Interdisciplinary Team Research with Undergraduates

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The Civil Engineering Department at Northwestern University is the site of a new National Science Foundation (NSF) interdisciplinary Research Experience for Undergraduates (REU) program. Research in industry is rarely conducted in isolation and, increasingly, academic research emphasizes interdisciplinary teams and collaborative efforts. To better educate our undergraduates for innovative problem solving, this novel program provides students with the interdisciplinary and cooperative research experience needed to be successful in either industrial research and engineering or academic positions. The experience focuses on civil engineering materials, although, the program recruits from all engineering and science disciplines as well as mathematics. Students may be placed with faculty mentors from their discipline or from another depending on the project, the student's background and the faculty's expertise and interests. A typical three student/three faculty team may consist of two civil engineers, a chemical engineer, an environmental engineer, a structural engineer and a geotechnical engineer, creating a truly interdisciplinary working group. This program incorporates alternative team structures that represent the many forms which interdisciplinary research may take including peer groups working in similar areas of study, peer groups working in different areas of study and peer groups working on thematic problems with a common goal. Students engage in a course of study that introduces them to a wide spectrum of research topics relevant to the central theme of civil engineering materials. They also attend a seminar activity designed to coach them in skills ancillary to research including literature search, report writing, oral presentation and laboratory safety. Teams of three students are advised by three individual faculty mentors and three graduate coaches. Teams meet weekly to formally review and cross-fertilize their research projects with input from their peers. Questionnaires are used to evaluate the students' understanding of interdisciplinary research before and after the program in an effort to establish effectiveness of the training. The team research model will be compared to other models. The many challenges of organizing such a program will be discussed along with the benefits and rewards to both students and faculty.

Background

The role of interdisciplinary and team related activities is becoming increasingly evident in research, engineering and other fields of practice and study. In a recent report titled, *Where is Science Going*, Hicks and Katz (1996) report that interdisciplinary interaction is among five increasing trends in modern research, which also include networking, internationalization, concentration of resources and application. Dahir (1993) summarizes a recent survey of the National Society of Professional Engineers (NSPE) that indicates that 80% of employers feel that being able to work in teams is an important attribute in new graduates while only 25% of the respondents felt that new graduates are adequately trained to work in teams. The engineering education community is, however, responding to both the movement towards interdisciplinary activities in research and the need to better prepare students to work in team environments. Masi (1995) reports that,

overall, universities in the U.S. emphasize teaching students to work as teams and communicate within interdisciplinary groups. Multidisciplinary approaches and team dynamics have also been cited among recent innovations in undergraduate civil engineering education by Pauschke and Ingraffea (1996) along with increasing emphasis on communication skills, synthesis of previously separated courses and hands on laboratory experiences for undergraduates. Furthermore, other researchers have reported improved retention of knowledge and preparedness for advanced studies when interdisciplinary approaches are used (Gulden (1996) and Mason (1996)).

Research experiences for undergraduates is cited as one of the most effective activities to attract and retain top students in careers in mathematics, science and engineering (1985). The NSF currently provides funding for several thousand undergraduates to engage in mathematics, science, and engineering related research experiences through the REU program. Individual site awards typically involve five to ten students in a single department. The majority of these programs are conducted during summer months and last for eight to ten weeks. While site awards have been made in virtually every science and mathematics discipline, it is less common to find interdisciplinary programs.

In a survey of the abstracts of roughly 200 REU site awards since 1989, only six were found to mention interdisciplinary study. Of these six, only three discuss the nature of the interdisciplinary approach and only two of the three focused on undergraduate training. With the growing interest and importance in interdisciplinary and team related interaction in both academia and industry, it seems prudent to establish a model for training undergraduates in such environments. The program outlined here being conducted by Northwestern University's Civil Engineering Department in conjunction with the National Science Foundation Center for Science and Technology of Advanced Cement-Based Materials (ACBM) is an on-going case study in interdisciplinary research with undergraduates. The following report summarizes objectives, design and results of the first year of the program's activities.

Project Overview and Expectations

Researchers in industry and academia do not work in a vacuum devoid of interaction between their colleagues. More and more, even at universities, teams of collaborators are forming to tackle complex problems that demand interdisciplinary solutions. It is the overall objective of this program to consider an alternative approach to traditional REU's that typically offer students the opportunity to work independently on a research project. Instead, students are integrated in teams working in thematic areas and collaborate to achieve their goals. The Northwestern University Civil Engineering REU program has three basic objectives: (1) to attract top students with U.S. citizenship including representative numbers of women and minorities to a career in research on materials of interest to civil engineers, (2) to train students in interdisciplinary team research, and (3) to provide a model for implementation of interdisciplinary team research programs for undergraduates which will be applicable in other fields of study such as polymers, electronic materials, environmental matters, biological science, etc.

