2006-401: INTERDISCIPLINARY DESIGN TEAMS - LESSONS LEARNED FROM EXPERIENCE

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Interdisciplinary Design Teams – Lessons Learned by Experience

Introduction

Capstone design has traditionally been a highlight of a student's study at LeTourneau University. As a general engineering program offering a B.S. in Engineering with concentrations in Electrical, Mechanical, Computer, Biomedical, and Materials Joining, it is our goal to involve as many students as possible in an interdisciplinary design experience involving two or more concentrations. As we offer projects each year, we define more clearly the purposes and guidelines for the senior design experience, important lessons in interdisciplinary design, and the factors for project success.

Student involvement in interdisciplinary teams is not only an expectation of industry but also has become a required outcome of the ABET engineering criteria. EC2000 criteria now include outcome 3d which states that "engineering programs must demonstrate that their graduates have…an ability to function on multi-disciplinary teams."[1] This requirement can be met in a number of ways, including a structured simulated experience or by an actual capstone project that requires the involvement of several disciplines.

Obstacles to multi-disciplinary teamwork, including disciplinary competition, communication problems, and scheduling difficulties often limit the effectiveness of such teams. We previously reported[2] on a series of curriculum "tools" which have been initiated in our program to insure that students will have a measure of success in project teamwork. These methods include (1) multiple and varied opportunities for projects in teams, (2) early involvement in senior project teams, (3) specific training for teamwork, (4) coursework in and application of project management techniques, and (5) the use of multiple items of feedback to determine the contribution of each team member.

Purposes and Guidelines

Senior design projects in our engineering curriculum serve a number of purposes for the students:

1. Experience involvement in a capstone design, using prior course material to solve an ill-defined problem and to develop a workable solution.
2. Bring a "paper" design to reality and learn from the experience of solving unexpected problems.
3. Gain familiarity with design techniques and project management tools.
4. Interface with a client, develop specifications, and present reports.
5. Develop teamwork skills.
6. Learn new techniques, which become required as the project develops.
7. Gain exposure to significant interdisciplinary work wherever possible.
8. Mimic industry approaches on a small scale.

Senior design faculty in our program have developed the following guidelines for the senior design courses:

- Every project must be approved by faculty members as being reasonable in scope and appropriate in level of difficulty.
- Every project must have an external client or faculty sponsor (other than the course instructor) to whom the students present progress and results.
- Every project must develop realistic specifications based on interviews with the client and others.
- Results of every project must be demonstrated and shown to work completely by the end of the second semester.
- Each project should include consideration of such realistic design constraints as economics, safety, reliability, ethics, standards, and social impact.
- Every project must include a complete final report and a public presentation to which we invite industry visitors.

Additional observations for our courses include the following:

1. A wide variety of project types have existed – SAE and other competitions, industry projects, funded research, and third-world development projects. Not all projects will have the same scope or requirements. Flexibility is essential.
2. Ideally, the original client should submit a written RFP (Request for Proposal), spelling out what is needed or expected.
3. Project needs, not project paperwork, must drive a project. Artificial paperwork and analyses should be avoided.
4. Project teams should report their progress on a regular basis, weekly or biweekly.
5. Students should be guided where necessary but questioned constantly on their choices and allowed room to fail if they do not follow through.
6. Ideally, student teams should be following concurrent engineering practices, with all parties involved at every stage.

The 2005-2006 interdisciplinary projects are shown in the following table:

Project	Disciplines	Description
Phoenix	EE, ME, CSE, CS	Develop unmanned autonomous vehicle for competition
Formula SAE	ME, ET	Develop Formula-style race car for SAE competition
EWH	EE, CE	Develop inexpensive pulse oximeter tester for third-world use via Engineering World Health
LEGS	BME, ME, MJE, Biology	Advance development of inexpensive prosthetic leg for third-world use
Prosthetic Arm	BME, EE, ME	Advance development of intelligent prosthetic arm
Welding Power Supply	MJE, EE	Develop alternative power supply to improve stud welding
Mini Baja	ME, MT	Develop Baja-style vehicle for SAE competition

Table 1. Current Interdisciplinary Senior Projects

BME – Biomedical Engineering concentration
CE – Computer Engineering concentration
CS – Computer Science major
CSE – Computer Science and Engineering major
EE – Electrical Engineering concentration
ET – Electrical Engineering Technology (technology concentration)
ME – Mechanical Engineering concentration
MJE – Materials Joining Engineering concentration
MT – Mechanical Engineering Technology (technology concentration)

In addition, a Design Technology student is available to most teams to assist with drafting and graphical presentations.

Lessons Learned

A valuable exercise after students have completed one semester of a two- semester project is to ask the students to share feedback with the class on "lessons learned by experience over the last semester." Nearly every team that responds includes the following observations among several on their list: "Be aware of the learning curve, but begin designing by mid-semester," "Early ordering of parts is essential," and "Good communication is critical."

