Crossing Disciplinary Borders: A New Approach to Preparing Students for Interdisciplinary Research

Kathryne M. Drezek, Deborah Olsen, and Maura Borrego
kmdrezek@vt.edu, dolsen@vt.edu, mborrego@vt.edu

Abstract – This paper presents a research-based developmental model to aid faculty in developing interdisciplinary graduate curricula. The model progresses from the recognition of disciplinary boundaries to the integration of multiple disciplinary approaches, and finally to a meta-cognitive stage in which graduate students were able to self-consciously reflect on the knowledge construction process within and outside of engineering. The model was developed using assessment data from student and faculty interviews, surveys and productivity reporting. Analysis was grounded in the qualitative methodologies of the social sciences. The setting is the EIGER program at Virginia Tech, which aims to reshape the graduate experience for engineers by complementing traditional discipline-based study with a program explicitly designed to foster in students the interdisciplinary and team-based knowledge and skills that are fundamental to successful collaboration. The findings of this study may have significant implications for efforts to reshaping and enhance graduate engineering curricula.

Index Terms - Interdisciplinary research, graduate training, IGERT program

INTRODUCTION

In the last decade, the National Research Council, NSF, and various foundations sponsored large-scale studies of doctoral education [1]. In its most recent report, the Council of Graduate Schools argued that American economic competitiveness will be dependent upon “workers who exhibit not just the mastery of a subject area, but the creative ability and drive to reshape the boundaries of knowledge”. The Council views “interdisciplinary research preparation and education” as “central to future competitiveness” [2]. This is a particularly salient issue in engineering education: according to a workshop report for the NSF, problems in infrastructure development are only 5% technical; the remaining 95% involves addressing the range of issues inherent to working in teams of diverse professionals [3]. That said, interdisciplinarity, though increasingly popular in and beyond the academy, is not well understood as an educational phenomenon, as social scientists have not yet “fully elucidat(ed) the complex social and intellectual processes” involved in interdisciplinary scholarship [4].

The purpose of this paper is to present a research-based developmental model to aid faculty in developing interdisciplinary graduate curricula. The model progresses from the recognition of disciplinary boundaries to the integration of multiple disciplinary approaches, and finally to a meta-cognitive stage in which graduate students were able to self-consciously reflect on the knowledge construction process within and outside of science and engineering. The model was developed using assessment data from student and faculty interviews, surveys and reports on student productivity. Analysis was grounded in the qualitative methodologies of the social sciences. The setting is the EIGER (Exploring Interfaces through Graduate Education and Research) program at Virginia Tech, which aims to reshape the graduate experience for engineers by complementing traditional discipline-based study with a program explicitly designed to foster in students interdisciplinary and team-based knowledge and skills. The EIGER program studied here is funded by the NSF’s Interdisciplinary Graduate Education and Research Training, or IGERT, program. The goal of this paper is to begin to clarify the educational value of interventions like the EIGER that are designed to explicitly promote interdisciplinary understanding in graduate students in the sciences and engineering.

DISCIPLINARY VERSUS INTERDISCIPLINARY UNDERSTANDING

I. Disciplinarity

Disciplines represent the “specialized scientific exploration of a given homogenous subject matter producing new knowledge and making obsolete old knowledge” [5]. Klein defined disciplinarity as “tools, methods, procedures, exempla, concepts, and theories that account coherently for a set of objects or subjects” [7].

Broadly speaking, disciplinary understanding is marked by an individual’s mastery of a specific body of knowledge characterized by a reasonably logical taxonomy, a specialized vocabulary, an accepted body of theory, a systematic research strategy, and techniques for replication and validation [8]. The development of disciplinary competence begins with the selection of a major course of study at the undergraduate level. However, it is at the graduate level, and more specifically within doctoral study, that this competence is characterized by increasingly sophisticated expertise in the discipline’s knowledge
construction process. As doctoral students learn to think like an engineer, a chemist, or a psychologist, they adopt their discipline’s epistemology, their discipline’s “theory of knowledge, its methods and validations” [9].

Donald examined the knowledge construction process across disciplines. For example, she contrasted the “orderly thinking” [10] of physicists with their emphasis on coherence with the “hard thinking” [11] of engineers, which required the application of structured knowledge to unstructured or ill-structured problems. She concluded that individuals learn different ways of making meaning and articulating that meaning “depending on their decision to concentrate on one discipline rather than another” [12].