This study investigates students' responses to these different research environments. Research groups consisting of at least three students are the foundation of the

interdisciplinary teams. The first-year design included four teams representing the spectrum of forms of interdisciplinary interaction: (1) two teams with projects that had a common focus, (2) one team in which the individual projects were not necessarily related, and (3) a control group that was independent of three others who did not interact as a team, with projects that were not necessarily related. Pre- and post-course questionnaires were devised to assess the level of team interaction among the various approaches.

Valuable data will be generated on the use of this experience as a teaching tool. Evaluation of the experimental matrix of the three test groups and a control provides a data base of information upon which a teaching method for interdisciplinary study can be suggested. The program is to be repeated for three consecutive years, while incrementally modifying the concept to focus entirely on the team approach which most benefits student interdisciplinary training. Given the small population size, however, it is expected that only qualitative information will be derived. Statistical confidence is neither sought nor expected from the limited data set.

This program seeks to challenge the REU tradition in the following ways:

- Recruit an interdisciplinary student body
- Integrate student activities into thematic teams
- Offer students an interdisciplinary course of study

There are five basic activities of this program:

- *Skills seminars*: A series of seminars are held which train students in skills which are ancillary to research such as computer information technology (literature searching), computerized interaction report writing, oral presentation, and laboratory safety.
- *Technical seminars*: An interdisciplinary course of study was designed to introduce students to a wide range of topics related to civil engineering materials, yet presented by a multidisciplinary group of faculty.
- *Team research*: The core component of the program is team research. Although several different experimental team structures were tested, it is intended to provide a team environment that fosters collaborative interaction between students.
- *Communications exercises*: The program focuses heavily on communications both written and oral. Students are coached through skills seminars in report writing and oral presenting as well as in the use of computer technology in presentations. Each student is required to prepare a publication quality research report. The program culminates with a formal oral presentation of the research findings to an open audience of faculty, students and guests.
- *Mentoring*: The hallmark of any REU is mentoring. The REU faculty meet regularly with the students, mentoring them in research conduct and reinforcing activities associated with the skills seminars such as report writing and group presentations.

Teams and Projects

The Student Body

The student body is the most critical part of this program. Without a well-balanced interdisciplinary student group, it is impossible to conduct this form of training. Students were recruited from the engineering disciplines, materials science, mathematics, physics and chemistry largely over the internet. The final group included three civil engineers, three chemical engineers, one general engineering major, one physics/math major and one geological engineering major.

Seminars

Students met weekly for the one-hour skills seminars. Students also met weekly for a technical seminar offered by faculty involved as research mentors. A detailed syllabus of seminar and technical topics is contained in Table I. These activities are typical of most REU programs since they are the basic components of research training. This program differs in the content of the technical seminar topics. Consistent with the interdisciplinary theme of the program, seminar topics were not confined within the departmental discipline. Many of the seminars were presented by faculty from outside of the civil engineering department or by individuals who hold joint appointments with other departments. Faculty presenters were coached to deliver their talks from an interdisciplinary point-of-view, illustrating linkages between disciplines where possible.

Teams

The NSF grant supports nine students. This year's nine NSF REU fellows were grouped with three other undergraduate students funded by other grants. Two students from Howard University funded through ACBM and one student from Northeastern University funded through the National Institute for Statistical Sciences (NISS) joined the interdisciplinary program. These three additional students made it possible to have four teams of three students.

As outlined in the overview, several different team concepts were to be evaluated. Disciplines of faculty and students as well as research projects are summarized in Table II. Each student had a faculty advisor. Most of the students also had a graduate student advisor, but this was not required.

The teams had the following expectations:

Team One: *Microbial Attack on Concrete* - This team worked on a single thematic problem with a common goal. Each student was expected to contribute to the overall project objective. Individual research was closely related and the work of each student (to some extent) depended upon the work of the others.

Team Two: *Processing of Concrete* - This team was organized similarly to Team 1, however, the individual projects were not as closely related. Overall, individual projects did not directly depend upon the results of others.

Team Three: *Chloride Transport and Mechanics* - This team included three remotely related topics yet had overlapping elements. Student research areas did not, in any way, depend on the results of the work of others.

Team Four: *Transport Processes* - In this group, all of the students had projects which fell within a thematic area, yet the projects were completely unrelated. This group was not required to meet formally and represents the control.