As projects are offered each semester the instructors also learn a number of new lessons about interdisciplinary teams, sometimes from areas that failed. Some of the recent significant lessons include:

1. Design documentation is as critical as design.

   Every project must be clearly documented, particularly if the project will be carried on by others in the future. Our teams develop some form of project notebook, final report, often a user's guide, and typically a CD containing all schematics or parts drawings, data sheets, and pricing. Design faculty need to emphasize that the report is not simply an exercise or an item to be read by the instructor but a vital item to be passed on to the client or to subsequent teams. Documentation skills need to be taught early in the curriculum, ideally in the freshman year.

2. Timely completion is as critical as the level of "perfection" in the engineering design.

   A project with great capability which is not fully functional at the end of the semester is essentially useless. In order to run verification tests and to prepare final reports, students should complete their projects a week or more before final presentation date. Ideally, a working prototype should be available a full month before completion date. Gantt charts and regularly scheduled progress reports become key elements in time management for the project teams. Faced with strong deadlines, students learn the importance of streamlining design and not wasting time adding "bells and whistles" which consume time and resources.

3. A clearly stated purpose statement can keep a team from losing focus.

   A constant "danger" for a student learning design is to become so focused on part details that he or she begins to miss the original objective of the project. The goal of a Formula Car or Mini-Baja competition team, for example, is not simply to produce an elegant design but to compete well and to be a top contender in the competition. This means that (1) the project specifications are driven by the competition rules, and, that (2) part of the planning must include adequate time for competition specific needs, such as driver or pilot training.

   Examples of purpose statements include:

   "It is our goal to successfully acquire and install all necessary electrical and electronic components required for the SAE formula competition vehicle in a timely, orderly, and professional manner in such a way as to have as little impact as possible on the vehicle's weight and ease of use and repair."

   "The EWH team exists to partner with the Engineering World Health organization in the design and development of a reliable, low-cost pulse oximeter tester for use in a third world hospital."

4. Close involvement by faculty sponsors/ advisors is indispensable to team success. If multiple faculty sponsors are involved, they need to maintain good communication with each other.

   A single faculty member cannot be deeply involved in five or six capstone projects. Each of our projects now requires a faculty sponsor in addition to the course instructor (who typically sponsors one of the teams). In certain cases, the faculty sponsor is the Principal Investigator in an area of research which includes student workers. The project sponsor meets weekly with the team or team leader and helps to keep the project on track, asking such questions as these:
   - Are the goals clear?
   - Is the time line reasonable?
   - Is the technical approach feasible?
   - Is there a backup plan including alternate leadership in case the team leader should become ill or drop out of the project?

   Currently the faculty sponsor is responsible for assigning at least 20% (and up to 75%) of the course grade based on observation of the student's planning, participation, and teamwork.

5. Monitoring of individual student effort is time-consuming but essential.

   Some of the teams have recently added a project management tool, the Action Item Matrix, to help keep individual students on track. The Action Item Matrix lists each task, the target date, and the person responsible. Bottlenecks are readily spotted.

In addition to assigned responsibility, evaluation of teamwork is important. A tool recently utilized is a simpler peer evaluation survey, with nine categories of peer evaluation related to team contributions. Seven of the nine categories come from *The Team Learning Assistant Workbook*.[3] On a scale of 1-5, each team member evaluates everyone else on the team in the following areas-

1. showing initiative by taking on tasks
2. preparing for and attending scheduled meetings
3. making positive contribution to meetings
4. reliably fulfilling assignments on time
5. producing work of high quality
6. supporting, coaching, and encouraging other team members
7. listening carefully to ideas and contributions of others
8. managing conflict effectively
9. responding well to constructive criticism

This evaluation can also be included in the course grade.

6. Excellent communication between the different disciplines is essential.

All members of the team must work from a common Gantt chart. Milestones must be agreed upon by all involved so that no sub-team is waiting for another sub-team in order to proceed.

7. Expectations of each discipline must be clearly communicated to all other disciplines.

The deliverable items and their "due dates" from one discipline to another must be fully understood by all team members and faculty. To insure that deadlines are followed, we now include a "milestones met" portion into the project grade.

8. The importance of good project management increases tremendously with the number of disciplines involved in the project.

An interdisciplinary project requires a strong team leader, able to lead students not only in their own discipline but in other disciplines as well. The student selected as overall team leader must essentially become both a project manger and a systems engineer for the year. That student must go beyond his or her own discipline and oversee all parts of the project, typically interfacing with a sub-team leader from each discipline. The project leader must be the one who continually keeps the "big picture" in mind.

The "Phoenix" Project

One highly interdisciplinary project undertaken by our students in recent years is the design of an autonomous flying vehicle to enter the aerial robotics competition sponsored by the Association for Unmanned Vehicle Systems International (AUVSI). The initial phase of this competition is to design and build a flying vehicle which can achieve autonomous flight and follow a path of designated GPS waypoints. The final phases of this competition culminate in the vehicle (or a sub-vehicle) autonomously entering a designated building and sending video surveillance information to the base. Our design team for this project has involved electrical, computer, and mechanical concentration engineering students, as well as computer science students.