II. Interdisciplinarity

Since the first seminal report on interdisciplinarity was published in the early 1970s [13], interdisciplinary research has been defined rather broadly in order to accommodate the diversity of activities that scholars associate with it. Most recently, the National Research Council offered a “point of departure” for future debate, defining interdisciplinarity as:

>a mode of research by teams or individuals that integrated information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field or research practice” [14].

The integration of different disciplinary tools, methods, theories, or paradigms is key to most definitions of interdisciplinary research. Significantly, most theories describing various types of interdisciplinarity place activities on a continuum based on the degree to which research activities achieve disciplinary integration [5], [15]-[18]. Most assessments of interdisciplinary work have associated “quality work with greater integration” [13], and have followed this model in a fairly linear fashion.

II. Interdisciplinary Understanding as a Learning Outcome

Few studies explore the student learning implications of interdisciplinary training experiences [19]-[20]. Boix Mansilla and Duraising’s [21] work is an exception, and provides the basis for the learning framework employed in this study. Their rubric, based on in-depth interviews with interdisciplinary experts, described key features of interdisciplinary understanding, which was defined as “the capacity to integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement...that would have been impossible or unlikely through single disciplinary means” [22].

The framework consisted of three core dimensions: (a) disciplinary grounding, the degree to which student work is grounded in carefully selected and adequately employed disciplinary insights; (b) integration, the degree to which disciplinary insights are clearly integrated so as to advance student understanding; and (c) critical awareness, the degree to which the work exhibits a clear sense of purpose, reflectiveness, and self-critique [21]. The final stage moves us beyond integration; it represents the attainment of a level of self-consciousness about the knowledge construction process. So defined, the rubric provides a useful mechanism by which we can begin to parse out evidence of specific changes in students’ thinking about the nature of scientific knowledge and inquiry.

Boix Mansilla and Duraising’s framework for interdisciplinary understanding is significant because it allows for the conceptualization of disciplinary and interdisciplinary approaches as potentially complementary strategies characterized by a productive tension [23-24]. Disciplinary expertise is valued as a necessary component for achieving interdisciplinary understanding. This grounding must occur not only within one’s “home” discipline, but must also include sufficient experience and skill within the vocabulary, tools, methods, concepts, and paradigms of a second discipline before appropriate and effective integration can be achieved. As such, this framework is well-suited to evaluating the educational value of a program like the EIGER, which is designed to augment, not supplant, traditional doctoral study in the sciences and engineering.

THE EIGER PROGRAM

Despite manifest need to address increasingly interdisciplinary research questions, most scholars admit that they received no training in this area, and that their interdisciplinary knowledge and skills developed through chance encounters and fortuitous exchanges with colleagues. Virginia Tech’s EIGER program was designed to fill this gap by providing doctoral students in engineering, the “hard” sciences, and social sciences with purposeful training that would develop their interdisciplinary knowledge and skills. Funded as part of NSF’s “furiously interdisciplinary” [25] IGERT program, the EIGER combines interdisciplinary science with practical experience derived from a combination of academic coursework, research, and internships. Named after the world-famous peak in the Swiss Alps, the EIGER program provides three separate courses to: (1) teach interdisciplinary knowledge and skills; (2) develop the team-based skills fundamental to successful collaboration and (3) model interdisciplinary treatment of a thematic research area i.e., interface science. Coursework is complemented by co-curricular activities on-campus (speakers’ series, brown bag luncheons, etc.) and by the intensive training received during internships at international locations. This paper will focus exclusively on the assessment of education and training efforts of the EIGER program, specifically the impact of the program on the development of students’ interdisciplinary understanding.
**METHODOLOGY**

I. Data Sources

Data sources for this study included semi-structured, one-on-one interviews, both closed and open-ended survey questionnaires, and student evaluations of the program’s core course on interdisciplinary research. Course-based assignments were reviewed for further evidence of interdisciplinary understanding. Data was categorized as evidence of (a) attitudinal openness to interdisciplinary research; (b) evidence of the development of interdisciplinary ability or behaviors; and (c) epistemological beliefs signaling interdisciplinary understanding.

