Interdisciplinary Graduate Experience: Lessons Learned

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Abstract

Engineers interact in the workplace with technical peers in other disciplines at all stages of design, development, and application. Awareness of the constraints and needs of the other disciplines can be key in many situations. Such interdisciplinary activity and the associated communication are facilitated if the all participants have a solid knowledge of discipline-specific terminology and an understanding of connecting concepts. Consequently, experience relating to interdisciplinary teamwork is a necessary component of engineering education.

The Smart Engineering Group at the University of Missouri-Rolla was established to conduct interdisciplinary research and to create interdisciplinary educational resources. The topical interest area is smart structures which requires the integration of materials, structures, sensing, signal processing, manufacturing, etc. The interdisciplinary research and educational activities of the group, the assessment of those activities, and the experiences of several graduate students will be described. The effectiveness of collaborative student work was tied to the students' understanding of the needed synergy and their comfort with cross-disciplinary communication. Also, an interdisciplinary course, which grew out of the group's experiences, provided systematic preparation for graduate research projects. The role of this course will be discussed as it relates to the quality of collaborative experiences from both student and faculty perspectives.

I. Introduction

Engineering work is rarely confined to a single discipline. The successful application of both established technologies and new technologies often depend on the interdisciplinary knowledge and abilities of the responsible engineers. Consequently, the needs for engineering education to cross traditional boundaries and to develop team skills are widely recognized.[1] Current accreditation criteria address this need directly by requiring that engineering graduates demonstrate an ability to function on multidisciplinary teams.[2] Furthermore, interdisciplinary activity and the associated communication are most effective if all participants have a solid knowledge of discipline-specific terminology and an understanding of connecting concepts.

Interdisciplinary training can benefit both undergraduates and graduate students, but the effectiveness of the training is enhanced when the students possess the in-discipline technical maturity resulting from completion of a B.S. engineering degree and when a graduate research project creates problems requiring interdisciplinary solutions. The goal of interdisciplinary training should be to develop specialists who have interaction skills, not to develop generalists. Engineers in a given discipline must be aware of the constraints and needs of the other disciplines. For instance, a load test on a new bridge element could involve civil, electrical, manufacturing, and mechanical engineers. The civil engineer needs an appreciation for sensor noise and processing accuracy; the electrical engineer needs to be aware of strain directions and bonding issues; etc. Failure to communicate assumptions and to coordinate activities can have serious quality and cost consequences. Knowing what questions to ask and understanding the terminology in the answer can be obtained through a combination of instruction and experience.

This paper describes the working collaboration of faculty and students in the Smart Engineering Group at the University of Missouri-Rolla (UMR). The group conducts applied research and academic activities in the interdisciplinary topical area of smart structures. While some undergraduates were involved in the group, the graduate group members were involved in all aspects of the activities. Also, their performance during graduate research projects provided a measure of the effectiveness of the preparatory activities. A supporting course was a formal means of interdisciplinary training. The course enrollment was primarily graduate students. Interdisciplinary research and educational activities of the group, the assessment of those activities, and the experiences of several graduate students are presented. Characteristics of successful collaboration are discussed from both student and faculty perspectives.

II. Project Environment for the Smart Engineering Group

The Smart Engineering Group involves faculty and students from the disciplines of electrical engineering, mechanical engineering, civil engineering, and psychology. Sponsored research and educational activities incorporate various combinations of technologies as illustrated in Figure1. Smart structures projects require the integration of sensing, materials, and structures. Associated educational projects apply educational innovation and Web-based methodologies in the context of the component disciplines.

The projects described in this paper were conducted by masters students who had taken the supporting interdisciplinary course. These example projects are listed below.

- Smart Composite Bridge:[3]
  An instrumented all-composite bridge for highway loads was laboratory tested and manufactured with the involvement of several government and industrial partners. It featured an integral fiber-optic-sensor network and a novel composite construction approach.[4]
- Smart Truss Bridge for Education:[5]
  An instrumented laboratory-sized truss bridge was designed and constructed. It demonstrated sensing technologies and structural analysis. Laboratory experiments were written for the interdisciplinary course.