Students conducted literature reviews, prepared a thesis statement, engaged in either mathematical, experimental, or synthetical research, synthesized the data and prepared both a written and oral presentation. All students were required to present an oral interim report at the seven-week point in addition to the final oral report.

To improve the communications between teams it was decided that an REU site would be established on the World Wide Web. At first, the site was used to post the syllabus and teams chart for internal use. However, the site has since grown to include a general description of the program, a student application form, announcement of student presentations and a description of the presentations and team pages for each of the four thematic groups. This site is expected to become a major part of the recruiting process and an important student reporting tool in succeeding years.

In yet another attempt to improve team communications, a campus-wide electronic conferencing software network called *FirstClass* was tested. This software provides a resource for establishing team conferences (folders) which participants with access privileges can add to and read from. The concept was intended to promote continuous communication between the teams. Software was launched somewhat late in the session, and so met with limited success; however, the preliminary results suggest that it can be a powerful communication and collaboration tool. It is anticipated that *FirstClass* will be used in subsequent sessions where it will be initiated before students arrive so that collaboration may begin remotely. Thus, when students arrive on campus, both they and their faculty advisors will already have employed the system.

Ongoing Evaluation

The first year's program was evaluated through several mechanisms:

- Student presentations were evaluated for content, rigor in student work and oral presentation.
- Student reports were evaluated for content, rigor in student work and written presentation.
- Pre-course and post-course questionnaires was evaluated to assess student impressions, particularly with regard to team and interdisciplinary aspects of the program.

Student Presentations and Reports

Student presentations, on the average, were 30 minutes long and included five to ten minutes for questions and discussion. Many of the students embraced the opportunity to use multimedia in their presentations. One student presented the results of a mathematical simulation in the form of a computer generated animation. The entire Microbial Team coordinated their three presentations with *Microsoft PowerPoint* presentation software. The content of presentations was technical. Students demonstrated rigor in their analysis and competency with the subject matter. Use of multimedia and the overall impressive quality of the presentations is generally attributed to the success of the skills seminars as well as faculty and graduate student advising in this area. Students were coached in their presentations through three seminar sessions and individually by their faculty advisors. One seminar session was dedicated to the use of multimedia technology in presentations. Student reports averaged 27 pages in length and are consistent with the clear oral presentations.

A unique aspect of the reporting process was peer review between students. Students reviewed each others' oral presentations. A form was given to each student containing a series of questions, which they were asked to complete for each speaker. Each question was to be ranked from one to ten with one being a low score and ten a high score. A blank for additional feedback was also provided for each question. The forms were completed anonymously during or just following each final presentation and were distributed to each speaker after the program. Students were observed to be very interested in their review and took the peer review process very seriously as noted by the comments and thoroughness of the completed review forms.

Pre-Course Questionnaire

A pre-course questionnaire established baseline data. Students were asked questions in three general areas:

- Understanding of interdisciplinary concept
- Understanding of team concept
- Administrative

A series of questions probed students' understanding of interdisciplinary interactions. Examples include: *What is interdisciplinary research? Can others in your own discipline contribute to your research? Can others in different disciplines contribute to your research? Are all problems classifiable into categories by discipline? Do you understand how different disciplines work together to solve complex problems?* and *Do you understand how the various subjects within your own discipline work together, i.e., transport phenomena and reaction kinetics, mechanics of materials and structural analysis*? Similarly, another series of questions probed the students' understanding and preparedness for working in teams. Questions included: *Is it easy to work in teams? Do researchers in universities frequently work in teams? Do researchers and engineers in industry frequently work in teams? Do you feel prepared to work in a team environment? Why or why not?* Student responses were open-ended and, hence, are difficult to

quantify. Although responses were varied, in general, the following summarizes the consensus.

Most of the students grasped, but not firmly, what interdisciplinary research was and were able to articulate this; however, several of the students missed the mark altogether thinking that it represents some inward, narrow description within a single field of study. All of the students felt that others from within and from outside of their own discipline could contribute to their research. All of the students felt that problems are not always classifiable into disciplines. There was, however, considerable difference among responses when asked if they felt they understood how sub-disciplines interact within their own major discipline. For example, *How do structural engineers interact with environmental engineers who study the biodegradability of concrete sewer pipes?* Similarly, there was considerable hesitation to commit when asked if they understand how different disciplines work together.

Concerning working in teams, students indicated mixed feelings when asked if they thought it would be easy to work as a team. Most students answered with words like “it depends” or “no." Most students indicated they thought that researchers in industry work in teams; however, there were mixed responses about researchers in universities working in teams. All of the students said that they were prepared to work as a team member, citing specific experiences which had prepared them for the opportunity.

