Catalyzing Multidisciplinary Research through Innovative Multidisciplinary Graduate Education

Scott F. Midkiff, George E. Morgan, C. Patrick Koelling, Sheryl B. Ball, Ingrid E. Burbey, Mary Jo Zukoski, David Maldonado Febus
Virginia Tech
Blacksburg, Virginia 24061 USA
{midkiff, gmorgan, koelling, sball, iburbey, mzikoski, davidm} @ vt.edu

Abstract - Virginia Tech created the Integrated Research and Education in Advanced Networking program with support from the National Science Foundation. Two important goals of the program are to prepare Ph.D. graduates to work more effectively in multidisciplinary teams and encourage multidisciplinary research and education in networking. Achieving these goals involves a change in philosophy and culture related to graduate studies and research, as well as specific educational experiences to provide students with the knowledge and skills needed to work across disciplinary boundaries and to effectively communicate with diverse audiences. The educational experiences include new multidisciplinary courses and workshops. We present an overview of the program and describe the courses and workshops. We also present and discuss results from a survey of students and faculty on the effectiveness of the program and its components.

Index Terms – Multidisciplinary research, Multidisciplinary graduate education, Entrepreneurship, Simulation and optimization, Networking education.

INTRODUCTION

With support from the U.S. National Science Foundation's (NSF's) Integrative Graduate Education and Research Training (IGERT) program, Virginia Tech created the Integrated Research and Education in Advanced Networking (IREAN) program. The goals of the program include: (1) preparing Ph.D. graduates to work more effectively in multidisciplinary teams that are increasingly common in industry and academia; and (2) encouraging multidisciplinary research and education in networking. Achieving these goals involves a change in philosophy and culture related to graduate studies and research, as well as specific formal educational experiences.

Within the IREAN program, we created two multidisciplinary courses and several workshops. We require these of IREAN Fellows (funded Ph.D. students) and make them available to other students. We also hold workshops on oral and written communication and an annual research workshop. This paper focuses on these educational experiences which intend to provide students with the knowledge and skills needed to work across disciplinary boundaries and to effectively communicate with diverse audiences.

To evaluate the program’s effectiveness, we conducted a summative survey of current and former students and faculty associated with the IREAN program to determine how the different program components and the overall program have contributed to students’ ability to work in multidisciplinary teams and affected students’ perceptions of multidisciplinary research and education.

We first provide a brief overview of the IREAN program and its objectives. The following two sections then describe the courses and workshops that comprise the formal component of our strategy for enabling and catalyzing multidisciplinary research. We then present student and faculty perspectives on the effectiveness of the program with respect to multidisciplinary education and research. The final section offers conclusions.

OVERVIEW OF THE IREAN PROGRAM

The IREAN program enables faculty and Ph.D. students from four programs in the College of Engineering (Computer Engineering, Computer Science, Electrical Engineering, and Industrial and Systems Engineering), one program in the College of Science (Economics), and the Pamplin College of Business to work on multidisciplinary education and research in networking. Faculty and students are located at Virginia Tech’s campuses in Blacksburg, VA and northern Virginia.

The IREAN program seeks to graduate Ph.D. students with: (1) strong research ability and in depth knowledge in an aspect of advanced networking; (2) the ability to integrate technical, business, regulatory, and global issues; (3) the ability to work effectively in distributed, culturally diverse, multidisciplinary teams; (4) the ability to communicate effectively and to be effective teachers as well as learners; and (5) the ability to cope with ethical dilemmas and conduct themselves in an ethical and professional manner. Multiple implementation strategies are being applied. Two strategies are particularly relevant to the goals of multidisciplinary research and education [1].

1. Creating a research program focused on overcoming barriers to achieving a vision of the future Internet – This research agenda, as first proposed, is overly broad. Over time, more specific thrust areas have emerged, but all provide opportunities for multidisciplinary research.

San Juan, PR

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R4C-17

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2. Revising existing and creating new for credit courses and non-credit workshops – The new courses and workshops provide the foundation for multidisciplinary research and, also, lay the foundation for the desired student attributes.

