Cooperative Learning: An Interdisciplinary Approach to Problem-Based Environmental Education

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Beginning in the year 2001, engineering education programs in the United States seeking accreditation will be evaluated according to *Engineering Criteria 2000* developed by the Accreditation Board for Engineering and Technology[1]. Outcome measures that will be used to determine the effectiveness of the engineering program include more than merely engineering design and ability to apply knowledge of mathematics, science, and engineering. Engineering programs must demonstrate that their graduates have

- an ability to function on multidisciplinary teams,
- an ability to communicate effectively, and
- the broad education necessary to understand the impact of engineering solutions in a global and societal context.

These outcomes reflect the student's ability to communicate engineering and scientific principles and concepts to his or her peers and to appreciate the perspective and knowledge other disciplines offer to solve societal problems. Engineers must understand that their solutions affect people and, therefore, must be sensitive to societal concerns and expectations.

Working Together for Better Results: Interdisciplinary Teams

Approaching problems from a single discipline produces limited results. In his article "Tearing Down Disciplinary Barriers," Roederer[2] states, "In recent years the solutions of . . . problems in practically all branches of science have been demanding . . . increased specialization on one hand, and the pursuit of an increasingly interdisciplinary approach on the other. This paradoxical development of increasing convergence and specificity . . . is beginning to have a considerable impact on the conduct of research programs. . . ."

The complex nature of the modern work environment and current research issues demand that scientists, engineers, and other professionals work together to understand the task at hand. Universities must answer this demand by educating students to appreciate the advantages of collaborating with professionals from other disciplines and those in their own academic fields. When interdisciplinary teams form, a lack of appreciation for each other's professional perspectives often prevents them from solving problems effectively. Intensive, cross-disciplinary dialogue is then required to produce knowledge all team members can understand. When barriers to interdisciplinary research are overcome, real scientific progress and problem-solving can occur.

An increasing number of publications discuss interdisciplinary teaching teams for university courses[3-7]. A few courses involve interdisciplinary teams of both students and faculty[8-11]. In these cases, "interdisciplinary" usually refers to a few related disciplines working together (i.e. electrical engineers working with computer scientists, chemists working with physicists and biologists, or engineers working with accountants). On the other hand, a course based on an environmental case study offers both students and faculty from a wide range of disciplines and colleges the opportunity to work together. During the spring semester 1997, the Center for the Management, Utilization, and Protection of Water Resources at Tennessee Technological University (TTU) sponsored an environmental case study to test the feasibility of introducing this interdisciplinary approach at the undergraduate level. An interdisciplinary team of faculty and other professionals team-taught this innovative, upper-division honors course.

Designing an Interdisciplinary Class: The Logistics

A three-semester hours course, "Society and the Environment: Conflict, Responsibility, and Opportunity" was a case study of Chattanooga Creek, a federal Superfund site located within minority communities in Chattanooga, Tennessee. A mentor team of 11 professionals (10 faculty and a technical communicator) was assembled. Mentor team members represented the disciplines of microbial ecology, chemistry, fisheries biology, economics, history, sociology, psychology, soil science, technical communication, and environmental engineering (Table 1). A core group of seven faculty members designed the course syllabus, presented lectures, and assessed student performance. The remaining members of the mentor team presented lectures pertaining to group dynamics, environmental history, economics, and technical documentation. Each mentor team member was available to the students outside of class to answer questions and provide guidance during the course.

Similarly, upper-division students majoring in engineering, chemistry, biology, technical communication, psychology, accounting, and education (Table 1) were placed in interdisciplinary teams to study the environmental problem. Students brought to their teams expertise they had acquired previously through class work, on-the-job experience, and extracurricular activities. At the beginning of the course, students completed a questionnaire to provide the mentor team with information about students' work experiences, job skills, and hobbies. The mentor team used this information, in conjunction with the information about academic disciplines, to place students into four teams with appropriate job responsibilities (Table 2). Team members' roles included sociologist, historian, biologist, chemist, economist, technical communicator, environmental engineer, and soil scientist. Due to disciplinary inequities in class enrollment, certain team members had multiple roles and corresponding responsibilities. Since more than half the students were engineers, some students had roles that were based on factors other than major, such as work experience and course work outside their disciplines. Several chemical engineering students were assigned the work of chemists, investigating the chemical properties of the creek's contaminants. Some psychology and education majors tackled sociological issues involved with this environmental problem. Each team selected its own project manager.

