, they are not concerned with learning outcomes: the competencies, skills, and attitudes we expect graduate students to acquire through their programs of study. Thus, making a clear distinction in practice between the two important types of measurement is important for assessment planning purposes (Hoey, 2008, p. 154).

In ABET parlance, program objectives are broad statements describing professional accomplishments of graduates (e.g., job placement), while learning outcomes are narrower statements of what students are expected to know and be able to do by the time of graduation, specifically skills, knowledge, and behaviors (ABET, Inc., 2008). While both are important, this study focuses primarily on student learning outcomes because it is the most neglected area of assessment within interdisciplinary graduate education. Specific courses may have learning objectives, which are focused on specific skills, knowledge, and behaviors (Felder and Brent, 2003). As well as accurately reflecting the values of the program, learning outcomes should be measurable, or

[A] statement of an observable student action that serves as evidence of knowledge, skills, and/or attitudes acquired …The statement must include an observable action verb (explain, calculate, derive, design, critique,…)… Understanding, for instance, cannot be directly observed; the student must do something observable to demonstrate his or her understanding (Felder and Brent, 2003, p. 10, emphasis in original).

Thus, learning outcomes and course objectives begin with specific action verbs. Wiggins and McTighe (2005) suggest different facets of knowledge to consider: interpret, apply, have perspective, empathize, and have self-knowledge. Many readers will recognize similarity to the types of action verbs emphasized in the cognitive domain of Bloom’s Taxonomy, e.g., describe, predict, analyze, design, evaluate (Bloom and Krathwohl, 1984; Krathwohl, Bloom, and Massia, 1984). Specific to graduate education, Hoey (2008) lists a number of typical skills originally described by Banta, Black, and Ward (1999) including:

- Knowledge of concepts in the discipline
- Ability to conduct independent research
- Ability to use appropriate technologies
- Ability to work with others, especially in teams
- Ability to teach others

Although these are not strictly worded as learning outcomes (beginning with action verbs), they still allow readers to begin to understand common outcomes for graduate education. Broadly speaking, experiences such as dissertation research and teaching assistantships are well-aligned to promote these skills. Similarly, public dissertation defenses and teaching evaluations provide valuable evidence that these outcomes are achieved.

While there are some clear parallels that encourage engineering faculty members to transfer their knowledge of assessment from the undergraduate to the graduate level, other specific characteristics of the graduate context demand adaptation. Hoey (2008) explains that individualized training during research phases, small program sizes, learning outcomes at a higher level of thinking, and the increasingly interdisciplinary nature of programs serve to complicate assessment of graduate education. Systems such as individualized dissertation committees of expert faculty have evolved to fill these needs. Nonetheless, some standardization in data collection, coupled with a greater reliance on qualitative data, is possible and desirable. In a program that admits less than 10 students per year (such as the IGERT sites currently under study), statistical significance is not meaningful, and timely feedback on student and program success is necessary before ample quantitative data can be accumulated (Leydens, Moskal, and Pavelich, 2004).

C. Instructional Design Framework

In Understanding by Design, Wiggins and McTighe (2005) describe a conceptual framework for instructional design to support student learning such that it is more focused, measurable, and effective in an effort to improve student achievement. The “backward design” framework emphasizes a design process that begins with the identification of the desired results and then “works backwards” to develop assessment criteria and student learning experiences. The three main stages are to: (1) identify desired outcomes and results, (2) determine what constitutes acceptable evidence of competency in the outcomes and results (assessment), and (3) plan instructional strategies and learning experiences that bring students to these competency levels. While the following sections, including our Results, seem to treat these three components as relatively separate, an important benefit of following these steps is achieving what John Biggs (1999) terms “constructive alignment.” Alignment occurs when desired learning outcomes are communicated to students, and learning activities and assessment tasks are coordinated to achieve these outcomes.
The emphasis in stage one is to define the long-term goals and objectives that will create “enduring understanding beyond the classroom” (Wiggins and McTighe, 2005). As described in the previous section, these learning outcomes should be specific and measurable. They often start with action verbs: conduct research, collaborate with fellow students and faculty members, or teach technical concepts to others.

In stage two, faculty members decide in advance what evidence will demonstrate that learning outcomes have been achieved, such as comprehension and skill attainment. Wiggins and McTighe define three types of assessment evidence: performance tasks such as a real-world challenge in context, criterion referenced assessments such as quizzes and tests, and less formal unprompted assessment and self-assessment such as observations and dialogues. Certainly all of these types of evidence are also present in graduate courses. However, for the research phases of graduate education, Hoey (2008) also recommends using the artifacts students already produce, including seminar presentations, research proposals, and preliminary or qualifying exam responses as assessment evidence. Scoring rubrics can be developed to guide faculty in evaluating student artifacts, and to generate quantitative data (Leydens, Moskal, and Pavelich, 2004).

In stage three, instructors plan the learning activities and environments that will prepare students for summative assessments such as performance tasks and exams. Wiggins and McTighe (2005) and Biggs (1999) emphasize the importance of closely relating all three stages to each other in a coherent, consistent manner. In other words, learning outcomes should be well-defined, and all teaching and learning activities should support achievement of the learning outcomes. If they do not, faculty members should consider whether the activities are worthwhile, and if so, whether learning outcomes should be added to reflect these values.