MULTIDISCIPLINARY CLASSES

We created two new multidisciplinary courses, “Commercializing Technology for Advanced Networks” and “Optimization and Simulation in Networks and Telecommunications.” We describe these two courses below.

I. Commercializing Technologies

The “Commercializing Technology for Advanced Networks” course was offered in Spring 2003 and Spring 2005. The course was team-taught by Sheryl Ball from the Department of Economics and George Morgan of the Department of Finance.

A. Overview and objectives

The IREAN program seeks to increase the entrepreneurial business skills of engineering graduate students, especially in ways that expose them to multidisciplinary teamwork that combines technology with business and policy issues. The Commercializing Technologies course focuses student energies on working in teams to develop a commercialization plan for a wireless or networking technology. The course has three main objectives.

1. Prepare students for their future careers with knowledge of commercialization – Entrepreneurship skills are important for today’s engineering researchers whether they will work for industry or in academia.

2. Enhance communication of technology to non-technical individuals – The team approach, which includes non-engineers, provides valuable practical experience at conveying the critical elements of a technology.

3. Learn how the business world works and how to work in heterogeneous teams – A major goal of this course, therefore, is to help the engineers learn to speak and hear the language of business.

The concept for the course is based on an earlier experience with a successful interdisciplinary course taught in engineering, geography, economics, and business [2, 3].

Project teams contain both business and economics graduate students and research-oriented engineering graduate students. Each team designs an entrepreneurial plan for bringing a technology out of the Ph.D. students’ laboratories and into practice. Using a technology on which a researcher is currently working provides a real research issue that directly connects with the engineering students’ interests.

B. Course projects and assignments

At the start of the semester, IREAN Fellows from engineering present the technologies that they are researching. Faculty members choose the projects to undertake and, then, the remaining students express their preferences on which project they wish to work. Project work creates a unifying element that forces collaborative work across disciplines. Since the projects have strong multidisciplinary content, each team member can make a contribution that will be recognized by their teammates as valuable.

Throughout the semester, lectures and guest speakers build the knowledge base “just in time” for achieving milestones leading to the final product. Lectures feature economic and financial building blocks, such as Porter’s five forces of competitive advantage, financial statement analysis and analysis of profitability, capital budgeting, marketing, organizational form, and game theory. Industry speakers and guest lecturers from other academic departments provide content on topics such as intellectual property (IP) protection, starting new ventures, venture capital financing, competitive analysis, and facilities for research.

C. Outcomes and lessons learned

Choosing the projects that create the best opportunities for team learning is a critical and time-consuming element of the course. The projects that are ultimately chosen are not necessarily those with the most commercial potential. Projects that are not technically as well-developed or that have technical obstacles that are very apparent to the experts may provide the basis for the best learning experiences. Students may, for example, learn more about the process of measuring market demand and developing a plan for approaching a market on projects that involve technologies that are not technically the most ground-breaking, the best-specified, or the most creative.

Student feedback has been important to the continuing development of this course. One strategy we changed from the first offering of the course to the second was adding structure to the interim assignments. Feedback on the assignments is important to maintain positive momentum. Several students commented that more feedback would be better, identifying a weakness of the course as “getting regular feedback.” This was a shortcoming of team teaching the course; it takes longer for two instructors to read assignments and agree on coherent feedback. Much of the student learning comes from interactions with other students; the downside is that this depends greatly on the personalities, experiences, and communication skills of other team members. Students who have little motivation or desire to commercialize their technologies do not change their plans by taking this course. However, they still gain valuable knowledge that should help them to cope with multidisciplinary teams in the future.

The guest lecturers were largely, but not universally, viewed as a strength of the course. A representative comment from students was that the most useful element was “Guest lectures and the in-depth discussions concerning business concepts,” while others identified the weakest element as “too many speakers and not enough practical educational components.” Given the vastly different backgrounds of class participants some lectures to “level the playing field” were necessary. Some students were impatient with review of material they already knew well.

