ENHANCING TECHNICAL COMMUNICATION SKILLS OF ENGINEERING STUDENTS: AN EXPERIMENT IN MULTIDISCIPLINARY DESIGN

Robert J. Fornaro¹, Margaret R. Heil² and Steven W. Peretti³

Abstract -- A multidisciplinary team of chemical engineering and computer science students collaborated to design a plant capable of producing commercial quantities of citric acid. This project required the students to produce a bench-scale chemical engineering facility and a computer system to monitor production in accordance with Food and Drug Administration (FDA) regulations. A previous attempt at student collaboration on a similar project produced less than stellar results. An evaluation of that experience revealed the most significant challenge to project success was establishing effective teamwork and appropriate technical communication across the two disciplines. This paper will describe the results of the most recent multidisciplinary team experiment, in which emphasis was placed on developing communication between student teams. A description of the synchronization of project development methodologies between the participating disciplines will be discussed as well as how this contributed to enhancing technical communication between the teams and enabled the latest project to progress to a successful conclusion.

Index Terms – Capstone Courses, Multidisciplinary Teams, Undergraduate Computer Science Education, Undergraduate Chemical Engineering Education, Senior Design Experience.

INTRODUCTION

It is often the intent of undergraduate capstone design courses to provide students with an experience that serves as a transition from academic to professional life. In refining the nature of that transition, supporters of engineering education have recognized the need to integrate teamwork more fully and formally into an undergraduate education [1-5]. Also, local industrial advisors have stressed the importance of teamwork, writing, and speaking in industrial practice. The Industrial Advisory Board of the NC State University (NC State) Computer Science Department, and the local chapter of the International Society of Pharmaceutical Engineering (ISPE), acting in an advisory capacity to the NC State Department of Chemical Engineering, both claim that communication skills are at least as important as technical skills for success in the corporate environment. Additionally, given the disciplinary diversity of the pharmaceutical industry, the ISPE recognizes the usefulness of placing undergraduates on multidisciplinary design teams. To encourage similar activity at NC State, the Carolina Chapter of the ISPE has spearheaded an effort to support capstone design courses offered at NC State by providing mentors to multidisciplinary teams of students.

In response to this advice, the Departments of Chemical Engineering and Computer Science, in the NC State College of Engineering, are cooperating to establish an ongoing multidisciplinary student experience. Initially, these two departments are participating, but the goal is to establish instructional principles and techniques and widen the multidisciplinary approach to include other departments in the College of Engineering as well as departments University-wide.

Over the past several years, computer science capstone design courses at NC State have included instructional components that emphasize teamwork, the relationship of teamwork to software engineering, and writing and speaking to various audiences about a project. The focus of these courses has been to encourage students to solve a problem using the framework that teaming provides to leverage their existing technical expertise in software design and development. We have previously reported on a cross-functional design experiment entirely within computer science that highlighted the importance of the incorporation of team training to overall project success [6]. In the experiment described in this paper, computer science and chemical engineering students, enrolled in two separate capstone courses, received identical formal training and coaching related to teaming, writing, and speaking. We describe the courses involved in this multidisciplinary effort, the nature of the experiment, and the approach to managing student teams. An overview of the specific student project is also provided. We conclude with a summary of observations and ideas for improving multidisciplinary student design team experiences.

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**MULTIDISCIPLINARY TEAM EXPERIMENT**

In this section, we provide details about the courses involved, the creation of the multidisciplinary team environment, and the student project.

**Course Descriptions**

Two senior design project courses were the focus of this experiment: one in computer science, CSC 492, and one in chemical engineering, CHE 451.

**CSC 492 – Senior Design Projects.** Over the past several years, the NC State Computer Science Department Senior Design Center has been developing a pedagogical model that integrates software development process methodologies, teaming, writing, and speaking. The Center supports a 15-week capstone senior design course, CSC 492, which offers teams of computer science students the opportunity to participate in developing a software product for a business in the local area. In addition to providing the project problem, the industrial sponsor also provides a contact engineer who helps to guide the student team throughout the semester.