III. METHODS

A. Setting

IGERT, the U.S. National Science Foundation’s $400 million investment in innovative graduate programs, includes in its stated purpose, “establishing innovative new models for graduate education and training in a fertile environment for collaborative research that transcends traditional disciplinary boundaries” (NSF, 2009). As such, it is considered the premier source of innovation in interdisciplinary graduate education, across a range of U.S. institutions. A total of 97 colleges and universities have received IGERT funding (Van Hartesveldt and Giordan, 2009). Information on specific disciplinary graduate education, including seminar presentations, research proposals, and preliminary or qualifying exam responses as assessment evidence. Scoring rubrics can be developed to guide faculty in evaluating student artifacts, and to generate quantitative data (Leydens, Moskal, and Pavelich, 2004).

In the summer of 2008, one author contacted the past and present PIs of the 195 IGERT awards with start dates from 1999-2007 using the public NSF awards site to locate awards and contact information. Ultimately, 130 proposals were collected which included all of the sections necessary for our analysis. The proposals were formatted for use in NVivo qualitative analysis software. Because this is a document analysis, no human subjects clearance was required; however, the authors of the proposals were ensured the same level of anonymity as if this study was governed by our Institutional Research Board. For these ethical reasons, we did not pursue collection of additional proposals through the Freedom of Information Act or similar requests which could be viewed as aggressive or antagonistic.

B. Data Collection

For this broad survey across a large number of programs, we elected to analyze funded proposals for three important reasons. First, because the program began in 1998 and grants regularly run as long as five or six years, there are many more funded proposals available to analyze than final reports. Second, the format for final reports focuses on program-level assessment and management (Hrycyszyn, 2008) and does not necessarily capture all that investigators have learned about interdisciplinary learning outcomes from the experience. Third, faculty members have developed a culture of sharing funded proposals with others, and these were likely to have included as much or more detailed descriptions than we could have collected via surveys.

Nonetheless, there are some limitations to relying on proposals. We expect that as in any educational program, best practices evolve over time and therefore are not necessarily reflected in initial proposals. For example, in our work as evaluators of the Eiger IGERT at Virginia Tech, we have seen firsthand how an interdisciplinary course and the internship requirement have changed significantly. However, we note that the curriculum alignment we argue for in this article should take place at the very beginning (the proposal phase) to ensure an assessment loop that informs future changes with empirical evidence. Our results indicate this is lacking. Additionally, in exploring possible analyses of this data set, we considered the subset of renewal proposals for which we also had the original proposal (n = 12 sets) to focus on what is learned from running an IGERT. We found few changes to text describing the curriculum plan; most of the differences focused on the challenges of maintaining a high level of participation in interdisciplinary activities among students and faculty members involved in the site (e.g., as described in Morse, Nielsen-Pincus, Force, and Wulffhorst, 2007). That is, many of the managerial challenges of conducting interdisciplinary research in higher education institutions can overshadow concerns about graduate student learning, making good planning doubly important.

In the summer of 2008, one author contacted the past and present PIs of the 195 IGERT awards with start dates from 1999-2007 using the public NSF awards site to locate awards and contact information. Ultimately, 130 proposals were collected which included all of the sections necessary for our analysis. The proposals were formatted for use in NVivo qualitative analysis software. Because this is a document analysis, no human subjects clearance was required; however, the authors of the proposals were ensured the same level of anonymity as if this study was governed by our Institutional Research Board. For these ethical reasons, we did not pursue collection of additional proposals through the Freedom of Information Act or similar requests which could be viewed as aggressive or antagonistic.

C. Sample

Of the 130 proposals obtained, 12 were renewal proposals (additional 5 years of funding) for which the initial proposal was also obtained. Thus, the data represents 118 unique interdisciplinary graduate programs or “sites.” Throughout the results sections, numbers and percentages reflect the 118 unique sites to avoid overrepresentation. Within this sample, 24 percent of the proposals were from
private institutions. Due to the focus on graduate education, nearly all of the institutions fall into research or doctoral institution categories of Carnegie classifications. Figure 1 presents the distribution of the proposals by start date.

As proposals represent the collaborative effort of as many as 20 faculty members, categorizing them by discipline is virtually impossible. Based on award abstracts on nsf.gov, 74 percent (n = 87) of the proposals analyzed included engineering or computer science as one of the disciplines. The distribution of engineering disciplines in the proposals is shown in Figure 2. Engineering (in general) was listed more frequently than any specific sub-discipline. This is likely because proposers were emphasizing the diversity of disciplines, and engineering was one item on a long list.

D. Data Analysis

Content analysis (Leedy and Ormrod, 2004) of the qualitative textual data was performed, and quantitative measures (such as percentages of proposals that cited certain strategies) were also included, as appropriate, giving this study the benefit of a mixed-methods approach (Sandelowski, 2003). We employed constant comparative

Figure 1. Proposals analyzed by start date.

Figure 2. Distribution of engineering disciplines represented in this study.
method (Strauss and Corbin, 1998) to thoroughly and systematically analyze our data and arrive at conclusions. Based on the three stages for instructional design to support student learning identified by Wiggins and McTighe (2005), we worked together to create a list of codes that would capture the most important information related to desired outcomes, evidence, and learning experiences. This process included reading the proposals, then coding segments, and re-coding and grouping codes into clusters of similar topics. Weekly meetings between the researchers were used to discuss the findings, structure the data for presentation, and highlight key findings. Multiple investigators contributed to the triangulation of the data (Maxwell, 1998). The overall coding structure is reflected in Table 2 and in the headings and subheadings of the results section which follows.