Field visits to companies have an unpredictable effect. Our effort to contrast a small entrepreneurial company with a large technology company on a day trip was successful in
II. Simulation and Optimization

The “Optimization and Simulation in Networks and Telecommunications” course was offered in Spring 2004 and Spring 2006. Pat Koelling of the Grado Department of Industrial and Systems Engineering taught the course both times.

A. Overview and objectives

Design and development of communication systems, whether they are simple or complex, requires one to be able to adequately anticipate system performance. This anticipation provides the impetus to design a system that is, in some sense, “better” than either another system or, at least, better than the existing system was before. This need to anticipate and improve performance requires adequate models that can be used to either understand system performance (simulation) or to select system parameters that will result in “better” performance (optimization). The ability to do that requires expertise in networking as well as simulation and modeling and is often lacking in networking research [4]. Enhancing this ability and providing experience in multidisciplinary teams doing simulation and optimization applied to networking were the purposes in presenting this course.

The course focuses on the application of several techniques used in the field of operations research. The class covers the fundamentals of modeling network and telecommunication problems for the purpose of (1) performing a discrete-event computer simulation of system performance under varying structures or system settings, and (2) building and solving optimization problems to find the “best” system design. Specific objectives as stated in the class syllabus are listed below.

- Develop and solve mathematical models for optimization problems with application to communication networks.
- Discuss results obtained from a formal analysis of these problems.
- Perform sensitivity analysis on optimization problems to understand the impacts of variable uncertainty and marginal change.
- Recognize the difference between linear, integer, and nonlinear optimization problems through written problem descriptions.
- Develop simulation models of various communication network systems.
- Accurately describe the random nature, and execution, of computer-based simulation.
- Design experiments using the concepts of simulation and proper statistical design methods.
- Execute proper statistical analysis of simulation output.
- Work as part of a multidisciplinary team to perform optimization and performance studies of communication networks.

B. Course projects and assignments

One of the vital aspects of the class is its multidisciplinary nature, of both the content and the students. While students in the class have been primarily from Electrical Engineering and Computer Engineering, there has also been representation from Computer Science, Industrial and Systems Engineering, and Economics. The resultant blend of disciplines has provided a dynamic mix for class projects – a key element of the course.

There are two class projects, one for simulation and one for optimization. Each project is conducted by teams, with a desired size of three. To the extent allowed by the composition of the class, the teams are composed of individuals from different disciplines. Thus, for example, a student more knowledgeable of the solution technique collaborates with a student who has more content knowledge.

When feasible, class projects relate directly to students’ ongoing research. For example, if a student is involved in research where building a simulation model is appropriate, every effort is made to integrate that into the class project for that student’s team (each team may work on a different project). This has, in fact, been the case in a majority of the simulation projects, though less so for the optimization projects.

IREAN Fellows are required to make presentations, early in the semester, on their own research. This enhances connection to the IREAN program and communicates a variety of problem types to all students in the class. It also provides an easy way for the other students to learn more about the IREAN students and IREAN program.

C. Outcomes and lessons learned

While the course’s objectives have largely been met in the two offerings to date, there are some difficulties in offering a course such as this. A diverse student population in a class always presents challenges. In this case, some students come in with strong operations research backgrounds and others with essentially none, so some of the more algorithmic discussion is difficult for the latter students and too easy for others. The content area presents another challenge. Students
in disciplines outside Electrical Engineering or Computer Engineering can be intimidated by their lack of knowledge in networks and telecommunications, making it more difficult to attract them to the class.

The course has been successful, but is still evolving. With the diversity of students and material, achieving the proper balance of theory versus application and of breadth versus depth has proven to be challenging. With perseverance this will improve with each offering of the course. At the same time, there are many successes, from students integrating the course content into their dissertations, and even conference papers resulting from the course projects, and these serve to reinforce the value of the course.

IREAN Workshops

One- and two-day workshops to develop skills and facilitate collaboration are described below.