Student grades are assigned based on 50% individual contribution and 50% team contribution. Individual contribution is measured by activity logs and peer and instructor evaluations. Documentation and other deliverables contribute to the team grade.

Supplemental instruction related to various software development methodologies and writing and speaking is also provided. Although technical skills are obviously required to complete the project, CSC 492 focuses on the choice and use of an appropriate software development methodology, the communication of that process, and the teamwork that provides energy to this entire scenario [7].

**CHE 451 – Senior Design Projects.** The primary focus for students in CHE 451 is to design a chemical facility using this prescribed methodology to guide them: 1) refine problem statement, 2) define operational flow sheet and simulate the process, 3) define equipment, and identify energy, utility and waste disposal requirements 4) perform preliminary analysis of profitability, 5) optimize the process, and 6) analyze environmental and safety issues. The projects typically focus on the performance of large-scale chemical facilities and deal only superficially with non-chemical engineering issues.

Team performance in technical areas is reflected in grades given for reports on each phase of development of the chemical facility, oral and/or written. Teaming performance is student-evaluated, with each team member submitting two peer evaluations per semester, one at mid-semester and one at semester end. These evaluations are used to modify the final grade for each individual on the team.

**Creation of Computer Science/Chemical Engineering Multidisciplinary Environment**

A Multidisciplinary Project. The creation of an appropriate multidisciplinary environment begins with identifying a project that has suitable depth and content to occupy relatively large teams of students over the course of a 15-week semester.

During the Spring 2000 semester, the Carolina Chapter of ISPE formulated a design project that required students to design a facility capable of producing commercial quantities of citric acid via fermentation and purification processes. The project also required that a Manufacturing Execution System (MES) be designed and implemented to support this facility in accordance with the Food and Drug Administration (FDA) regulations.

Regulations instituted by the FDA regarding drug production mandate a complex set of reporting requirements. Likewise, these regulations in large part drive the structure and accessibility of the data archive system. The definition of the system is derived from specific product and associated manufacturing operations. The student team ultimately chosen to participate in this project needed to understand these regulations as well as the chemical processes and procedures, the points at which the data needed to be collected, and the nature of the interface with human users. Archival elements of such a system also needed to be defined and developed.

The instructors of CSC 492 and CHE 451 used this project to create an experiment that required the development of a multidisciplinary team. In this context, a multidisciplinary team refers to a relatively large group of students, industrial sponsors, and faculty mentors committed to solving a single application problem that spans more than one discipline (in this case, computer science and chemical engineering).

A Multidisciplinary Problem Solving Superstructure. Capstone projects in the NC State Computer Science Department use teaming as a framework to improve student project performance. The pedagogical goal of this approach is to integrate teaming, technical communication, and software development. The importance of team instruction and monitoring to the overall success of projects is emphasized. This approach shows how effective teaming strengthens development methodology and technical
communication which, in turn, lead to the creation of a high quality product.

In order to use this approach in a multidisciplinary environment, it is necessary to define a problem solving superstructure that can be understood and used by all of the disciplines involved, to define and solve calendar and scheduling issues, and to define an appropriate format for teaming instruction.

Each discipline relies upon a specific culture and language to establish a methodology for problem definition and solution. When multidisciplinary projects are undertaken, the concept of a common problem-solving methodology is not clear. Language differences need to be overcome and some common agreement as to the elements of the joint problem-solving approach needs to be defined by all participants.

Calendar and scheduling issues in a discipline-specific single course are self-contained and relatively easy to solve by participants. However, when a project overlaps disciplines, advanced planning with respect to calendar issues and instructor collaboration on grading, policies, and deadlines for deliverables is critical. These issues seem obvious at first, but if they are neglected, multidisciplinary efforts can fail based solely on these issues alone. Faculty and staff involved must also function effectively as a multidisciplinary team prior to the initiation of the project.