IV. RESULTS

The results are presented and organized according to reflect the framework shown in Table 2.

A. Desired Outcomes

1) Technical Outcomes: The most frequently stated or implied student outcome in the proposals was development of technical skills specific to each site’s primary focus and interdisciplinary domain (n = 80, 73 percent). For example, some sites were focused on what was assumed to be an inherently interdisciplinary field such as biophotonics, and stated that the “program will provide students and faculty with a collection of scientific and engineering tools and the expertise necessary to perform biomedical research at the molecular, cellular, and tissue levels and the ability to perform research on bio-inspired photonic devices.” Another example of technical skills includes familiarity with a certain piece of equipment or a specific technique. One such proposal stated that in addition to basic knowledge of their discipline, students will also “acquire expertise in spatial data and methods of analysis. GPS readings, digitized maps, various coverages (e.g., hydrography, road networks), aerial photographs, and satellite images are central to core research in population, land use, and the environment.” Clearly, the nature of technical skills varies across interdisciplinary research areas, but most proposals identified particular skills, tools or methods specific to the domain. These domain-specific outcomes are certainly related to, but distinguishable from, multiple disciplinary perspectives, which are described in the following section.

2) Broad Perspective: A large number of proposals described some type of perspective broadening that students would experience in the interdisciplinary program. The proposals suggested several different ways this would be accomplished. Many (n = 59, 50 percent) stated that by earning a degree in one discipline, students would be able to better understand the other disciplines involved in the program, e.g., being able to do research “from a perspective well-grounded in a chosen discipline but with a broad understanding of scientific, engineering, and policy dimensions” or to train “Scientists with a strong disciplinary base but with training in both [natural and social science] perspectives.” Another way some proposals (n = 36, 30 percent) hoped to broaden students’ perspectives was by integrating knowledge from multiple disciplines and emphasizing systems thinking. One proposal would “require understanding a breadth of disciplines, including biology, computer science, statistics and mathematics, and how they can be integrated to solve specific research problems,” while another will offer students “training in systems-level engineering research.”

While some proposals emphasized various disciplinary perspectives, others (n = 28) listed different perspectives, which we refer to as transdisciplinary (see Table 1 for definition). Examples include: being “sensitive to the wider range of human diversity,” having “new perspectives on social impact and viability,” awareness of environmental and social responsibility and global issues, and “bridging the gap from science to policy.”

Only 14 proposals employed the analogy of boundary crossing, e.g., one site “will create a cadre of scientists capable of forging links between traditionally separate fields.” Even fewer programs suggested focusing students on a project to help them think beyond disciplinary boundaries and access the expertise necessary to solve complex problems. There was also limited reference to establishing common ground between students from different disciplinary degree programs, although this was one benefit frequently touted when student program requirements were described in the proposals (discussed in section IV.A.5).

3) Teamwork: The most clearly articulated interdisciplinary learning outcome was teamwork and/or collaboration (n = 48, 41 percent). Compared to the others, these outcomes were more often articulated through the use of action verbs. For example, under a heading of “Teamwork and Professionalism,” one proposal listed three specific outcomes: (1) “Understanding of group dynamics associated with leadership, membership, and peer-to-peer interactions,” (2) “Ability to listen, give, and receive feedback,” and (3) “Ability to set appropriate goals, milestones, and division of labor.” Other proposals listed “work efficiently in multidisciplinary teams” or “enable them to collaborate successfully and productively across traditional disciplinary boundaries” as goals for the students. Another decided that students’ “[r]esearch will be conducted in interdisciplinary teams. […] Working within a

Table 2. Final coding scheme and percentage of 118 sites (130 proposals minus 12 duplicates due to renewals) representing each code.
team, students will experience both the conflicts and the triumphs that come with interdisciplinary research.” This focus on teamwork is not surprising, given the emphasis on “team science” reflected in science and engineering practice, the literature (Stokols, et al., 2008), and engineering accreditation criteria.

4) Interdisciplinary Communication: Communication was identified as an important component of professional development in many proposals; however, only 28 (24 percent) associated these skills with interdisciplinary. For example, some stated that students would be able to “communicate technical challenges, ideas, and results to diverse audiences,” or communicate “across disciplines and with local communities, managers, and policy makers.” Similarly, some proposals stated that the program would develop students’ “communication skills in multiple disciplines” or help the students “acquire language skills to move comfortably across disciplinary boundaries.” Within the learning objectives, specific skills such as writing and presenting research were listed; however, interdisciplinary communication was just as often referenced when describing collaboration and teamwork. The most frequent allusion to interdisciplinary communication was describing the communication barrier that generally exists between different disciplines (e.g., Bromme, 2000; Salter and Hearn, 1996) and emphasizing that students will overcome that barrier. One proposal stated, “As disciplinary language is often a barrier to collaboration and understanding, Fellows will learn to ‘speak one another’s languages’ by studying the approaches, methods, terminology, and questions of other disciplines.” It is clear from comments like these that the proposals frequently combined the four outcomes we identified, and closely related interdisciplinary communication to teamwork and collaboration.

5) Interdisciplinary Environment: One program-level goal not directly focused on students is also worth mentioning. When describing the program broadly, several proposals (n = 57, 48 percent) listed the goal of creating an interdisciplinary environment for students. Examples include “use active collaboration across disciplines to create an educational environment in which students can work comfortably in all three fields (biology, physical science, and engineering) as well as gracefully span the interfaces between them,” and to offer “uniquely rich environments for interdisciplinary team investigations […] creating] a community of research rather than fiefdoms.”