The course was divided into two phases. During the initial phase, the mentor team provided students general information regarding factors to be considered when addressing environmental problems (Table 3). These factors included group dynamics, history, sociological issues, aquatic chemistry and microbiology, fish and wildlife habitat, soil physics and chemistry, hydrology, engineering design, technical communication, and economics. Guest speakers presented information on the political and regulatory issues surrounding the problem. The mentor team placed resources on reserve in the university library for student team members needing a more in-depth understanding of a particular topic. In addition, student teams accessed information on the Internet and other available databases. After students acquired some basic information regarding the study area, a site visit was conducted.

At the end of the first phase, each team submitted to the mentor team a written proposal that provided background information about the environmental problem and a detailed work plan describing the process by which the team planned to obtain contaminant data and socioeconomic information needed to develop an action plan to remediate the environmental problem (Figure 1). In addition to the written proposal, the team orally presented and defended its proposal to the mentor team. The mentor team evaluated each proposal and graded the work according to the following criteria: a clear, concise problem statement; defined objectives; well-defined approach that will achieve objectives; defined project organization that delineates responsibilities of team members; anticipated deliverables; and a realistic time schedule to carry out the work plan. The proposals and oral presentations were due at midterm. The mentor team gave each team written and oral comments concerning the strengths and weaknesses of their proposal. This midterm evaluation showed the student teams where they were in relation to what the faculty expected of them. The presentations also allowed the faculty to clarify their expectations to the students.

Student teams devoted the second half of the term to implementing their work plan. Each week the mentor team met separately with each student team to receive a progress report and discuss problems and approaches to resolving them. In addition, students arranged one-on-one appointments with individual faculty members to gain specific input. The entire class was reconvened only for guest lectures. Teams were free to contact state and federal agencies, consultants, and hazardous waste remediation industries to get detailed information about the case study site, land use, meteorological information, demographic information, watershed hydrology, treatment technology and associated costs, educational materials, etc. The mentor team provided team members with possible sources upon specific request. An objective of the course was to provide each team the freedom and guidance to accomplish the work plan and derive an action plan. At the end of the semester, each student team produced a written remedial action plan including a detailed budget (Table 4) and made an oral presentation and defense of the plan to the faculty team (Table 5). Students submitted individual written reports and team members rated each other’s work, allowing the mentor team to evaluate each student’s contributions.

Learning Leadership: Student Project Managers

Students conducted research for the team based on the roles the mentor team assigned. Each team then selected one student to take on the additional role of project manager. The project managers faced challenges unique to this role. At the beginning of the term, each project manager was faced with the task of inspiring teamwork in a group of people from different majors who had never worked together. As the teams approached their first tangible goal of defining the problem, project managers had to conduct research about the case study while simultaneously learning about their individual team members. Even though teams were limited to six students, the diversity within the groups was great enough to challenge every project manager. Once the teams defined the problem, project managers helped synthesize the many ideas team members contributed. Sometimes facing opposition from the team, each manager worked to limit the project's scope in order to create a list of objectives the team could realistically accomplish by the end of the semester.

Each project manager was also faced with scheduling the work of individual members so that everyone could have as much time as possible to complete the assigned tasks. Scheduling was complicated by the interdependence of roles: economists needed design information from the engineers before they could calculate costs; engineers required information from the chemists before they could choose an appropriate remediation technique; and the editor needed everyone's completed work before pulling together and smoothing out the proposal and final report. As a consequence of this interdependence, project managers learned that it is often difficult to distribute the work evenly. Few team members could work on their tasks from the beginning of the semester, but no one's workload seemed to diminish as the final deadlines approached. Aside from trying to keep the team to a time schedule, project managers were often required to help complete a task or reassign it to another team member if someone had difficulty accomplishing it on time. Student project managers gained an intense understanding and appreciation for the different roles within their teams.