II. Sample

Participating students came from the sciences, engineering, and social sciences. The sample included all students participating in the EIGER program during the 2005-2006 (n=9) and 2006-2007 (n=14) academic years. The sample from 2006-2007 included both new and returning EIGER students; all students from year one persisted to year two. Additionally, with an eye toward theory construction [26], a non-traditional “comparison” group of students was developed; students were matched to participating EIGER students based upon interest in and experience with interdisciplinary, disciplinary home, and lab environment. This sample of non-EIGER graduate students (n=7) was included to offer potential points of contrast and comparison. The comparison group participated in both the semi-structured interviews as well as survey questionnaires regarding levels of interdisciplinary interest, knowledge, skill, and activity. They did not complete either the course evaluation or course-based assignments, as they were not enrolled in the EIGER program’s core courses.

III. Conceptual Framework

The EIGER program was developed based on general principles gleaned from current scientific and educational literature on interdisciplinarity as well as the goals of the IGERT program. Beyond the mastery of our interdisciplinary research course content and evidence of students’ ability to integrate different disciplines in a cohesive and productive manner specific learning outcomes related to changes in students’ thinking or knowledge construction process were not articulated initially. As a result, the researchers examined student response to the EIGER program using grounded theory which allowed for the exploration of the largely uncharted waters ahead [27]-[29].

Grounded theory provided “systematic, yet flexible guidelines for collecting and analyzing qualitative data” [29]. In line with the principles of grounded theory, the researchers: (a) engaged in simultaneous data collection and analysis; (b) constructed codes and categories from the data, not from preconceived hypotheses; (c) employed the constant comparative method, making comparisons at each stage of the analysis of the EIGER program, (d) made notes and wrote memos to further refine the categories and identify gaps in the data; and (e) developed the literature review after an independent analysis of the data [26]-[28]. Themes related to attitudinal, ability/behavioral, and epistemological changes in participating students emerged. For purposes of this paper, the researchers will briefly provide evidence related to students’ attitudes and behaviors, and then focus on issues related to the knowledge construction process in interdisciplinary training, which provides the infrastructure for the developmental model of interdisciplinary understanding. Students’ epistemic beliefs were operationalized as how students view the construction of knowledge and the nature of scholarship as it resides in, as well as transcends, their home disciplines [9]. In other words, the researchers looked for evidence of students’ habits of mind, which “include not only disciplinary content, but also styles of thinking, styles of presenting, and styles of questioning” [30]. It is important to note that subsequent to our coding, the researchers encountered Boix Mansilla and Duraising’s framework of interdisciplinary understanding, and that was used to further refine the analyses.

**RESULTS**

I. Attitudes toward Interdisciplinarity

Data on students’ attitudes toward interdisciplinarity came primarily from self-reported data on course evaluations. Students were asked to rate the level of agreement with statements related to their experiences within the interdisciplinary course on a five-point Likert scale (1=Strongly Disagree to 5=Strongly Agree). Generally, students credited their EIGER experience with enhancing their interdisciplinary perspectives. Table I presents a summary of students’ mean responses to attitudinal items. Significantly, when asked how likely they were to pursue interdisciplinary research in the future, 10 of the 13 EIGERS who responded to this question indicated that they were “very likely” to do so, as compared to only two of the seven non-EIGER comparison group students.
II. Interdisciplinary Abilities and Behaviors

Students indicated that the EIGER program enhanced their ability to engage in interdisciplinary research, as well as impacted the likelihood that they will participate in interdisciplinary behaviors and activities. Table II summarizes students’ mean responses to items regarding interdisciplinary abilities and behaviors. Furthermore, within the first two years of the EIGER training program, students attended 26 interdisciplinary conferences; delivered 24 interdisciplinary conference presentations, poster presentations, and/or invited talks; and authored or co-authored 15 interdisciplinary papers.

III. Changes in Epistemic Beliefs: A Developmental Model for Achieving Interdisciplinary Understanding

While self-reported data regarding changes in students’ attitudes, abilities, and behaviors was important, particularly in the formative assessment of core components of the EIGER program, the researchers were most concerned with identifying, documenting, and evaluating changes in students’ thinking as a result of participation in the program.