Creating an interdisciplinary environment for learning is important for two reasons. First, it allows for interactions between disciplines (Newswander and Borrego, 2009). Interdisciplinary education lends itself well to a sociocultural perspective on learning that takes into account the environment for learning as well as social interactions as a source of learning (Nardi, 1996), e.g., when graduate students help each other in a research lab. Second, specific to this proposal analysis, it is indicative of an indirect approach to interdisciplinary education of graduate students. In many cases, the proposals focused more on the environment than on specific learning objectives. Instead of setting the goal of having students learn to communicate informally with members of another discipline, for example, they create an environment and assume that student learning and development will inevitably follow. In other words, professors will work hard to develop an environment for students to take advantage of, but they may not work directly to help students navigate this space. We believe this is an underlying assumption of the proposals we analyzed, and that more direct emphasis on student outcomes would help focus efforts and ensure student outcomes are actually met.

B. Evidence

The second stage of “backwards” curriculum design is evidence that the desired outcomes have been met. Each proposal contained a section on program evaluation, as required by the request for proposals. However, only 31 percent (n = 37) of these assessment sections directly mentioned evaluating how well the students learned interdisciplinary or other skills. As Hoey (2008) predicted for graduate programs, many of the assessment plans were based more on student qualifications and throughput associated with program-level evaluation rather than student learning. Examples of these primarily quantitative measures include: student GPAs, number/percentage of students from underrepresented groups, number of students in attendance at activities, and student placement in academic positions. There were also additional interdisciplinary research productivity measures such as coauthored articles, conference papers/presentations, and proposals, particularly those involving students and faculty members from different departments. Focusing evidence on program-level measures rather than student learning is not inherently problematic; it is the mismatch between stated goals—teamwork, communication, and broad perspectives—and evidence that by and large does not address student acquisition of these skills. These high-level measures are particularly important for the funding agency to report overall impact of a funding program. However, an important complement is direct evidence of student learning—and one that is being increasingly emphasized by funding agencies.

One of the proposals which did directly address student interdisciplinary skills stated:

We also value students’ progress in developing communication, teamwork, project management and mentoring skills. Qualitative assessment tools for these skills include annual evaluations by the research advisor, […] and Advisory Board members of presentations by the trainees at the Annual Symposium, and evaluations by the internship mentor(s) and undergraduate mentee(s). Assessments from the Annual Symposium are anonymized and shared with each trainee to help build their skills.

Examples of other common assessment methods include: surveys/questionnaires (of faculty members, graduate students, alumni, employers), focus groups and interviews (of students and faculty members), interdisciplinary course evaluations, teaching evaluations of graduate students, portfolios, and annual reviews of student progress, dissertation committee evaluations of doctoral research, and analysis of student laboratory notebooks/journals. Self-report items such as surveys and interviews are helpful in measuring attitudes toward interdisciplinary research. Many of the others, if used properly, can serve as direct measures of interdisciplinary research skills.

Many proposals included descriptions of which personnel were responsible for completing evaluations. Figure 3 shows the frequency with which these techniques were described in the proposals. The two most prominent were to hire an internal or external evaluation expert (n = 50) and/or to use an advisory board (primarily external) (n = 50). In general, “Assessment Experts” were faculty members or consultants with educational training in evaluation and assessment.
“External Advisory Boards” were technical experts in the interdisciplinary domain from industry, government or academia. Other means included using university resources such as the “Center for the Enhancement of Teaching and Learning” or the “Learning Technology Center” (similar to assessment experts but internal to the university) or to have an assessment sub-committee (a committee of faculty members within the program responsible for assessment) \( (n = 32) \). Enlisting the help of external experts is important, both to draw upon their expertise and to maintain objectivity towards program success. However, it is also important to assign someone internal to the program to ensure evidence is collected, analyzed, and distributed in a timely manner so that evidence can be used to improve student learning and the overall program.

C. Learning experiences

As required by the request for proposals, each proposal included an extensive education plan, which addresses the third component of our curriculum design framework. PIs were creative in designing a wide range of education, professional development, and outreach activities for graduate students. Terms such as “workshop,” “seminar,” “discussion group” and “project” were used frequently but with a variety of meanings. Thus, we coded specific items in the education plans according to the major learning outcomes identified in section IV.A, rather than by the frequently overlapping characteristics of these program components.

U.S. academics rely heavily upon coursework to provide interdisciplinary learning experiences for doctoral students in traditional disciplines, unlike their counterparts in other countries where graduate programs frequently do not include coursework (Nerad and Heggelund, 2008). The most popular strategy to achieve the learning outcomes in this data set was undoubtedly new course development \( (n = 94, 80 \text{ percent}) \). Most of these courses would be “team-taught” by an instructor team representing various disciplines. One proposal explained, “Courses will be developed and taught by faculty members from different departments; thus, they will be interdisciplinary.” In addition to new courses to be created, many proposals also required that students take already established courses outside their home discipline in order to understand basic content, ways of thinking, and methods in complementary discipline(s). An example from one proposal is that “biologists need[ed] to take two to three computer science courses.”