- Smart Health Monitoring using Neural Networks:
  The analysis and measurements for selected configurations of the Smart Truss Bridge were used to train and test a predictive neural network. The processing demonstrated the capability for intelligent health monitoring.
- Web-Based Educational Resources:[6,7]
  A Web-page with extensive multimedia and tutorial elements was created for the interdisciplinary course. The student use of the site was tracked and their performance was assessed in the context of educational psychology.

The typical project has a primary faculty co-advisor and a secondary faculty co-advisor. Students work closely with both co-advisors, supervise undergraduate assistants, and often interact with other graduate students. The nature of the projects requires equipment and facilities from multiple departments. The complexity of the projects produces critical coordination tasks, many of which are handled by the students.

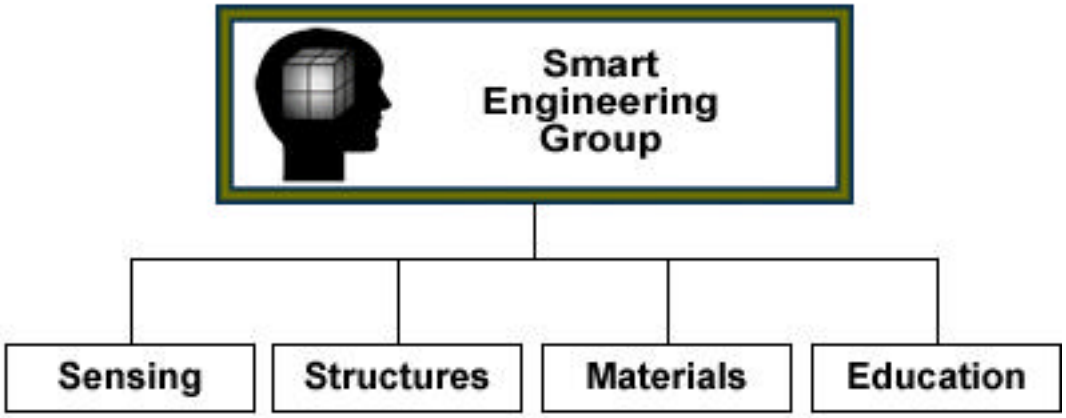

Figure 1: Component Technologies for Smart Engineering Group

A principle educational project, and a formal means for student training, is the Smart Materials and Sensors course.[8,9] The technical focus is smart composite structures which involves use of composites for structural applications and the use of sensors for monitoring and control. The UMR Smart Composite Bridge is a field laboratory for the course[4] and an innovative Web-resource is the primary content resource.[7,8] The learning objectives of the interdisciplinary course are (1) to integrate cross-disciplinary knowledge, (2) to build interdisciplinary collaborative skills, and (3) to gain related applied experience and the implementation of the objectives are based on a cognitive sciences approach. Functional knowledge is developed through problem-based assignments and laboratory activities. Interdisciplinary collaborative skills are practiced through group problem sets, laboratory activities and reports, and capstone design or analysis projects with both written and oral documentation. Most activities are conducted in a collaborative team setting.[10]

III. Assessment of the Interdisciplinary Experiences

The interdisciplinary experiences were assessed within the course, by an external review panel, and by the faculty participants. The course assessment instruments were pre-class and post-class surveys, i.e. surveys were given the first and last day of classes. Both the target engineering concepts, as identified by the instructors, and the educational components were addresses in the assessment.[9] The course components consisted of web-based tutorials, lectures, team activities, and applied laboratory exercises. The assessment included all enrolled students - fourteen students enrolled in 1999 and fifteen enrolled in 2000. A mix of electrical, mechanical, and civil engineering students participated. The external review committee examined the collaborative activities including research projects and the course. The full-day review included student interviews. The committee consisting of five industry and academic professionals with a variety of educational and technical specialties (see acknowledgements section).[9]

The course was received favorably by the students. In general, ratings and comments on the course methodology were positive. Although some anxiety by the students was evident as they used out-of-major concepts and collaborated in the group activities, they rated the applications high and displayed a working knowledge of target concepts. The most satisfied and successful teams were those that took time to teach each other concepts and vocabulary.