Post-Course Questionnaire

The post-course questionnaire reiterated questions in the areas of the pre-course questionnaire to measure how students’ impressions changed. Questions were added about program content, how their team functioned, their past and present experiences and program administration.

Responses suggest that the vision of interdisciplinary research was clarified for the students as a result of the summer’s experiences. The answers, although still varied, were more consistent in content and articulation. Most said that interdisciplinary research involved teams of researchers from different disciplines working toward common goals. Virtually, all of the students feel that they now have a better understanding of how different disciplines interact.

Student responses were tabulated to quantify the level of team interaction. Most of the students met at least once a week with their faculty advisors. Some met as often as once a day. Participants who had graduate student advisors met daily. All students had contact with either a graduate student advisor or a faculty advisor on a daily basis. Almost all of the teams met weekly with at least one of the faculty or graduate student advisors present. Team three, which was not as strongly bonded by a common objective, met less frequently. Team four, the control, was not required to meet and consequently did not. Students met independently in working groups without the graduate students or faculty on an average of every other week. Again, Teams one and two meet more consistently than the peer group Teams three and four. Likewise, when asked if the program taught them about teamwork and if the team concept contributed to their research, students from Teams one and two responded favorably, saying that they

experienced team interaction and the team did make contributions that would not have otherwise been expected. Students on Teams three and four clearly could not see the connection between peer research when it was not directly related and driven by a common goal. This reaction was exacerbated by fewer meetings. While positive responses might not be expected from Teams three and four with respect to team related interaction, it would be expected that they would view interaction between their faculty or graduate student advisor to represent a team interaction. However, it was clear that the students in Team four, the control, which models a traditional REU, did not feel the experience offered any degree of team interaction. While lack of interaction and interdisciplinary experience is no reflection of the effectiveness of the REU programs, overall, it does suggest that a deliberate team structure must be implemented if team interaction is expected to be a result of the experience.

Overall, the students reported a fruitful experience whether or not they engaged in team activities. Those who did experience team work, however, appear to report a more fulfilling and enriched experience.

Recruiting, Student Demographics and Other Notes

Students were recruited from civil, chemical, mechanical and geotechnical engineering, materials science, physics, chemistry, geology and mathematics. Recruiting strategies included mailings to colleagues, general mailings to departments, contacting professional society headquarters and direct e-mails to students. E-mails to students were found to be effective. E-mails were sent to student officers of various professional societies whose addresses were obtained via World Wide Web. This channel was particularly effective in attracting women applicants through the Society of Women Engineers. This year's student population included five females, four males and one minority male student. On the average, applicants had a grade point average of 3.44. The nine awardees had an average GPA of 3.51 with a high of 3.80 and a low of 3.13. Table III contains a detailed breakdown of the student population.

To promote cohesiveness among students, all students were housed in close proximity to the Civil Engineering Department in one co-educational dormitory. Students were also greeted on the first day with a *get acquainted* gathering. Similarly, there was a gathering at about mid-session and one again at the end of the program. These gatherings have proven to be a very effective forum for the students to meet the faculty with whom they may not be working and to promote and create a sense of community among the students and faculty.

Plans for Next Year's Program

Recruiting

Although recruiting this year was successful despite a late start, it is anticipated that earlier recruiting should produce better opportunities to recruit top students, improve disciplinary diversity and increase chances of attracting women and minorities. In addition to the tactics employed this year, announcement of the fellowships will be posted in the NSF Center for ACBM newsletter, *Cementing the Future*, as well as an

article in the American Society of Civil Engineers (ASCE) newsletter, *ASCE News*. More emphasis will be placed on direct recruiting of students via e-mail. Opportunities to recruit students via campus visits to Historically Black Colleges and Universities (HBCUs) will also be pursued.

Program Content

The program content will remain basically unchanged although emphasis will now be placed on integrated thematic teams Type one and Type two while the peer group teams Type three and Type four will be de-emphasized.

Communications

Despite limited success with *FirstClass*, this tool will continue to be promoted and used. Early training and off-campus use of the tool will be employed to engage students and faculty earlier. Reporting results via World Wide Web and use of multimedia in presentations will be emphasized earlier in next year's seminar topics.

Ongoing Dissemination Activities

As mentioned above, a World Wide Web site has been established at http://www.civil.nwu.edu/ACBM/undergradact.html#REU. Generally, information about this REU program will be disseminated from this Web address.