1) Broad perspective and interdisciplinary community: Building an interdisciplinary community and/or providing students with a common base of knowledge was described in 85 of the proposals. (In this section these two outcomes are combined because most proposals described them in ways that were difficult to separate.) There were many different activities planned to help achieve these related outcomes. Figure 4 includes major categories of program components described as building community. Coursework was the most popular activity; 39 programs described using coursework to build a community and establish a common based of knowledge. One proposal explained:

These breadth courses are intended to provide a solid foundation for our students in [Fuel Cell] fundamentals, systems, engineering, and entrepreneurship. The integrated sequence of courses is in development and care is being taken to provide students of diverse backgrounds with the tools they will need to grasp, work with, and expand upon the material learned in class.

The courses based on creating common knowledge within the interdisciplinary program were usually introductory courses covering the fundamentals of each of the disciplines participating in the program. This common knowledge also helped the students to better participate in out-of-class activities, such as seminars and research groups. The added side-effect of creating this shared knowledge is that the students then have an easier time forming a social network within the program. Many of the out-of-class activities were more focused on nurturing these social, communal bonds. One program stated that their off-campus retreat would bring “together the faculty and students in a mix of structured and unstructured exchanges, encouraging the informal familiarity and social interactions critical to effective integrative research.”
2) **Teamwork:** Teamwork was one of the most explicitly stated objectives in the proposals. Figure 5 lists the various activities associated with teamwork in the proposals. There was an equal number of references to the students working as a team in and out-of-class \((n = 41\) in each case). However, the descriptions of in-class activities were expressed more clearly with focused objectives and detailed team tasks. On the other hand, the out-of-class learning experiences offer an opportunity to create a more long-term interdisciplinary research project that would be more authentic preparation for eventual employment, particularly in the case of internships. Many of these were described only vaguely, through claims that students would be “trained to work in teams” or the activity would be “essential to building teams.”

*Teamwork was addressed in the course descriptions of 41 proposals. Frequently, teamwork was to be achieved through class team projects. The purpose of one team project is described here:*

> These tasks will be performed as a group effort to promote team interaction and to develop interdisciplinary skills. The goal is to get the group of students functioning as a team, with each student playing an integral role. At the same time, it is important that the students develop an appreciation for the skills that the other members of the team bring to the collaborative effort.

An example of one such project was for engineering and neuroscience students to “be given both the scientific question to be addressed and the experimental technique to address that question, and will be instructed to reach beyond that current technique to develop new or improved ways to measure important quantities.”

The same number of proposals \((n = 41\) addressed teamwork outside of coursework, frequently in the context of interdisciplinary research \((n = 19\). One proposal describes the approach:

> [I]t can give [students] research experience in an area complementary to their eventual dissertation research. The goal of the project is to bring together a small, interdisciplinary team of students with diverse experience, to complete a research project that exemplifies interactive digital media, such as an interactive art installation, a digital performance, or a mobile multimedia database application.

Finally, we note that while there were indeed a total of 62 sites that referenced teamwork and teambuilding in their education plans, only 43 of those associated the team or its task with interdisciplinary.

Depending on the nature of seminars, internships, workshops, and research projects, the actual extent of teamwork experience may be severely limited. For example, seminars would develop informal communications skills that are valuable in teamwork, but typically not direct experience working on a team. Similarly, some proposals explained that dissertation committees comprising faculty members from different disciplines would provide teamwork experiences for students. Unfortunately, it will rarely be the case in these students’ future careers that they will be working unaccompanied for multiple supervisors; we expect that they will be working toward a common goal with a team of peers or near-peers. When the learning experiences are not authentic to real-life practice, it is a case of poor alignment between desired outcomes and learning experiences.

3) **Interdisciplinary communication:** Closely linked to teamwork were the interdisciplinary skills to work with others, which were described in 73 (62 percent) of the proposals. Interdisciplinary communication skills were to be built primarily through presentations, written artifacts, and informal discussions across disciplines. Proposals reasoned that these presentations, papers, and discussions would occur in the presence of all students in the program (representing various disciplines) and would therefore be interdisciplinary.
However, the discussion skills to be developed in informal settings (as opposed to presentations or writing) were most often associated with interdisciplinarity. Seminars, for example, would afford students the opportunity “to practice communication in an interdisciplinary context” where “students from several different disciplines provide unique perspectives on selected issues.” (For a study of this phenomenon, see Anthony et al., 2007.) At other times, interdisciplinary discussion skills were closely aligned with other outcomes, such as common understanding enabling communication skills: “The goal... is the need to create a common language. [...] For students to work effectively at this interface requires the ability to speak both [biology and physical science] languages and to recognize the inherent importance and origin of each mother tongue.” Similarly, the few references to written interdisciplinary communication skills referred to reports of team projects. In the context of oral presentations, references to interdisciplinarity were oblique at best; class presentations would “force the students to synthesize their results and integrate them into a logical presentation,” while seminar presentations would provide “feedback from experts in different aspects of a problem while developing articulation and presentation skills.”

In addition to the implicit and explicit links of communication to interdisciplinarity, we also note experiences with undergraduates, K-12 students, or the public. Figure 6 illustrates the breakdown. Some proposals clarified “interdisciplinary communication” to mean both informal communications with other disciplines as well as the public. Public and outreach audiences may be in the same discipline as the graduate student, but they are not at the same educational level as the student, and the communication skills needed in this environment are similar to those required to communicate across disciplines.

As is evident in Figure 6, the number of sites describing interdisciplinary communication requirements (n = 73) is almost equal to the number of communication references that did not appear to relate to interdisciplinarity (n = 68). Examples of communication statements unrelated to interdisciplinarity include activities that would “develop professional and personal skills such as communication” or require students to “produce a conference quality paper.”