One part of the pre-class and post-class surveys related the twelve target course topics as identified by the instructors. The course topics were fiber reinforced polymer (FRP), composite (FRP) manufacturing, composite (FRP) materials, smart structures, bridge design, active vibration control, damage monitoring, strain measurement, electrical resistance gauges, piezoelectric sensors and actuators, fiber optics, and optical interferometric sensors. The instructors and the students rated all possible pairs of the topics for their similarity on a scale of one to five. For instance, a low rating results when one of the topics is not known or when the pair is perceived as independent in function or application. The Pathfinder scaling algorithm was used to transform the proximity matrix of ratings into a node link network.[11] Such a network is a concept map that shows the perceived similarity and interconnectedness of the topics. A learner's structural knowledge (knowledge interconnectivity) can then be quantified by comparing the learner's pathfinder network with that of an expert. This comparison can be done via a congruence or closeness measure that correlates the similarity of link structures between two pathfinder networks.[11] This approach has been found to be an effective measure of knowledge interconnectivity in previous research.[12] Figure 2 shows the Pathfinder network for the electrical engineering instructor, i.e. the expert. A line between topics indicates a strong similarity or interconnectedness of the topics; no line indicates a weak relationship. Figure 3 and 4 show the pre-class and post-class networks for a typical student with a congruence comparison with the instructor. Both pre-class and post-class student networks show less interconnectivity than the instructor's network, but the students clearly added interconnectivity, i.e. more lines. Their course experiences helped them see the whole of the smart structures area. Furthermore, the student view of the concepts became more congruent with that of the instructor, i.e. the congruence increased from 0.33 to 0.42. Hence, as a result of the course, the students viewed the core topics as more interdependent and their perspective grew closer to that of the instructors.