This project has been in existence in our program for two and a half years (with a new team of seniors each year), has run into many obstacles, and made good progress, but has not yet achieved autonomous flight. This is a highly interdisciplinary team, with the project being "driven" by the electrical discipline students, but with critical roles begin filled by mechanical and computer engineering students, as well as computer science students. Following are some lessons learned from this experience:

1. It is very important to have a strong leader and particularly difficult when the strongest leader on the team is not in the "driving" discipline. This year, the team leader is a mechanical concentration student. It is very challenging for him to oversee and provide leadership to the electrical and computer students on the project when their disciplines are "driving" the project. In this case, strong student leadership skills are even more important and it becomes even more crucial to have strong faculty sponsor involvement.

2. It is very important that students of the different disciplines establish a common Gantt chart that includes crucial milestones where the disciplines "interface." Unless very clear inter-disciplinary milestones are established, the students in a particular discipline will oftentimes blame their failure to reach a critical milestone on the "fact" that students of another discipline did not provide something that was crucial to the process. The needs of each discipline which depend on another discipline must be very clearly defined and understood by all disciplines.

3. One must be very careful to do the proper preparatory work when working with students from "across campus." At our university, the computer science (CS) students are part of the department of math and computer science, which is part of the School of Arts and Sciences. The faculty members who teach the engineering senior design courses have no grading authority over these students. It is important to work with the CS faculty to find appropriate coursework for these students to receive credit for their work and to communicate clearly concerning expectations and grading standards.

The L.E.G.S. Project

Our most successful and well-publicized interdisciplinary design project to date has been the L.E.G.S. Project of 2004-2005. This project used the talents of four students from three engineering disciplines: two mechanical, one biomedical, and one materials joining, as well as a Biology (Pre-Med) student to assist with rehabilitation. The team was charged with developing a functional and high-durability prosthetic leg for above-knee amputees. Since most amputees in developing nations are unable to afford an articulated joint prosthesis, the leg was designed for on-site production using local staff in a developing nation at a cost of under one hundred US dollars. Engineering issues included design of the knee joint, support strength, choice of materials, and socket design, as well as rehabilitation and gait performance. The leg needs to last for at least three years, with ease of fit and alignment. Prototypes were tested in our gait lab before the final design was approved. In June of 2005, the entire team traveled to the Bethany Crippled Children's Hospital in Kinjabe, Kenya, and fitted patients with the newly-designed prosthetic.

A polycentric knee was designed to balance ease of swing with knee stability. The knee is made of Delrin TM, a dense durable plastic. The foot is also made of Delrin TM and designed for maximum deflection during normal and medium loading conditions. Both the knee and foot are able to be cut and finished with existing power tools (band saw and drill press) in the Kenyan clinic. Sockets are custom-fit to patients, built from fiberglass and nyglass.

The prosthetic designs were subjected to static, fatigue, and impact loading tests. Mechanical testing was based on the ISO 10328 standard for lower limb prostheses. Students designed a test fixture for a Tinius Olson compression machine as well as a fatigue testing machine specifically for the leg. In addition, the prosthetic designs were tested for gait analysis, motion analysis, patient energy consumption, and comfort of fit on patients in the Biomedical Engineering gait lab.

Among the qualities of high-performing teams Thamhain and Wilemon[4] list the following, which, according to faculty, characterized the L.E.G.S. students:

- High involvement, work interest, and energy.
- Capacity to solve conflict.
- Good communication.
- Good team spirit.
- Mutual trust.
- Self-development of team members.
- Effective organizational interfacing.
- High need for achievement.

Interdisciplinary team success for the L.E.G.S. project hinged on five factors according to the project sponsor:

1. The project and specifications were clearly defined and understood by all. The prosthetic developed had to be inexpensive, maintenance- free and capable of providing functional gait.
2. Team roles and expectations were clearly defined. Mechanical Engineering was responsible for the design of socket, knee and foot. Materials Joining Engineering had the task of selection, joining, and testing of materials. Biomedical Engineering interfaced with patience and had oversight of gait lab experiments.
3. Individual student involvement was maximized. The nature of the project, particularly the aspect of humanitarian aid and "providing a blessing" to a disabled child overseas was a strong motivation for working on the project far beyond the bounds of the course.
4. The student team leader/project manager kept the team on track. The team leader spent the previous summer researching prosthetics used in developing nations, traveled to Kenya over Christmas break (mid-point in the project) to pilot-test the design, and worked with American patients to test the legs in our gait lab.

5. The team was sufficiently small that problems were readily worked out. An area of lab space was assigned to the team for the year, and the students met almost daily to work on the project and to discuss problems and progress.

Conclusions

Interdisciplinary teamwork is ideally learned by participation in a well-structured senior design project experience. Both technical and interpersonal problems will arise naturally, and students will develop a measure of confidence in solving such problems. The structure of the capstone course as well as earlier courses will change incrementally as lessons learned get implemented into the courses. Students who complete these courses and projects will be well-prepared for similar experiences in industry.

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