Understanding the Impacts: Societal Considerations

The teams' sociologists found most of their demographic information from the U.S. Census Bureau's web site[13] or the Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) files, available on CD-ROM[14]. The most meaningful information, however, was collected by talking with representatives from the affected community. During the site tour, influential Chattanooga Creek residents described struggles to inform the community about remediation efforts in the area. One resident told the class that researchers had come into the area to study the pollution and its health effects for decades, but the affected population's opinions had never been polled, and the community was never informed of the research results. Researchers came in and worked in their own fields, ignoring how the factors interact, or how their work affected the people who live in the contaminated site every day. Residents seemed excited that university students considered listening to them an essential part of their research. The experience made some students wonder how society ever makes progress with such a myopic approach to problems.

The importance of community opinion became obvious when one team picked bioremediation as the site remediation method. Reaction from the team's sociologist was indicative of how area residents might take the news of bioremediation in their community: the student was terrified by the thought of the engineers releasing bacteria into the environment. All this student had ever heard about bacteria was negative, and therefore, it was difficult to listen to engineers explain that the world could not survive without bacteria. The team was stunned. Isolated in their scientific curriculum, the engineering students had never before dealt with such a strong anti-technology reaction. Approaching the problem in a scientific and detached manner, they had chosen the technique they evaluated as the most efficient and thorough, ignoring how the community might react and how community reaction would affect the plan's progress. They expected the community to trust their scientific knowledge and quietly accept any decision the engineers made.

During the site visit, Chattanooga Creek residents did indicate that they are wary of plans to "help them" because of the government's poor track record in this community. One team's sociologist responded to this concern by recommending a community education effort to supplement the remediation plan and allow residents to be involved in the decision-making process and ask informed questions. Many applicable community education resources are itemized on the U.S. Environmental Protection Agency's (EPA) web site[15]. Scientific information contained in these resources, the team felt, would also help residents make healthy choices regarding their contact with contamination in the area. In response to a request from the affected community, the final products from each student team will be sent to an information repository in the Chattanooga Creek community where residents can access the information. The community has already received 500 copies of a Superfund coloring book[16] one team's sociologist received when she called EPA and requested a "sample" to include in the final report.

Investigating the Problem: Scientists and Engineers

Engineering students often solve problems by treating them as ideal cases or closed systems. Much of the skill associated with engineering is knowing how well models can be used for real-world problems. Unfortunately, traditional university approach may not meet these needs. The Chattanooga Creek case study was a positive departure from traditional courses. Engineers were forced to apply existing models and data in an appropriate manner. The course's focus on the community also helped engineers to see the societal impacts of their work.

Once each team defined the project's scope and specific objectives, the team scientists and engineers began their research. Since field sampling and data analysis were not possible within the framework of the course, teams relied on existing data and documents to characterize the site and determine the applicability of various remediation methods to problems peculiar to Chattanooga Creek. A listing of the contaminants present and other relevant site information were found in the U.S. Agency for Toxic Substances and Disease Registry's (ATSDR) public health assessment[17] for the area and the EPA's sediment profile[18] of the creek and ecological assessment[19]. In locating this information, the Internet was an invaluable resource for the teams. ATSDR's web site includes public health statements[20] and toxicological fact sheets[21], which provided students with chemical characteristics and toxicity information for contaminants found at the site. This information helped the teams' engineers select techniques capable of remediating the site. Several teams then approached engineering consultants and environmental companies over the telephone and via e-mail to obtain cost information for potential remediation techniques. EPA's Hazardous Waste Clean-up Information web site[22] and published materials such as *Common Cleanup Methods at Superfund Sites*[23] also provided documentation detailing the costs and effectiveness of treatments used at other Superfund sites. Some teams also downloaded the EPA database VISITT: Vendor Information System for Innovative Treatment Technologies[24] to further research remediation techniques and cost information and to locate vendors who provide such services.