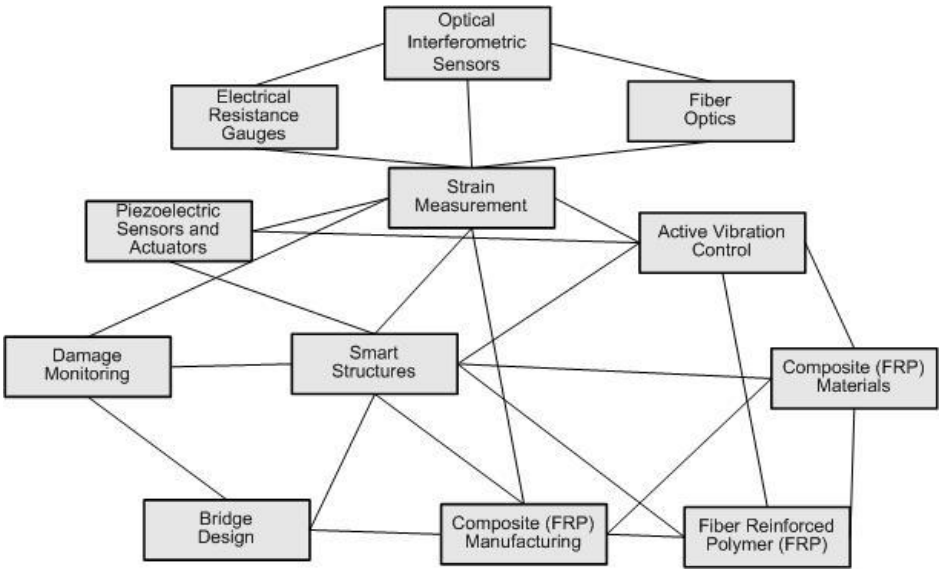

Figure 2: Instructor's Pathfinder Network

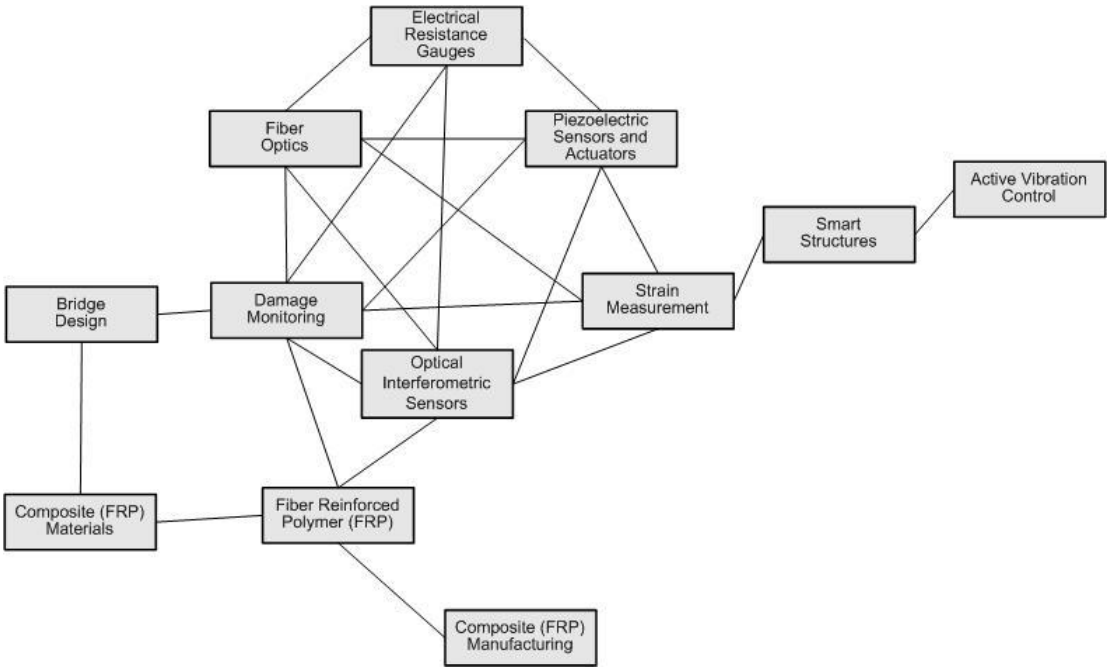

Figure 3: Sample Student's Pathfinder Network from Pre-Class Survey (congruence with instructor 0.33)