V. DISCUSSION

One hundred thirty funded interdisciplinary graduate program proposals were analyzed using a three-stage curriculum design framework. The results provide an overview of common values and practices in interdisciplinary engineering and science graduate programs. On the one hand, these results may not seem particularly profound. One form of validation of the findings is that the desired outcomes reflect the core values and daily experiences of engineers and scientists reading this article. On the other hand, technical outcomes were implied by less than three quarters of proposals, and teamwork was an outcome in less than half, so the results are by no means universal. We note that descriptions and definitions of outcomes such as broad perspective, teamwork, and interdisciplinary communication skills were pieced together by combining text from 130 proposals. Even then, the combined descriptions are not particularly meaningful. Indeed, deeper descriptions of teamwork and integration across disciplinary perspectives are found in the social science and humanities literature (e.g., Repko, 2008). However, to understand their relevance to engineering and science, empirical investigations must begin somewhere, and this work is an important first step.

However, our finding that “constructive alignment” (Biggs, 1999) between learning outcomes, assessment evidence and learning experiences is severely lacking in interdisciplinary graduate programs is noteworthy. While a handful of these proposals enumerated specific learning outcomes or what skills specific student activities would cultivate, most spoke in broad generalities that provide little guidance once the proposal is funded. We struggled with finding a suitable categorization scheme for educational components such as internships, courses, and seminars. In presenting these results using the same categories as the learning outcomes, we may have overemphasized alignment between learning outcomes and learning experiences. Strongest alignment was observed for activities to build interdisciplinary community. We argue that while this may be a necessary condition for interdisciplinary learning, it is by no means sufficient. Students’ ability to conduct research in teams is severely hindered if their training is restricted to course projects of
limited duration or indirect experiences such as organizing a dissertation committee of faculty members from different disciplines. Although dissertation committees comprised of faculty members from different departments were common in the proposals, there was little evidence that dissertation research would be explicitly evaluated for interdisciplinary integration. Rather, more serial or multidisciplinary evaluation for various aspects of the research meeting various disciplinary standards is more likely. Similarly, communication experiences emphasize presentation of results, rather than interpersonal negotiation and collaboration skills emphasized in the learning outcomes. The focus of assessment on program-level goals rather than providing evidence of student learning is particularly troubling. Very few of these programs had planned from the outset to collect the data that would tell them whether their students were actually becoming better interdisciplinary researchers.

These findings are not surprising given the technical focus of the faculty members who wrote the proposals, who themselves need to be leading researchers in interdisciplinary fields to have any hope of securing this highly competitive funding. Maintaining expertise and a reputation in two or more fields is challenging in itself; evaluation and curriculum design need not be an additional burden. In the spirit of improving interdisciplinary graduate education through collaboration, we offer the following recommendations.

VI. RECOMMENDATIONS

A. Define Clear Learning Objectives

As reiterated throughout this paper, clear learning objectives provide focus for designing assessments and learning experiences. They communicate values and goals to a broad range of stakeholders, including students, faculty members, advisory boards, administrators, and funding agency personnel. Biggs (1999) explains that since learning takes place inside students’ heads, they must take some responsibility for learning, and clearly defined objectives help them. Goals and objectives are also the first piece of information assessment/evaluation experts will request to assist them in developing an evaluation plan. While these experts can facilitate a discussion of outcomes, they cannot articulate them without significant input from technical content experts. Some examples of clear and measurable interdisciplinary learning outcomes drawn from our analysis include:

- Apply [tool or analysis method] to problems in [technical area]
- Describe the perspectives, methods and expertise that [disciplines] bring to [technical area]
- Identify important research problems in [technical area]
- Assemble a team of disciplinary experts to solve a specific problem in [technical area]
- Work with researchers trained in other disciplines to solve problems in [technical area]
- Teach undergraduates and the public about [technical area]
- Write professional reports and papers describing the results of their interdisciplinary research

B. Enlist Assessment/Evaluation Expertise

When developing a new interdisciplinary program, it is important to seek assistance with assessment/evaluation from multiple sources. We advocate a combination of the benefits identified in several proposals by utilizing both an external advisory board of technical experts and an assessment expert, usually with an education background. Meetings with external advisory boards of technical experts are analogous to graduate program reviews conducted for degree programs. External advisory boards have the expertise to assess if the program is technically sound. They will be able to evaluate whether or not the students are achieving the appropriate level of expertise and integration of their field(s) and as interdisciplinary scholars, and can otherwise assess the technical quality of their research. Advisory board members, however, are not experts on curriculum or course design and will probably not be able to directly help in these areas.

Experts in educational assessment, on the other hand, are more than capable of evaluating and improving the curriculum. This was summarized by Olds et al.

Neither measurement experts nor pre-college education researchers will necessarily know the content and constructs...
that are important to engineering education [or any particular educational context]; however they will know rigorous practices that are available for validating assessment instruments and constructing an appropriate educational research design (Olds, Moskal, and Miller, 2005, pp. 20-21).