Funding agencies like NSF are often most interested in concrete, tangible interdisciplinary outcomes, such as numbers of interdisciplinary grants written/awarded; number of interdisciplinary conferences attended; or number of interdisciplinary papers published. While such outcomes provide significant evidence of interdisciplinary achievements, this paper contends that the development of appropriate epistemic beliefs – i.e., a framework by which students can begin to consciously navigate the knowledge construction process both within their home discipline as well as within other disciplines – is a necessary antecedent to engaging in meaningful interdisciplinary research. Figure I provides an illustration of the model.

![Figure I: Developmental Model for Achieving Interdisciplinary Understanding](image-url)

In alignment with the data gathered from the course evaluations regarding EIGER students’ interdisciplinary attitudes, abilities, and behaviors, our initial coding of the first- and second-year interviews revealed that EIGER students – as well as their non-EIGER peers – exhibited a general openness to interdisciplinarity and engaged in a range of behaviors and activities that could be characterized as interdisciplinary in nature. That said, closer reading of

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>MEAN STUDENT RESPONSES TO ATTITUDINAL ITEMS (5 = STRONGLY AGREE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items</td>
<td>Mean</td>
</tr>
<tr>
<td>I was stimulated to discuss course-related topics outside of class.</td>
<td>4.33</td>
</tr>
<tr>
<td>As a result of this course, my interest and curiosity about interdisciplinary issues and questions in science has grown.</td>
<td>3.44</td>
</tr>
<tr>
<td>Interaction with other students in the course encouraged me to think about my research in new ways.</td>
<td>3.00</td>
</tr>
<tr>
<td>Students’ attitudes and values varied more than in other courses I have taken.</td>
<td>3.78</td>
</tr>
<tr>
<td>As a result of this course, I am more fair-minded in interpreting, analyzing, and evaluating alternative points of view.</td>
<td>3.44</td>
</tr>
<tr>
<td>In the future, I will be much more inclined to collaborate with individuals outside my field on research issues.</td>
<td>4.00</td>
</tr>
<tr>
<td>This course has ensured my enduring interest in interdisciplinary research.</td>
<td>3.67</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE II</th>
<th>MEAN STUDENT RESPONSES TO ABILITY/BEHAVIORAL ITEMS (5 = STRONGLY AGREE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items</td>
<td>Mean</td>
</tr>
<tr>
<td>In this course, I learned to better evaluate the quality of the arguments and positions of researchers in other disciplines.</td>
<td>4.00</td>
</tr>
<tr>
<td>Exposure to interdisciplinary topics in this course has increased my appreciation for the methods and accomplishments of my own discipline.</td>
<td>3.78</td>
</tr>
<tr>
<td>As a result of this course, I am better able to access and apply information from outside my own discipline.</td>
<td>3.44</td>
</tr>
<tr>
<td>I developed the ability to identify problems from the vantage points of other disciplines.</td>
<td>3.56</td>
</tr>
<tr>
<td>Because of this course, I plan to integrate different disciplinary techniques into my research.</td>
<td>3.22</td>
</tr>
<tr>
<td>Because of this course, I plan to integrate different disciplinary concepts into my research.</td>
<td>3.56</td>
</tr>
</tbody>
</table>
the interview transcripts suggested that EIGER students’ thinking about research and scholarship tended to change more than comparison students over the course of the two years of the program. As such, it was decided that a more targeted consideration of how doctoral students viewed and constructed knowledge within an interdisciplinary context was required. As discussed, the themes grounded in the initial coding resonated with Boix Mansilla and Duraisingh’s framework. Ultimately, what was heard in student interviews, particularly comparing second year interviews to first-year interviews for each student, was an intellectual evolution proceeding through three developmental stages.

Stage I. Both EIGER participants and nonparticipants demonstrated a baseline confidence in their disciplinary expertise, viewing interdisciplinarity as an extension of the traditional disciplines. As exposure to interdisciplinarity increased, EIGER students began to identify levels of disciplinary differentiation, as demonstrated by one student’s comment on variation in units of analysis and their epistemological significance: “Engineering is on a bigger scale. In geosciences you look at things on a smaller scale. With these…courses you get a more complete picture…it’s important to do this especially when you are getting a Ph.D. You get so focused you get lost in the details of your work.”

