

Five Curriculum Tools to Enhance Interdisciplinary Teamwork

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Abstract

An ability to function well in a multidisciplinary team has become an expectation of modern industry and a major goal for engineering students. Since LeTourneau University offers a general engineering degree with five concentrations, multi-disciplinary design projects naturally arise at all levels of the curriculum. Current capstone projects involve student teams from up to three engineering disciplines, plus computer science, design technology, and marketing. Obstacles to multi-disciplinary teamwork, including disciplinary competition, communication problems, scheduling difficulties, and minor “turf wars” can limit the effectiveness of such teams. A series of curriculum “tools” have been initiated 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.

Introduction

Interdisciplinary engineering teams have become a standard expectation in industry and a requirement in education. The following paper presents a number of ideas for enhancing teamwork in the engineering curriculum.

Most engineering graduates employed in industry will work in collaborative teams. Current projects, particularly those in aerospace, defense, and vehicle design, are of such magnitude that the involvement of multiple disciplines becomes essential. Separation of disciplines essentially disappears in much of modern industry.¹

Some of the advantages of project teams include:

- Teams provide the most efficient use of workers’ skills.
- Employees are able to pool knowledge and ideas to arrive at better and more creative problem solutions.²
- Teamwork based on coordinated tasks and peer leadership permits removal of layers of hierarchy.³
- Teams benefit from the combination of people with diverse characteristics, skills, knowledge, and capabilities.⁴
- “Effective teaming and other group performance disciplines will spell the difference between organizations that succeed and those that fail.”⁵

Projects carried out by interdisciplinary teams are not only an expectation of industry but also have 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.”⁶ This requirement can be met by a structured simulated experience or by an actual capstone project that requires the involvement of several disciplines.

Employers show increasing interest in student projects, especially capstone design projects completed by graduating seniors. (“Tell me about a particular team project you worked on as a student and what part you played in the project.”)

Katzenbach and Smith, authors of *The Wisdom of Teams*, define teams this way: “A team is a small number of people with complimentary skills who are committed to a common purpose, performance goals, and an approach for which they hold themselves mutually accountable.”⁷ A “multi-disciplinary (engineering) team” would then be a group with diverse skills formed for a common purpose comprised of members from various engineering disciplines or from engineering and other disciplines.

For several years in the engineering program at LeTourneau University our approach to teamwork had been to assign students to team projects with the optimistic expectation that teamwork would naturally emerge. (“Throw ‘em in the water and they’ll learn to swim.”) The reality was that a recurring series of difficulties arose. Each year we found that at least one team ran into trouble in one of these areas: lack of team cohesiveness, communication breakdown, ineffective leadership, unequal effort from members, or missing deadlines. We concluded that a team project is really successful only if it is completed (1) on time, (2) within budget, (3) in a way that meets all requirements (and tests the design against them), AND (4) with a positive team effort and experience.

Dorf and Byers, in their study of technology ventures, list the following among the characteristics of an effective team:

1. All members have a share in the leadership and ownership of the team’s tasks.
2. Communication flows continuously among members in an informal atmosphere.
3. Members clearly understand all tasks and purposes.
4. Group members listen to each other and are comfortable with disagreements.
5. Team members arrive at decisions by consensus.
6. Feedback on performance occurs frequently.
7. The division of tasks and work effort clearly exists.
8. Members determine their own, shared interim deadlines for stages of the project .
9. Team members rely on each other with accountability.⁸

Part of the difficulty we have seen with project teams is that effective teamwork, particularly at the college level, does not arise naturally. Throughout most of their education, students have learned to be competitive rather than cooperative. High school rankings, SAT scores for college entrance, college GPA, senior rankings, industry placement, and graduate school entrance all encourage competition. Much of education is geared towards individual mastery of knowledge and skills (which, in fact, are essential for a student to contribute successfully to a team.)

Individual differences may also provide a barrier to the formation of a cohesive team. Students differ in personality, culture, and technical background. Those individual differences which help to make teams effective can also be a source of tension or irritation within a team. (See Appendix A on personality issues.) Differences in schedules, work habits, individual commitment to the project, and personal expectations can lead to breakdowns in communication.

Interdisciplinary project teams provide an additional set of challenges beyond those of traditional teams. A sense of discipline pride may arise which interferes with team unity: (“EE’s are smarter than CE’s,” “ME’s work harder than EE’s,” “CE’s always hold up the project,” ...) Since upper division students have most of their classes together, members from other disciplines may be inadvertently left out of the communication loop. Miniature “turf wars” may arise over the use of labs and equipment or the allocation of the project budget. Team members from one discipline may develop work habits that become a source of irritation to others. (We observe that computer science students often like to work alone, use the Linux operating system, and develop code from scratch, while electrical engineers prefer to collaborate on programs, work with Windows, and use available software.)