In anticipation of creating a multidisciplinary team, instructors of CSC 492 and CHE 451 coordinated syllabi and calendars. This required a reconciliation of the chemical engineering design methodology discussed earlier in this paper with the traditional waterfall software development methodology used in computer science. The reconciliation led to the parallel development tracks illustrated in Figure 1. The intent was to coordinate the project phases of both disciplines so that student collaboration was encouraged.

**Multidisciplinary Team Formation.** A multidisciplinary team of 9 students was formed (5 chemical engineers and 4 computer scientists). **After given a chance to review available projects, computer science students were asked to complete information sheets listing their expertise and interests, 1st, 2nd, and 3rd project choices, and class/work schedules.** The instructors reviewed the information sheets and considered student interests and schedules while forming teams. Chemical engineering students were chosen from a larger class by the CHE 451 instructor based on expertise and interests.

**Multidisciplinary Team Instruction and Collaboration.** Teaming instruction supports the interaction that occurs within the multidisciplinary environment. The students must be introduced explicitly to the notion of teamwork and given specific instruction regarding components that contribute to successful teaming. It is insufficient to simply charge a student group with a project and explain the necessity for collaboration. That approach does not overcome disciplinary differences within the group and leads to recriminations among students along disciplinary lines when project benchmarks are not achieved.

The multidisciplinary experience was team taught by computer science and chemical engineering faculty members and a technical communication consultant (i.e., the Team Coordinator) with expertise in teaming, writing, and speaking. Time was allotted in the beginning of the semester to provide students with formal training on the principles of teamwork. Students were given formal team training in the areas of role development, leadership direction, interpersonal communication, effective meetings, and task planning.

The Team Coordinator provided teaming instruction at different times to both computer science and chemical engineering students. Students were also taught the difference between team meetings and work sessions: Meetings are a time when the team convenes to decide on major directional decisions and to report on completed research and work; work sessions are described as times

### FIGURE 1
"CONSENSUS" COMPUTER SCIENCE & CHEMICAL ENGINEERING METHODOLOGIES

<table>
<thead>
<tr>
<th>Software Development Methodology</th>
<th>Chemical Facility Design Methodology</th>
</tr>
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<tbody>
<tr>
<td>Problem Statement Refinement</td>
<td>Refine Problem Statement</td>
</tr>
<tr>
<td>Requirements Analysis &amp; Definition</td>
<td>Process Flowsheet Definition</td>
</tr>
<tr>
<td>Design of System Architecture</td>
<td>Detailed Equipment Description</td>
</tr>
<tr>
<td>Implementation &amp; Testing</td>
<td>Integration of Unit Operations</td>
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<tr>
<td>Installation</td>
<td>Process Optimization</td>
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when two or more team members are working together on a specific task.

The Team Coordinator worked with the multidisciplinary team to establish a task plan, identifying dependencies and deadlines. The correct usage of meeting minutes and agendas was explained and motivated as a means to support the task plan and to clarify individual responsibilities and contributions.

The team’s collaboration was monitored by the instructors throughout the semester. The Team Coordinator facilitated student team meetings and reviewed meeting minutes as well as individual contribution logs. One student liaison from each discipline was selected and responsible for coordinating meeting times and communications with the faculty and sponsor advisors. A team leader from each discipline was also chosen; this student designated tasks to subteams and monitored their progress.

**Multidisciplinary Team Communication.** Students participating in this multidisciplinary effort were required to interact with various audiences. The Coordinator provided supplementary instruction appropriate to the technical communication requirements (i.e., writing and speaking) set out by the problem solving superstructure and synchronization of deliverable deadlines. Students were expected to communicate with fellow students in their discipline, teammates in another discipline, faculty and industrial mentors of various backgrounds, and general scientifically literate audiences. This experience provided a rich communication structure where students were required to write and speak using languages of various discourse communities.