They can, for example, develop rubrics, surveys, interview protocols and the like in consultation with technical faculty members. Assessment experts have direct experience collecting and analyzing student and faculty data in efficient, valid, and reliable ways. They have direct experience collecting data on people and their learning, an area where engineering and science academics may be uncomfortable (Leydens, Moskal, and Pavelich, 2004). Assessment experts with educational backgrounds also know how to mix quantitative and qualitative data for programs with a small number of participants (Olds, Moskal, and Miller, 2005). Leydens, Moskal, and Pavelich (2004) discuss qualitative methods for assessing courses as well as ways to establish trustworthiness (the equivalent of “rigor” in quantitative research) and analysis techniques for the various methods. Olds, Moskal, and Miller (2005) relate ABET criteria to learning objectives and discuss a variety of assessment methods. Additionally, assessment experts’ experience with assessment and curriculum design frameworks similar to the one used for this analysis will help focus and align the goals, program components, and assessment plan of any new interdisciplinary graduate program.

When working with a professional evaluator, it is important to balance objectivity with collaboration (Borrego, 2006). Funding agencies increasingly prefer an evaluator external to the program to obtain an unbiased review of program strengths and weaknesses. However, due to the integrated nature of curriculum design and assessment, it is also beneficial to involve evaluators early in the design process. Prior research on collaborations between engineering and education faculty has found that both parties are more satisfied and report higher productivity when they view the relationship as a learning experience rather than simply a contracted business arrangement (Borrego and NewsWander, 2008). To ensure that the relationship is mutually beneficial, a range of potential resources and benefits should be explored; in addition to financial resources, evaluators may be interested in access to research subjects, collaborations with a particular university or research center, and the opportunity to publish their results, particularly if they are also tenure track faculty members. Early and open communication about the mutual benefits of such a collaboration are key.

C. Constructively Align All Aspects of the Curriculum

Following “backward” curriculum design principles (Wiggins and McTighe, 2005), decisions about assessment evidence should be driven by the learning outcomes, and decisions about learning experiences should be guided by helping students develop the ability to provide this evidence. Constructive alignment (Biggs, 1999) means ensuring that all three stages support each other. This alignment might be demonstrated through a table with rows for each outcome and columns for assessment evidence and learning experiences, as in Richards-Kortum, Dailey, and Harris (2003) and Table 3. This visualization enables faculty members to communicate alignment to each other, to students, and to funding agencies. It can also aid in the curriculum design process; if one of the cells is empty, a component needs to be added. For example, in Table 3, the writing workshop is the only direct experience addressing the outcome of communicating research results and is therefore particularly important. Likewise, if a component (e.g., seminar) does not fit anywhere, faculty should consider whether the activities are worthwhile, and if so, whether learning outcomes should be added to reflect these values. (In the case of building an interdisciplinary community or network, the activity may address a program-level goal.)

We note that sometimes a single assessment instrument or learning experience can address multiple learning outcomes. For example, if managed properly, laboratory rotations can teach specific tools/analyses, expose students to other disciplinary perspectives, and provide teamwork experience. Student presentations or proposals might be evaluated for component technical abilities as well as integrative qualities and communication skills. As Hoey and others emphasize, the artifacts students already produce, including dissertation-related proposals and presentations, can and should be used as assessment evidence. Additionally, a brief scoring rubric could help focus faculty members on evaluating the interdisciplinary aspects of the work. Finally, communication skills were frequently addressed through extracurricular requirements rather than integrated into courses and research, which are the core of graduate education. It is important not to rely on coursework to achieve all outcomes, and at the same time not relegate professional skills to extracurricular activities. Communication in particular should be

<table>
<thead>
<tr>
<th>Learning Outcome</th>
<th>Assessment Evidence</th>
<th>Learning Experiences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apply [tool or analysis method] to problems in [technical area]</td>
<td>Course final project grade, dissertation committee and/or advisory board evaluation (rubric)</td>
<td>Laboratory or analysis course, dissertation research, internship, laboratory rotation</td>
</tr>
<tr>
<td>Describe the perspectives, methods and expertise that [disciplines] bring to [technical area]</td>
<td>Dissertation proposal—evaluated by advisor, committee or assessment expert (using a rubric)</td>
<td>Seminars, workshops, retreats, laboratory rotation, coursework, internship</td>
</tr>
<tr>
<td>Work with researchers trained in other disciplines to solve problems in [technical area]</td>
<td>Internship or laboratory supervisor evaluation (survey, rubric or interview), course project grade</td>
<td>Internship, project course, laboratory rotation</td>
</tr>
<tr>
<td>Write professional reports and papers describing the results of their interdisciplinary research</td>
<td>Productivity report of conferences and publications (which applies a simple definition of interdisciplinary work)</td>
<td>Writing workshop, informal mentoring and coauthorship</td>
</tr>
</tbody>
</table>

Table 3. Example of constructively aligned interdisciplinary graduate curriculum.
VII. Future Work

This work opens many potential avenues for future investigations. The results of this analysis, focused on graduate students, will also have relevance to undergraduate engineers. “An ability to function on multidisciplinary teams” has been an outcome for all engineering undergraduates since new criteria were piloted in 1996 by ABET (Prados, Peterson, and Lattuca, 2005). Similarly, The Institution of Engineers Australia (IEAust) values the “ability to function effectively as an individual and in multidisciplinary teams” (Nafalski, McDermott, and Göl, 2001, pp. T4A–23). Similar skills are valued in Europe and elsewhere (King, 2008; Patil and Codner, 2007). When Shuman, Besterfield-Sacre, and McGourty (2005) reviewed state-of-the-art practice in U.S. teaching and assessment of the multidisciplinary teamwork criterion, conspicuously absent from this discussion was any mention of the multidisciplinary aspect, precisely because there is limited research to guide interdisciplinary learning at the undergraduate level (recent contributions include Borrego, News wander, McNair, McGinnis, and Paretti, 2009; Borrego, News wand er, and McNair, 2007; Richter, 2008; Richter and Paretti, 2009; Richter, Paretti, McNair, and Borrego, 2009). Though a direct application of graduate results to undergraduate education may not be possible, this research can be adapted or tested in future work for generalizability to undergraduates.