Conclusions and Internal Assessment After First Year

Students can be engaged in meaningful team activities as part of a Research Experience for Undergraduates program. Such activities must be well coordinated, however. It is unlikely that undergraduate students brought to campus for a summer will spontaneously interact as a professional peer group despite technical similarity of projects and deliberate grouping and identification as a team. The team concept works well when faculty and graduate student mentors engage actively in team interaction and when individual research projects have clear common goals. Most students failed to see the subtle contribution of peer interaction without obvious connection between each students' project.

The interdisciplinary team program is a considerable departure from the traditional REU approach. The demand that students work in teams necessitates additional faculty involvement and willingness to accommodate this requirement. Such a program can only work where the faculty are willing to engage in team-related meetings and interactions. More coordination is also required on the part of the REU director. It is not only the director's responsibility to identify faculty who are willing to engage but also to draw them into teams. It helps to have an existing infrastructure of interdisciplinary projects ongoing. Through such a structure, students can be integrated with minimal disruption to the base research activities.

Recruiting can also be more difficult. Since an interdisciplinary team of students must be enrolled in the program, additional effort is required to recruit from a multiplicity of disciplines on a nation-wide scale. In addition students outside of the home discipline, in

this case civil engineering, are reluctant to apply to the program. While this year's applicants were well represented by civil and chemical engineering, it was not as well represented by chemistry and materials science. As a consequence, the 1996 program was somewhat less diverse than was hoped. A targeted recruiting strategy is necessary to attract the students diversity of desired.

Table I

Interdisciplinary Team Research in Civil Engineering Materials Summer 1996 Syllabus

Week No.	Skills Seminar Topic	Technical Seminar Topic	Milestones-Other
1	On-line Literature Search Pre-Course Questionnaire	Interdisciplinary Research and Concrete Materials Overview (Civil)	Reception
2	Laboratory Safety	Microstructure and Chemistry (Materials Science/Civil)	
3	Computing Network Resources FirstClass* Training	Environmental Topics (Civil/Environmental)	
4	Report Writing I	Microbial Issues (Chemical/Civil)	
5	Report Writing II	Chloride Attack in Saudi Arabia (Civil/Geotechnical)	Get Together
6	Creating and Giving Presentations	Industrial Topic (Industry Researcher)	Review Report Outlines
7	Student Interim Presentations	Mathematical Modeling (Applied Mathematics)	Review Presentation Outlines
8	Creating PowerPoint Presentations	Transport (Civil/Geotechnical)	Review Final Presentations
9	Post-Course Questionnaire	Mixing (Chemical)	Student Presentations Graduation Picnic

*Electronic conferencing software.

Table II

Research Projects and Teams - Summer of 1996

Student Topic	Student's Discipline	Faculty's Discipline
Microbial Attack		
Microbial Growth on Concrete	Chem. Eng.	Environmental/Chemical
Preparation and Characterization*	Civil Eng.	Materials/Structures
Field and Literature Data*	Civil Eng.	Geotechnical
Chloride Transport and Mechanics		
Microstructure Permeability Relationships**	Civil Eng.	Civil
Modeling Finite Strain	Civil Eng.	Theoretical and Applied Mechanics
Modeling Chloride Transport	Geological Eng.	Geotechnical
Processing		
Mixing Phenomena	Chem. Eng.	Chemical Eng.
Hydration and Gelation Kinetics	Chem. Eng.	Chemical Eng.
Mathematical Modeling	General Eng.	Mathematics
Transport Processes (Control Group)		
Proton NMR	Civil Eng.	Materials Science
Capillary Intrusion	Physics/Math	Physics
Metals Immobilization and Leaching	Civil Eng.	Environmental

* Sponsored by the Center for Advanced Cement-Based Materials.
** Sponsored by the National Institute for Statistical Sciences

Table III

Student Demographics Summary - 1996

	Applicants	Awardees
Gender		
male	47	4
female	31	5
unknown	3	0
total	81	9
Citizenship		
US citizen	58	9
non-US citizen	11	0
permanent residence	4	0
unknown citizenship	7	0
dual citizenship	2	0
Ethnicity		
American Indian	0	0
Asian	18	2
Black (non Hispanic)	2	1
Hispanic	3	0
Pacific Islander	0	0
White (non Hispanic)	43	3
unknown	15	0
Academics		
average population GPA	3.44*	3.51
Chemical Engineering	17	3
Civil Engineering	36	3
Physics	9	1
Chemistry	1	0
Geology	5	1
Materials Science	3	0
Others	2	1
Unknown	8	0

* Average of 69 applicants who reported GPA with application.

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