Others commented on the phenomenon of becoming cognizant of the limitations of their own knowledge base. An engineering student remarked: “When I was in…courses with scientists…I realized how little science I know. The scientists definitely go more in-depth.”

Students also appeared to develop an appreciation not only for other disciplinary bodies of information, but also for their “theory of knowledge, (their) methods, and validation” [9], a necessary step to developing “interdisciplinary competence” [31].

Stage II. Across the board, students perceived integration – the second phase of the model - as a necessary component of interdisciplinary work. Most first-year students spoke in terms of methodological integration. One saw interdisciplinary research as a way to “broaden” his expertise by learning specific methods and techniques, while another described it as a means to an end. A third student saw the EIGER as providing “access to equipment” and specific laboratory training.

By the second year, however, a number of EIGER students and, to a lesser degree, a few comparison group students expressed a more sophisticated notion of integration. As one student commented: “by really learning and understanding someone else’s research and bringing your own knowledge to it – new questions, new skills and the ability to solve problems develop”, and interdisciplinarity is no longer simply a “division of labor.”

Commenting on her experience working with geoscientists, one engineering student stated:

“Engineers tend to tackle problems with equations and with a quantitative approach.

Geoscientists investigate the same problems more qualitatively. They look at physics and nature. They ask why things are happening and not just the equation. It has helped me to use both approaches.”

For these students, integration was no longer simply a process of adding new techniques and new tools to old ways of thinking. Instead, the integration of new theories or new conceptual perspectives began to qualitatively change students’ thinking, which may not necessarily occur through methodological borrowing alone.

Stage III. The greatest developmental distinction could be made between second-year EIGER students and their first-year EIGER as well as their non-EIGER peers. There was substantial difference in the degree to which second-year EIGER and other students were able to self-consciously reflect on the knowledge construction process within and outside their disciplines. New disciplines offered not only more information and new methods but new ways of thinking about research questions and even a new set of problems, never before considered. Students implicitly began to understand that problems are in fact constructed by researchers, not found in nature [32]. Many of the students commented that in the press of courses and research, intellectual horizon tends to shrink and one can become mired in the details of his or her work. As one student put it, “You can go through your entire doctoral career and never once think out of the box.” The EIGER program offered a time and space for thinking out of the box, refocusing on the “big picture,” and considering new alternatives.

Finally, students began to realize the costs attendant to this more complex form of research and began to calibrate when it was appropriate and when not, recognizing the need to be purposeful [33]. As one student concluded after engaging in several successful interdisciplinary initiatives:

“People should not do interdisciplinary research without a really worthwhile interdisciplinary research topic. It can take too many precious resources. I read journals outside my field now first, to see if I can solve the problem by myself. [You] should be selective in finding a collaborator from another discipline…you both need to be interested in carrying it out. Before launching, spend some time assessing [the] feasibility of it.”

CONCLUSION

The results of the study support the work of the EIGER program and suggest that a graduate learning environment that systematically promotes interdisciplinary scholarship contributes to doctoral students’ interdisciplinary understanding. Whereas most students entering the program identified themselves as being interdisciplinary scholars already, exposure to scholarship outside their disciplinary homes aided in the development of attitudes, abilities, behaviors, and epistemic beliefs that would enable them to engage more effectively in interdisciplinary research. Students spoke of evolving habits of mind that signaled...
changes in students’ views and construction of knowledge. This study supports the view that educational interventions like the IGERT program that supplement traditional doctoral study with explicitly interdisciplinary experiences represent an effective compromise in reforming doctoral education.

ACKNOWLEDGMENT

This study was supported by the NSF IGERT program.

REFERENCES


[29] Charmaz, 2006, p. 2


AUTHOR INFORMATION

Kathryne M. Drezek, Doctoral Candidate, Educational Psychology, Virginia Polytechnic Institute and State University, kmdrezek@vt.edu.

Deborah Olsen, Associate Professor, Educational Psychology, Virginia Polytechnic Institute and State University, dolsen@vt.edu.

Maura Borrego, Assistant Professor, Engineering Education, Virginia Polytechnic Institute and State University, mborrego@vt.edu