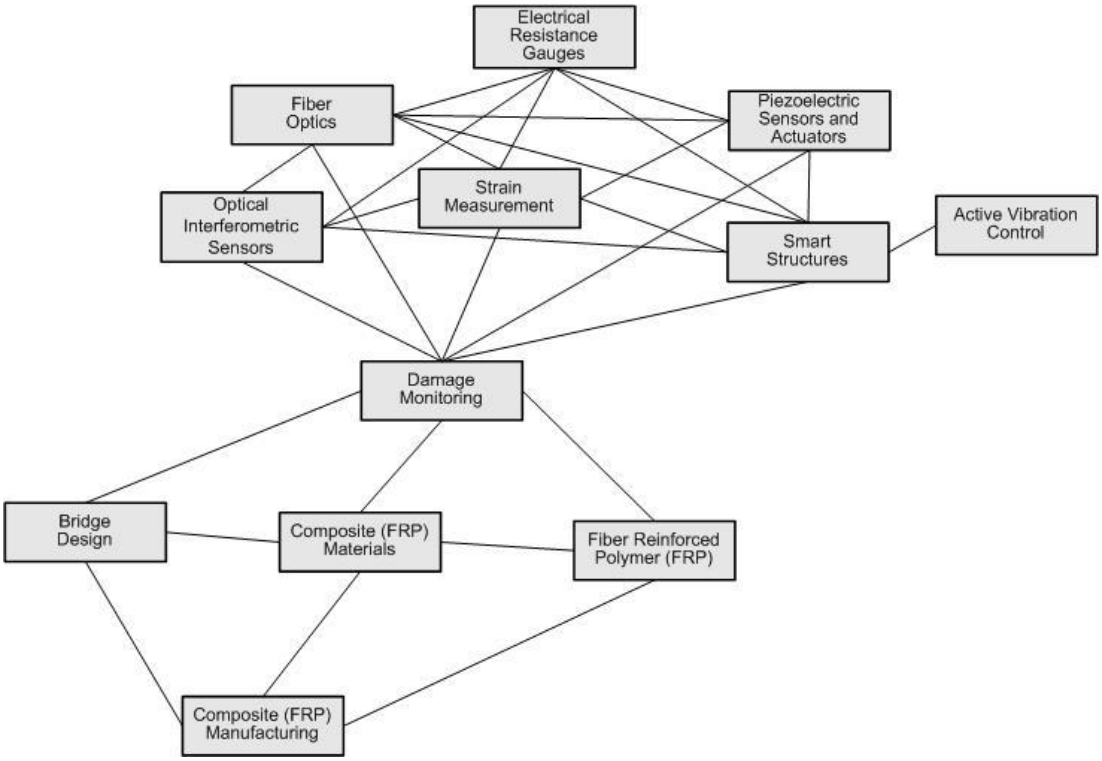

Figure 4: Sample Student's Pathfinder Network from Post-Class Survey (congruence with instructor 0.42)

Other aspects of the pre-class and post-class surveys explored student satisfaction with each course component (web-based tutorials, lectures, team activities, and applied laboratory exercises) and with long-term, perceived usefulness of the experiences. Student satisfaction and perceived usefulness improved between the 1999 class and the 2000 class due to increased depth in the topical tutorials and greater emphasis on interdisciplinary applications.[9]

The external committee and internal faculty review supported the cognitive sciences approach and the educational structure of the course. In particular, the committee report noted the quality of the samples of student work and included the following general comments.

- "This type of course should not be an optional course, academia should teach life skills and … (industry) should not have to fill (the collaboration and communication training role)."
- "After taking the class the students realize that it made them a lot better communicators."
- "Synergy of faculty in different disciplines, of centers, and of external organizations is excellent."

The problem-based collaborative experience and the structured communication tasks had the most educational value from a faculty perspective. Relating the course activities to anticipated or ongoing student projects, especially graduate projects, improved motivation. For subsequent interdisciplinary masters projects in the Smart Engineering Group, the knowledge of discipline-specific terminology and connecting concepts seemed to be the most-used aspects of the course.

IV. Experience of the Graduate Students

The masters students and their projects described previously are summarized in Table 1. All group faculty were involved as primary or secondary advisors. Each student had significant work components outside of their major area. Also, the Smart Composite Bridge project had the student working through an internship with the industry partners and interacting with the assembly crew on the shop floor. The Smart Truss Bridge and Smart Health Monitoring projects were closely tied, were a continuation of undergraduate collaboration,[13] and required the most extensive student-to-student interaction. The Web-based Resources project required the student to integrate engineering concepts and non-engineering educational concepts. Near the end of their graduate programs, the students described their project experience through an exit interview and the questionnaire shown in Figure 5. Some salient comments are listed below.

- ***Did Motivation to do Interdisciplinary Work Increase or Decrease as a Result:***
  "Increase" and "Increase – the variety was interesting"
- ***Interdisciplinary Aspect(s) of Project for which you were Least Prepared:***
  "Terminology, applied math in other fields,"
  "Planning and resources on the civil side," and
  "Civil topics with my partner, … I couldn't rely on what I already knew."
- ***Recommendations and Comments:***
  "Overall, I would say that this has been a lesson in learning to communicate and work with someone with a different background and training than myself." and "One of the biggest challenges was in the differences in connotations of words between CE and EE."