**Project Execution**

Although the students attempted to follow the side-by-side methodologies in Figure 1, they soon recognized obstacles that would not allow them to fully develop the system requirements in time to meet established deadlines using that approach. The student team then adopted an iterative approach based on Watts Humphrey’s Team Software Process [8]. This forced both groups outside of their “comfort zones,” which probably contributed significantly to their subsequent teaming success. The chemical engineers had to provide computer scientists with relevant information on a timely basis, but before operational analyses were complete. Simultaneously, the computer science students had to develop a complementary interface to the system that changed over time, depending upon feedback obtained from the chemical engineers. The important element here is that the students recognized the need to restructure the project's design methodology.

To set the stage for this level of interactive decision making, the initial team meetings and work sessions focused on having the students teach each other about discipline-specific languages and problem-solving approaches. The students were encouraged to describe to each other concepts of their discipline, and to share their expectations of the capabilities of practitioners of the other discipline. Initially, this exercise was divorced from any mention of the project itself. The familiarity that grew out of this exercise was instrumental in facilitating subsequent discussions focused on the project. Ultimately, this led to the development of a working environment in which the students could recognize the need to restructure the team’s operating strategy, and to implement such features as a project web site to provide a convenient platform for cross-disciplinary communication. The result of all this was that the students agreed to three successive versions that built upon one another as illustrated in Figure 2.

Each iteration of the software system is illustrated by shading variations, read from bottom to top, in Figure 2. This design represents a successive refinement of the overall application. Delivery dates for each iteration functioned as synchronization points between the discipline-focused activities, motivating progress that ultimately supported the team’s overall performance. For example, at the start of the project, the chemical engineers provided baseline information to the computer scientists so that the initial system development could be started. As the computer science students were creating the initial iteration of the system, the chemical engineering students were taking the unit operations involved in citric acid production from paper into the laboratory. The insights that the chemical engineers provided led to successive refinements of the software system.
engineering students gained from this experience prepared them to provide detailed, productive feedback to the computer science students who could then create a more sophisticated iteration of the system.

This iterative approach also allowed the system to develop with essential usability checkpoints. A basic graphical user interface (GUI) was developed as a part of the first iteration. After the chemical engineering students tested the GUI, they offered suggestions to the computer science students about ways to improve the GUI for the next iteration. This user-centered testing ensured a higher quality final product.

**Observations**

There were a number of important observations made during this experiment. Scheduling differences were a major problem. The nine students on the multidisciplinary team had a difficult time finding common intersecting meeting times. Student schedules are varied and solving this appropriately requires prior planning.

Initially, the concept of “the team as a whole” was difficult for the students to grasp. The chemical engineering and computer science student groups spent significant time and energy discussing which of them was the “project sponsor” and defining deliverables. They persisted in thinking of the groups as separate, with little formal interaction. This mindset was broken down as a result of team instruction and facilitation. For example, once the students were persuaded that ISPE was the sponsor and that they were a single design team, one computer science student and one chemical engineering student from the team met and created paper prototypes of the system’s graphical user interface. This simple interaction proved to be a pivotal point in the project because technical language differences were specifically identified and explored. These discoveries were shared with the entire team and eventually led to the development of the coded interfaces of the system.

Many of the team’s presentations were prepared collaboratively. By necessity, the students were required to integrate disciplinary concepts into one package to present to various audiences. This helped them to build confidence using the language of a discipline other than their own.

On the other hand, written documents were not prepared collaboratively. The computer science students wrote a document related to each iteration of their software system, and chemical engineering students wrote documents related to each phase of the prescribed chemical engineering methodology. Although each of their documents contained scattered information about the discipline other than their own, that information indicated a superficial understanding of that discipline and a devaluation of the contribution made by that discipline to the overall effort.