The oral and written presentations provided an added benefit for the engineers. The class forced engineering students to communicate to a wider audience than within a single discipline, teaching them to explain technical information and ideas in terms understandable to the entire team. They were also forced to understand the material thoroughly before explaining it to others since the audience was not simply a group of fellow engineers who already understood the fundamentals. Engineering is often characterized as impersonal because of its focus on numbers and designs. All work, however, ultimately affects people as individuals. This point was made clear by the course and especially by the visit to the Chattanooga Creek community. By seeing that their work is not abstract, but that it affects people, engineers can begin to take social and ethical responsibility to correct and prevent problems like those in Chattanooga Creek.

Communicating Effectively: The Editor's Role

The bulk of the editorial work came late in each phase of the class, so the teams' editors often took on the continual task of translating technical information within the team. The engineers seemed accustomed to talking to each other in technical jargon that they all understood, but this was a foreign language to the student team 'sociologists,' who actually were either psychology or education majors. The need for translation became greater as teams strived to include a community education component in their remediation plans. To make a community education plan work, the scientists and engineers had to make technical information regarding the remediation plan understandable to the teams' sociologists and editors, who were responsible for creating community educational materials for a population where a high school diploma was rare. Therefore, the editors needed a clear understanding of their audience at all times. They had to speak in highly technical terms with the scientists and engineers to gain a thorough understanding of the material thus avoiding subtle wording changes in the final report that would drastically alter meanings. This final report was aimed at a technically educated audience of agency representatives who would decide whether to put the remediation plan into action. As part of that plan, the editors also helped the sociologists/community educators convey this complex information to a population with high illiteracy rates and little technical knowledge.

Once the matter of "audience" was resolved, the biggest editorial task became reworking each team's final report to flow logically and sound as if it had a single author, even though the report was written in pieces by six students reflecting diverse academic backgrounds and varying writing styles. More daunting was the fact that this was all last-minute work. To cover the material thoroughly, editors gave their teammates as much time as possible to write their sections of the report, leaving themselves with as little as two days to pull the report together and fill in any gaps in content. According to the mentor team's technical communicator, this aspect of the class indeed paralleled real-life working situations.

Learning to Work Together: Group Dynamics

The simulated work environment of this class was some students' first opportunity to put their course work into action, since many had not participated in a cooperative education/work program in their majors. The course was also their first group project involving students from other disciplines. The mentor team included a lecture about group dynamics as the first class meeting of the semester, because they felt it was an important topic for an interdisciplinary class. Students agreed that it could have been one of the most important lectures of the course but wished the material had been presented later in the semester, after the teams had experienced some group conflict. If the lecture had occurred a week or two into the teams' first deadline, for example, students might have paid more attention. They might have identified with the information as relevant to their lives and found ways to apply it to team problems, instead of receiving it as merely psychological theory.

Evaluating the Results: Faculty Expectations and Student Achievement

The mentor team designed a course in which students from various disciplines and colleges worked together to solve an environmental problem. In effect, the class was a course in communication, both oral and written, which created an intense dialogue between disciplines in order to erode barriers that cause a lack of appreciation of each other's professional perspective. This course engaged students in the process of learning through sharing of each student and faculty team member's experiences and knowledge. As one technical communication student stated, "This course took learning out of the classroom and placed it in a life situation. It was like an intense practicum[25]." All students brought something unique to their teams; without their expertise the teams were limited in their ability to achieve their objectives. The mentor team was somewhat surprised when none of the students dropped the course after the workload was revealed. In the students' evaluation of the class, they attributed their perseverance to peer pressure: dropping out would let the team down.

Competition between student teams was not the mentor team's intention, but occurred as a natural result of the course's design. Course enrollment was limited to students who were highly motivated and scholarly. Also, student teams were given separate times to meet with the faculty mentors, allowing little direct communication between teams during the second half of the term. This competition was reflected in the teams' level of effort to obtain information. Students contacted professional consulting firms, federal and state agencies, and hazardous waste management firms and used electronic resources to obtain information to enable their team to develop a feasible action plan with realistic remediation strategies and costs that considered human factors. The team oral and written reports surpassed all expectations of the faculty, reflecting the teams' hard work and dedication, which was due in part to their competitiveness.