While interdisciplinary training at the undergraduate level usually takes place in individual courses (at least in engineering), extensions may be made to unique interdisciplinary degree programs or research experiences for undergraduates (which has been identified as a recruiting best practice for IGERT interdisciplinary programs). The themes identified through analysis of the qualitative proposals now provide better structure for follow-up surveys or interviews with faculty members and graduate students involved in graduate and undergraduate interdisciplinary programs. The specific findings of this study can be further validated by applying them to current IGERT programs and new proposals and reporting on the process.

Teamwork was a very important component of interdisciplinaryity identified by the engineering and science academics who wrote these proposals. However, the tradition of single-author theses and dissertations and the rigid structure of disciplinary academic departments conspire against integrated interdisciplinary graduate education. The U.S. academics represented in this study relied heavily on coursework to accomplish the learning objectives. The rigid structure of departments forces both an operationalization of interdisciplinary work across departments, as well as a disincentive for interdisciplinary activities (particularly when advising students in another department is not allowed). We believe this is a major challenge for the future of graduate education. According to a report published by NSF IGERT program officers, one recommendation for future interdisciplinary graduate education is to develop mechanisms to “support teamwork in graduate education and in thesis topic research.” To aid in the advancement of this recommendation, an important direction for future work would be to examine the disconnect between team values and individual dissertation work, and to highlight creative solutions. Examples include the “[g]radient schools at the University of Idaho and the University of Minnesota [which] allow students to include chapters that are co-authored by multiple students, i.e., the same chapter is used in multiple dissertations.” (Van Hartevelt and Giordan, 2009).

Finally, some readers might question to what extent our findings are unique to interdisciplinary settings. Few engineering and science faculty members would say they do not want their graduate students to have a broad perspective of their research area, collaborate with other researchers, and communicate their results to the broadest audience possible. However, it is politically incorrect to insist that all graduate students should receive interdisciplinary training—present, this opportunity is limited to willing accomplices. If interdisciplinarity is viewed as a special case of the types of diverse experiences and skills desired for all students, then these findings might eventually have much broader implications. For example, Downey et al. (2006) define global competence, or working effectively with different cultures, as “learning to work with people who define problems differently than oneself.” While specific international experiences can expose students to different cultures, the important outcomes of the training, they argue, are (1) foundational knowledge about differences across cultures, (2) the ability to integrate or translate across these, and a (3) predisposition or attitude that the integration is worthwhile. Interdisciplinary work is described as requiring similar cross-cultural competence (Reich and Reich, 2006). These outcomes parallel the way some researchers assess interdisciplinarity. For example, Boix Mansilla et al. (2007; 2009) describe a framework for assessment of interdisciplinary work that features (1) foundational knowledge of constituent disciplines, (2) integration to develop a synthesized product, and (3) reflection on the integration process itself. Others (Borrego and News w ander, 2008) have identified a positive attitude toward learning from collaborators as indicative of successful interdisciplinary collaboration. While some changes in the rhetoric are evident, empirical studies linking or broadening previous definitions could accelerate this movement as well.

VIII. Acknowledgments

The authors wish to thank the U.S. National Science Foundation for supporting this work through grant number EEC-0643107. The views expressed in this paper are those of the authors and do not necessarily represent those of the National Science Foundation. We are also grateful to IGERT PIs for sharing their successful proposals, Veronica Arroyave and Lynita News w ander for initial data analysis, and anonymous AAEE and JEE reviewers for constructive feedback.

REFERENCES


King, R. 2008. Addressing the supply and quality of engineering graduate for the new century. Sydney, Australia: Carrick Institute for Learning and Teaching in Higher Education.


Maura Borrego is an associate professor and director of the Graduate Program in the Department of Engineering Education at Virginia Tech. She is also the evaluator for the EIGER IGERT at Virginia Tech. She holds U.S. NSF CAREER and Presidential Early Career Award for Scientists and Engineers (PECASE) awards for her engineering education research. Her research interests include interdisciplinary graduate education. She teaches graduate level courses in engineering education research methods and assessment. All of Dr. Borrego’s degrees are in Materials Science and Engineering, M.S. and Ph.D. from Stanford University, and B.S. from University of Wisconsin-Madison.

Address: Engineering Education (0218), Blacksburg, VA 24061; telephone: (+1) 540.231.9536; e-mail: mborrego@vt.edu.

Stephanie Cutler is a first year engineering education Ph.D. student at Virginia Tech and an NSF IGERT fellow through VT’s EIGER program. She is also working towards her Master’s degree in Industrial and Systems Engineering. Her undergraduate degree is in Mechanical Engineering from Virginia Commonwealth University in Richmond, VA. Her research interests include interdisciplinary education and student learning assessment.

Address: Engineering Education (0218), Blacksburg, VA 24061; telephone: (+1) 540.231.6555; e-mail: cutlersl@vt.edu.
Copyright of Journal of Engineering Education is the property of ASEE and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.