I. Writing and Presentation Workshops

Improvement of communication skills is a key objective of the IREAN program. A one-day communication workshop is offered each year, alternately focusing on scientific presentations and writing. Each has been offered twice to different groups of students by Michael Alley of the Department of Engineering Education. The primary objective of these workshops is to improve students’ oral and written presentations.

The workshops consist of lectures, discussions, and exercises. Students are required to bring a short presentation about their research or their latest article. Students apply the lessons learned to their own work, aided by the instructor’s suggestions. The presentation workshop ends with each student giving his or her newly-modified presentation to the rest of the group, who critique the presentation. The writing workshop follows a similar path, beginning with the submission of the students’ most recent writing. Along with the instructor, the students review and improve their own written work.

By the end of both workshops, students have the knowledge and skills to present their research in front of an audience, a strong presentation of their work, and a well-written research paper. The students are also supplied with books [5, 6] to support their future work.

II. Research Workshops

We have held a research workshop each year beginning in 2002. The research workshops span two days and are held alternately in Blacksburg and northern Virginia. Three objectives of the research workshop relevant to multidisciplinary education and research are to: (1) provide IREAN Fellows and Associated Students (participating students not funded by the NSF IGERT grant) with the opportunity to present research results and/or research plans; (2) develop a shared understanding of research interests and opportunities within the IREAN community and identify potential research collaborations; and (3) provide an opportunity for students, especially new students, and faculty to get to know each other better.

The research workshops include 20-minute presentations by all of the IREAN Fellows and Associated Students (10 minutes for new students), as well as two or three discussion sessions. We have also had guest speakers for some research workshops. Students provide information about their educational and technical background, the multidisciplinary aspects of their work, and their current status and future plans. The main body of the presentations focuses on the students’ research topics. Students have the opportunity to showcase their accomplishments, and there is an opportunity for students and faculty to provide constructive feedback on the research problems and methods.

Some students find it difficult to identify the multidisciplinary aspects of their research. Not all students fully embrace a broad definition of multidisciplinary research. The multidisciplinary section of the presentation encourages students to take a closer look at how their research might reach beyond their own area and evolve into a more multidisciplinary project. Faculty and other students also often suggest ways to make research more multidisciplinary.

Breakout sessions engage students in issues related to the IREAN program. Questions concerning the well-being, strengths and impacts of the program are the focus of some discussions. There are also discussion sessions on other topics, such as identification of opportunities for multidisciplinary research and new and emerging multidisciplinary technical areas.

The research workshops also provide an opportunity for social interaction. During and after the workshops, students and faculty find opportunities to share in both formal and more relaxed ways, giving participants a chance to better understand each other. Students find the social interaction to be one of the most useful aspects of the workshop.

Evaluation and Outcomes

A survey was created to collect the opinions of the participating students and faculty regarding the IREAN program. The survey was meant to evaluate the acceptance and effectiveness of the two new IREAN courses and expectations of the program. We surveyed current and past IREAN Fellows, Associated Students, and faculty associated with the IREAN program. Faculty respondents were asked to answer the survey from the perspective of students with whom they had worked. The survey was online and anonymous. There were 36 responses for a 67% response rate.

I. Objectives and Initial Expectations of the IREAN Program

Respondents were given a list of program objectives and asked to specify their agreement on how well each objective was met. Table I lists results, showing a strongly positive agreement with the multi-dimensional objectives of the IREAN program.

Survey participants were also asked to evaluate their overall experience with the IREAN program in terms of how it met their initial expectations. Responses are shown in Table
II. The very positive response to the last statement, “The IREAN program provided me with opportunities I would not have had otherwise” is a strong indication of the success of the program.