Table 1: Overview of Collaborative Projects

	Student Major	**Advisors**	**Components**	**Comments**
Smart Comp. Bridge	Electrical Engineering (EE)	Primary – EE Secondary - ME	Sensing, Testing, & Manufacturing	Industry Involvement
Smart Truss Bridge	Civil Engineering (CE)	Primary – CE Secondary - EE	Design, Testing, Analysis, Sensing, & Neural Networks	Extensive Student Interaction & Coordination
Smart Health Monitoring	Electrical Engineering (EE)	Primary – EE Secondary - CE		
Web-based Resources	Electrical Engineering (EE)	Primary – EE Secondary – Psy	Programming & Assessment	Non-engineering Component

All of these students felt that the interdisciplinary course provided valuable background and experience as preparation for their project work. They generally liked doing and were challenged by work that extended outside the traditional bounds of their major. The research projects were technically significant and several publications are pending. A potential problem was different expectations of the two co-advisors. (The faculty felt that handling this issue was the advisors' responsibility. Major expectations should be defined as a group and a primary advisor should be identified.) Also, the students needed to know their role in the work and how the advisors viewed the collaborative process. Most felt that they were good communicators at

the start, but they noted that clear communication with faculty and student co-workers took on added importance in the interdisciplinary context. Even with the course preparation, the students had to be sensitive to different vocabulary and word connotations as the project progressed. The main recommendations are that students in similar situations should understand why synergy is needed and should expect an ongoing cross-disciplinary communication.

The questionnaire deals with your experience working on an interdisciplinary masters research project. Please give a general description for each category as well as any specific occurrences that you can recall.

Project Description:
Nature of Interactions with Faculty and Other Students:

Immediate Value of Interdisciplinary Aspects (Job Placement, Advancement, …):
Applied Value of Interdisciplinary Aspects (Did it make you a better professional?):

Did Motivation to do Interdisciplinary Work Increase or Decrease as a Result:
Match of Expectations at Start of Graduate Work and Actual Experience:

Interdisciplinary Aspect(s) of Project for which you were Best Prepared:
Interdisciplinary Aspect(s) of Project for which you were Least Prepared:

Value of the Supporting Course:
Recommendations and Comments:

Figure 5: Exit Questionnaire on Interdisciplinary Project Experience

V. Summary

The UMR Smart Engineering Group conducts research and academic projects that require interdisciplinary collaboration. An interdisciplinary course, which grew out of the group's experiences, provided systematic preparation for graduate research projects. After the course, the students had a broader view of the interdisciplinary topics and were better able to address constraints and needs of the other disciplines. The thesis projects supervised within the group had significant interaction among faculty and students from several disciplines. The formal training and the subsequent experience were favorably viewed by both students and faculty. Also, the faculty credited the approach, specifically the course experiences and the co-advising structure, for superior performance of these students as compared to prior graduate students. These students performed their projects with great independence and displayed excellent team skills. These students habitually asked appropriate and necessary questions relating to out-of-major issues. The external review panel felt that the approach addresses a problem area in engineering education and that the graduate-level emphasis was appropriate.

Multidisciplinary interaction on project work should occur between faculty, between faculty and students, and between students. The last interaction, between students of different disciplines, is often the most challenging. The success of such interdisciplinary research and training depends on a variety of factors. Perhaps the most important factor is the involvement of the faculty in the collaborative efforts. The faculty should model effective collaboration themselves, should address the disparity between faculty (expert) and student technical perceptions, and should explain the student roles and expectations. Next, the formal coursework is an effective means of teaching discipline-specific terminology and of promoting an understanding of connecting concepts. Finally, the student participants should be aware of needed discipline synergy and should be comfortable with cross-disciplinary communications.

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