Looking to the Future: Changes to Consider

The faculty team wanted to include several activities in the class that were omitted because of time or logistical constraints. For example, students would have benefitted from understanding how their performance compared with students performing the same role in different teams. However, with all teams working on the same problem, the mentor team ensured that students did their own work and found resources on their own by limiting the groups' contact with each other. This secrecy between groups prevented students from gauging their progress in relation to the rest of the class and increased competition tremendously. Student teams also did not watch each other's proposal and final presentations so the team presenting last could not take advantage of information presented by previous teams. Videotaping the presentations would have been a simple way to solve the secrecy problem while allowing students to see how other teams had approached the problem, once the final action plans were complete. Taping would also allow students to observe their own presentations and better evaluate their communication skills. The mentor team also wanted an EPA representative to visit the class after the final presentations to discuss EPA's remediation plan for Superfund site studied in class. Such interaction would allow students to see how their work compares to professionals in the field and whether the teams' action plans were realistic. Time constraints made such a visit impossible, however.

Conclusion

Higher education in the United States has evolved to the point where students are taught principles and concepts that focus primarily on their respective disciplines. Once on the job, however, they work in an environment that requires interaction with people of different disciplines and varying education levels. Universities must educate future engineers, scientists, social scientists, and economists to appreciate that their particular expertise is merely one piece of a puzzle which cannot be solved without the expertise of many disciplines. Higher education must provide opportunities where students from multiple disciplines are taught to effectively communicate with each other.

"Society and the Environment: Conflict, Responsibility, and Opportunity" was designed to provide an opportunity to upper division undergraduates in engineering, sciences, education, and humanities to learn how to communicate between disciplines in order to solve a real environmental problem facing a community. Eleven professionals, representing nine academic departments in the university, collaborated to provide a case study where students from diverse disciplines learned how to communicate effectively to solve a problem. According to Dr. Marvin Barker, provost and vice president of academic affairs, TTU is using the class as a model for planning a university-wide interdisciplinary course[26].

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Table 1. Student and faculty disciplines

Academic Department	**Students**	**Faculty**	**Core Faculty**
Accounting	1		
Agriculture: Soil Science		1	X
Biology		2	X
Chemical Engineering	7		
Chemistry	1	1	X
Civil & Environmental Engineering	3	2	X
Early Childhood Education	1		
Economics		1	
Electrical & Computer Engineering	2		
History		1	
Mechanical Engineering	2		
Multidisciplinary Studies	1		
Psychology	2	1	
Sociology		1	X
Special Education	1		
Technical Communication	2	1	
TOTAL	2	11	7

Table 2. Project teams and individual role(s)

Team Name	**Member Role**	**Student Discipline**
RED	Technical Communicator, Historian	Technical Communication*
	Sociologist	Psychology
	Economist	Accounting
	Engineer, Biologist, Chemist	Chemical Engineering
	Environmental Engineer	Chemical Engineering
	Chemist	Mechanical Engineering
BLUE	Technical Communicator, Biologist, Historian	Technical Communication
	Sociologist	Special Education
	Economist, Engineer	Chemical Engineering*
	Chemist, Economist	Chemical Engineering
	Environmental Engineer	Civil & Environmental Engineering
GREEN	Technical Communicator	Electrical & Computer Engineering*
	Sociologist	Early Childhood Education
	Economist, Engineer	Electrical & Computer Engineering
	Chemist, Biologist	Chemistry
	Environmental Engineer, Soil Scientist	Civil & Environmental Engineering
	Chemist	Chemical Engineering
SMOG	Technical Communicator, Sociologist	Psychology*
	Sociologist	Multidisciplinary Studies
	Economist	Mechanical Engineering
	Engineer, Biologist	Civil & Environmental Engineering
	Environmental Engineer	Chemical Engineering
	Chemist	Chemical Engineering