### Table I

**Program Objectives**

<table>
<thead>
<tr>
<th>The IREAN program has…</th>
<th>Student Ranking</th>
<th>Faculty Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>improved my ability to perform research.</td>
<td>4.11</td>
<td>4.44</td>
</tr>
<tr>
<td>increased my knowledge of networking.</td>
<td>4.28</td>
<td>4.22</td>
</tr>
<tr>
<td>provided me with opportunities for collaboration.</td>
<td>4.08</td>
<td>4.44</td>
</tr>
<tr>
<td>provided me with opportunities for multidisciplinary education.</td>
<td>4.28</td>
<td>4.56</td>
</tr>
<tr>
<td>provided me with opportunities for multidisciplinary collaboration.</td>
<td>3.92</td>
<td>4.44</td>
</tr>
<tr>
<td>provided me with opportunities to work in a distributed environment.</td>
<td>3.83</td>
<td>3.78</td>
</tr>
<tr>
<td>provided me with opportunities to work with culturally diverse teams.</td>
<td>4.06</td>
<td>3.78</td>
</tr>
<tr>
<td>provided me with opportunities to work with multidisciplinary teams.</td>
<td>3.89</td>
<td>4.11</td>
</tr>
<tr>
<td>improved my technical writing.</td>
<td>3.81</td>
<td>3.56</td>
</tr>
<tr>
<td>improved my technical presentations.</td>
<td>4.19</td>
<td>3.89</td>
</tr>
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</table>

### Table II

**How Well Initial Expectations Were Met**

<table>
<thead>
<tr>
<th>The IREAN program…</th>
<th>Student Ranking</th>
<th>Faculty Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>improved my ability to perform research.</td>
<td>3.75</td>
<td>4.00</td>
</tr>
<tr>
<td>increased my knowledge of networking.</td>
<td>3.94</td>
<td>4.11</td>
</tr>
<tr>
<td>provided me with opportunities for collaboration.</td>
<td>3.72</td>
<td>4.44</td>
</tr>
<tr>
<td>provided me with opportunities for multidisciplinary education.</td>
<td>4.00</td>
<td>4.11</td>
</tr>
<tr>
<td>provided me with opportunities for multidisciplinary collaboration.</td>
<td>3.50</td>
<td>3.78</td>
</tr>
<tr>
<td>provided me with opportunities to work in a distributed environment.</td>
<td>3.64</td>
<td>3.78</td>
</tr>
<tr>
<td>provided me with opportunities to work with culturally diverse teams.</td>
<td>3.78</td>
<td>3.44</td>
</tr>
<tr>
<td>provided me with opportunities to work with multidisciplinary teams.</td>
<td>3.64</td>
<td>3.22</td>
</tr>
<tr>
<td>improved my technical writing.</td>
<td>3.61</td>
<td>3.67</td>
</tr>
<tr>
<td>improved my technical presentations.</td>
<td>4.06</td>
<td>3.78</td>
</tr>
<tr>
<td>provided me with opportunities I would not have had otherwise.</td>
<td>4.42</td>
<td>4.78</td>
</tr>
</tbody>
</table>

**III. Evaluation of the Optimization and Simulation Course**

Results indicate that this course was highly effective in meeting its objectives; 87% of respondents agreed that this was the case. The percentages of respondents who agreed that the course positively impacted their research and their careers or preparation for careers were 93% and 73%, respectively. 60% felt it was effective in aiding multidisciplinary education. This was the highest number seen in the survey for the latter category of question.

The difficulty in instructing a class with a diverse representation in disciplines can be seen in the comments. Some students (presumably those with backgrounds in simulation and optimization) felt that the class was too elementary in those areas, while others (doubtless lacking such background) desired more instruction. Likewise, there were analogous dichotomous comments regarding networking and we can make similar assumptions concerning the backgrounds of those comments’ authors.

**IV. Evaluation of Workshops on Presentations and Writing**

Respondents were overwhelmingly complimentary in their survey responses and comments. Most (77% of respondents for writing and 89% of respondents for presentations) agreed or strongly agreed that the workshops had a positive impact on their research, with similar numbers (82% for writing and 84% for presentations) for impact on their careers or preparation for careers. Since many of the IREAN students returned to graduate study from industry careers and, presumably, already had significant experience in writing and presenting information, these results are particularly impressive. Summaries of the results for each workshop are in Table III.