The administrative structure of the two courses was responsible for some of this continuing dichotomy. Despite arranging for common meeting times, and insisting on collaborative documents, the faculty could not (or did not) fully separate these teams from the rest of their disciplinary design classmates, so that final presentations were required for each course in different venues, to dramatically different audiences. This supported the tendency on the student’s part to think of the project as a “computer science” or a “chemical engineering” project, so students tailored their presentations, emphasizing disciplinary aspects in their presentation rather than presenting it as a fully integrated project.

**Conclusion**

The most important outcome of this experiment was, by any measure, that the project was easily rated a success. Technical components from each discipline accomplished all the goals that were defined. Chemical engineering students defined and documented unit operations and actually produced a bench run of citric acid. Computer science students defined and documented an appropriate database and interface and built and demonstrated a prototype understood by and useful to chemical engineers. All participants, students, faculty, and industrial sponsors alike, observed a transformation over the course of the semester. At the beginning, typically, students were uncertain and somewhat muted in their enthusiasm for the multidisciplinary elements of the project. At the end, all exhibited openness with each other and pride in their joint accomplishment. It is the authors’ opinion that the multidisciplinary environment, as established and described above, set the stage for this successful outcome.

Comment from reviewers: Needs an objective assessment of the benefits...how did the Advisory Board, the ISPE, and the industrial mentors rate the experiment? Was there any process for students who participated to rate their experiences? Is there any follow-up with graduates as to the enhancement to their marketability and/or suitability to current work environment?

Steve, we need to address the above. We have informal feedback from sponsors saying how great this is and the students have often said how much they are able to discuss such experiences during interviews. Our course evals are generally very good-excellent.
FUTURE DIRECTIONS

The most striking lesson learned from our experiences with multidisciplinary design projects is that the ultimate success of the team is determined by their ability to overcome communication and organizational problems, not technical ones.

The communication challenges recognized during the experience described in this paper reinforce the perception that explicit instruction in teaming and communication is a critical element of successful multidisciplinary design courses. The experience of the students also indicates that the development of a team website would promote multidisciplinary team communication. Students should be able to view course syllabi, calendars, and class notes, as well as submit written assignments via the website. They should also be able to access automated individual log files for evaluation and record keeping purposes. This website would permit instructors to accommodate the wide range of student schedules and locations inherent in multidisciplinary projects. Development of such a collaborative and instructional website is currently in progress.

The creation of a common multidisciplinary problem-solving process that could potentially encompass (or at least accommodate) problem-solving methodologies from several disciplines seems to be in order. Mackay and Fayard propose an approach they call, "triangulation," for the solution of multidisciplinary problems [9]. They observe that research and design activities often force a particular population outside the normal paradigm for their discipline. Triangulation refers to the use of problem solving methods normal for one paradigm within others. More specifically, it is a framework that includes both deductive and inductive approaches to experimentation. This encourages researchers to bring various skills to the multidisciplinary problem-solving table. The authors conclude that such triangulation is more likely to be beneficial in multidisciplinary fields such as human computer interaction. To adopt their approach, it would be necessary, for example, to take a problem and see how it is approached by the cooperating disciplines to determine its solution. A similar activity was carried out as a component of this experiment, when instructors collaborated to produce "side-by-side" problem solving steps appropriate to computer science and chemical engineering. This proved to be one of the most important elements of the multidisciplinary environment created in this experiment.

To further bolster the students communication skills, the NC State Chemical Engineering Department has begun a program with the NC State Campus Writing and Speaking Program, supported by the National Science Foundation (NSF) to develop teaching modules related to writing, speaking, and teaming in a multidisciplinary, design environment. Students from all disciplines will attend the communication/teaming module, which will run through the entire semester. The oral presentations and written reports required for the design course will serve as the basis for formal instruction and workshop activities centered on team collaborative efforts.

This is one part of a larger effort by the Chemical Engineering Department to initiate an interdisciplinary undergraduate program that integrates cooperative learning instruction, teaming activities, writing and speaking opportunities, hands-on experimentation, and multidisciplinary design. The goal is to create a thematic, cross-disciplinary, multifunctional learning experience that represents a revolutionary approach to engineering education.

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