*Project manager

Table 3. Course syllabus

Topic	**Time (hrs)**
Lecture 1: Group Dynamics	1.15
Class Questions & Discussion	0.25
Lecture 2: Historical Factors	1.15
Class Questions & Discussion	0.25
Lecture 3: Sociological Factors	2.5
Class Questions & Discussion	0.3
Group Delineation	
Lecture 4: Chemical Factors	2.5
Class Questions & Discussion	0.3
Lecture 5: Microbial Factors	2.5
Class Questions & Discussion	0.3
Lecture 6: Soil Factors	2.5
Class Questions & Discussion	0.3
Lecture 7: Aquatic Vertebrates & Macrovertebrates Factors	2.5
Lecture 8: Regulations	2.5
Class Questions & Discussion	0.3
Lecture 9: Watershed Hydrology	2.5
Class Questions & Discussion	0.3
Lecture 10: Engineering Factors	2.5
Class Questions & Discussion	0.3
Lecture 11: Economic Factors	1.15
Class Questions & Discussion	0.25
Oral and Written Presentation of Project Proposals Due	
Student Team Sessions with Mentor Team	12
Team Presentations and Final Action Plans Due	

Table 4. Sample cost breakdown for student team final action plan[12]

Final Action Plan Component				**Costs**
Engineering				
Method	**Price**	**Amount**	**Cost**	
Excavation	$100/yd^3	20,354 yd^3	$2,035,400	
Cofferdams	$10,000 each	2	$20,000	
New Soil	$40/yd^3	20,354 yd^3	$814,160	
Transport to Port Arthur, TX	$1144.50 ($1.50/mi @ 763 mi/trip)	120 trips	$137,340	
Transport to Emelle, AL	$400.50/trip ($1.50/mi @ 267 mi/trip)	1078 trips	$431,739	
Incineration	$500/yd^3	2035 yd^3	$1,017,500	
Landfill	$100/yd^3	18,319 yd^3	$1,831,900	
Phytoremediation	$100,000/ac	9 ac	$900,000	
TOTAL Engineering Costs				$7,188,039
Chemistry				$36,750
Sociological				$253,230
Contingency				$747,802
RED Team Firm Costs				$261,730
TOTAL				**$8,487,551**

Table 5. Sample final action plan evaluation

Factors	**Score (0-100)**
Executive Summary	85
Problem Description	95
Clear Objectives	95
History	80
Risk Assessment	70
Sociological Considerations	90
Engineering Considerations	
a. Alternative Selection Criteria	80
b. Design Considerations	80
Economic Analysis	
a. Capital Costs or Amortized Costs	90
b. Operation and Maintenance Costs	90
Presentation of Action Plan	85
Plan Achieves Objectives	95
Final Report	
a. Formatting & Editing	80
b. Figures & Tables	80
c. Referencing of Materials	80
d. Supporting Material	70
Total Score	1345
Total Possible Score	1600
Ratio	0.84

I. Introduction

- Problem Statement or Delineation of Problem
- Scope - *“To prepare a preliminary remedial action plan for selected uncontrolled hazardous substances disposal sites in the Chattanooga Creek area.”*
- Objectives

II. Background Material

Describe the events leading to the situation where the public became aware of the problem and demanded action.

III. Approach

- Type of Information Needed by the Team
    - Risk Assessment Information
    - Hazard Identification
        - Physical and Chemical Properties
        - Toxicological Effects
        - Route of Exposure
    - Dose Response Assessment
        - Exposure Assessment
        - Risk Characterization
    - Information Characterizing the Population at Risk
        - Cultural Characterization
        - Economic Characterization
        - Educational Levels
        - Community Decision Making Structure
        - Age Distribution
    - Information Characterizing the Watershed
        - Hydrology
        - Land Use Delineation
        - Soils Characterization
        - Point and Non-Point Sources of Contaminants

The information gathered will be both quantitative and qualitative.

- How the information will be collected
- How the information will be analyzed
- Organizational plan of the team

IV. The Products to be obtained from the study

V. Proposed Time Schedule

Figure 1. Proposal Outline