**Table III**

**Impact and Effectiveness of Writing and Presentations Workshops**

<table>
<thead>
<tr>
<th>The IREAN Workshop…</th>
<th>Technical Writing Ranking</th>
<th>Presentation Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>improved my ability to perform research.</td>
<td>4.35</td>
<td>4.00</td>
</tr>
<tr>
<td>was effective in aiding multidisciplinary education.</td>
<td>3.18</td>
<td>3.00</td>
</tr>
<tr>
<td>had a positive impact on my career/preparation for a career.</td>
<td>4.18</td>
<td>4.50</td>
</tr>
<tr>
<td>was effective in meeting its objectives.</td>
<td>4.35</td>
<td>4.27</td>
</tr>
</tbody>
</table>
With regards to the workshops’ effectiveness in aiding multidisciplinary research, only 23% agreed or strongly agreed, with 15% disagreeing or strongly disagreeing, and 62% having no opinion. These numbers can be attributed to the discipline-neutral characteristic of the instruction, aimed at improving the quality of a student’s writing and presentation, regardless of the content.

V. Evaluation of the IREAN Research Workshops

The research workshops were viewed positively in all categories, as indicated in Table IV. Fully 91% of respondents agreed or strongly agreed that the workshops had a positive impact on their research and more than three-quarters (79%) felt that the seminars assisted them in multidisciplinary research. In addition, 79% believed that they benefited in terms of their careers or preparation for careers.

<table>
<thead>
<tr>
<th>Table IV: Impact and Effectiveness of the IREAN Research Workshops</th>
</tr>
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<tbody>
<tr>
<td>Technical Writing Ranking</td>
</tr>
<tr>
<td>The IREAN Workshop…</td>
</tr>
<tr>
<td>improved my ability to perform research.</td>
</tr>
<tr>
<td>was effective in aiding multidisciplinary education.</td>
</tr>
<tr>
<td>had a positive impact on my career/preparation for a career.</td>
</tr>
<tr>
<td>was effective in meeting its objectives.</td>
</tr>
</tbody>
</table>

The general consensus among respondents was that the workshops were intended to bring the IREAN members together; to inform others of ongoing research; to share ideas (particularly in hopes of fostering collaboration); and to provide experience in giving presentations and receiving feedback. These aims were also listed among the most useful aspects of the workshops—a commonality surely responsible for its high rate of success in objectives met: 73% felt the objectives were fully or mostly met and 12% somewhat met (15% had no opinion). It should be noted that a repeated and unexpected emphasis on the communal aspects of the workshops was observed in the results. Respondents viewed these gatherings not only as an opportunity to share research, but also to better know their fellow students, particularly those from other disciplines.

“Length of presentation” was widely regarded as the least useful feature, though it was divided into two points of view. One group thought presentations were too short, while the other group thought they were too long, thus proving that “you can’t please everyone.”

SUMMARY AND CONCLUSIONS

In this paper, we provided an overview of the IREAN program, described two novel courses, “Commercializing Technology for Advanced Networks” and “Optimization and Simulation in Networks and Telecommunications,” and discussed three non-credit workshops used to develop skills and foster collaboration. We also presented results from a survey administered to current and former students and faculty associated with the IREAN program.

The courses and the workshops have been, for the most part, successful in meeting their individual goals and the program has been generally successful in better preparing Ph.D. students for multidisciplinary teamwork and catalyzing multidisciplinary research. As indicated by survey results, there are also challenges in designing the classes and workshops and these experiences can only do so much to meet overall program objectives.

There are significant barriers to multidisciplinary research and education, including the inherent bias in academia toward discipline-specific research and the allocation of university resources, especially for education, largely along disciplinary boundaries. Barriers associated with resource allocation are clearly problematic. For example, there are currently no plans to offer the Commercializing Technologies courses this coming spring due to resource constraints within the instructors’ departments. Fortunately, we have overcome at least some of the barriers associated with the bias toward discipline-specific research, although perhaps only through “baby steps” of progress. We have developed innovative classes that foster multidisciplinary teamwork and we have created a thriving “intellectual community” of students and faculty that cross disciplinary boundaries.

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