An additional challenge involves overall scheduling and coordination. Schedules may vary widely between the discipline sub-teams. Our mechanical students spend their first capstone semester defining the design structure and the second semester fabricating and testing. Electrical students spend the first semester developing modular circuits and prototyping; their second semester consists of the preparation of printed circuit boards and software integration.

Interdisciplinary collaboration requires the recognition that each discipline has a unique role and individual priority in the project, a respect for the contribution of each team member, individual accountability, and a common technical language.⁹ At LeTourneau University, we have begun a series of initiatives to enhance the success of engineering project teams. These efforts include (1) multiple opportunities for teamwork, (2) early involvement in project teams, (3) teamwork training in design courses, (4) a required course in project management, and (5) multiple areas of feedback to assess individual participation.

The Five Tools

(1) *Provide multiple and varied opportunities for practice in teamwork.*

At LeTourneau University, we offer a single degree, the Bachelor of Science in Engineering, with concentrations in biomedical, computer, electrical, materials joining, and mechanical engineering. Ten of the engineering courses are required and common to all concentrations. With this structure, interdisciplinary projects naturally arise. In the Mechatronics course, for example, electrical students who have already had experience with microcontrollers and active filters may be teamed in projects with mechanical students who have already had experience with mechanisms and kinematics.

Team experiences begin in the freshman year, in the Introduction to Design course, in which student teams develop and program Lego Mindstorm-based vehicles to follow a course track. Team projects continue in several sophomore and junior level courses and culminate in the two-

semester capstone design project. At least eight different courses in the curriculum require a design project, carried out in teams. The following table summarizes our team design courses:

Course	Level	Concentrations Involved	Project
Fundamentals of Engineering Design	Freshman	All	Lego Mindstorms vehicle
Dynamics	Sophomore-Junior	All	ASME competition
Digital Electronics	Sophomore-Junior	All	Advanced hardware project (student choice)
Thermodynamics	Junior	All	Heat engine design
Mechatronics	Junior	All	Inverted pendulum vehicle
Electronics Design Lab	Junior	Electrical	Rube Goldberg design
Machine Design	Senior	Mechanical	Advanced machine design project (student choice)
Biomedical Engineering Research Experience	Junior-Senior	Biomedical	Intelligent Prosthetic Arm or Third World prosthetics
Senior Design I	Senior	All	Approved project (separate courses)
Senior Design II	Senior	All	Approved project completion (separate courses)

Table 1 – Team Design Projects in the Engineering Curriculum

The formation of teams takes place in various ways, and different aspects of design are learned in different courses. Most lower-level projects allow for students to choose and organize their own teams. In our senior design courses, students choose a project from an approved list of projects with oversight by the faculty. With the biomedical project, the faculty sponsor (project P.I.) often recruits team members.

In Electronics Design Lab, the population is usually around fifteen electrical students. This is a laboratory to teach students how to design and build electrical systems, with an emphasis on the practical use of theory in the creation and testing process. In this laboratory the instructor (RWG) is careful to choose pairs of students or singles if an odd number is enrolled. Part of the team formation is related to perceived growth needs of the student. Three students should never be put on one team because one will be left out. Students are allowed a voice in choosing a partner but the instructor will veto a decision if there is a difference of two letter grades between them, using the previous lab grade as a measure. For instance, A-B and C-D students can work together but not A-C or B-D. Experience has shown that female students should be paired together, if possible, because in a male-female team the male will almost always do the hands-on part of the lab to "show off" to the female, leaving her to "take data". This course is the precursor to the Senior Design course for the electrical concentration, and the instructor is careful to insure that both individuals contribute to the team fairly equally. This is done by giving individual pop quizzes and ten minute quizzes throughout the semester to determine if each member knows the theory behind the experiments and also the practical implications that were illustrated. Although the experiments are done in teams, each person must submit his/her own separate report of each experiment. This forces the development of writing skills in all students. All students must also design and build several working modules and document their specifications. They are also required to learn and demonstrate some basic functions using LabView. Once a student learns a

task, he or she becomes the "guru" for that task in the class, and teaches it to other students. In order to familiarize these students with the projects being done by the seniors, each student must also apprentice on one of the senior teams for five hours' worth of work designated by a senior on his own senior project. The senior fills out a rating form which is included in the junior's dossier. This is a 3-credit lab course, and students are expected to put in extra, unscheduled lab time to bring their total time for the course to about 140 hours. They receive credit for time invested, to prepare them for the fact that they will be expected to account for their time in the industrial setting.

Our current capstone design projects originate from industry, local research and competitions, and offer the greatest mix of disciplines:

- The Phoenix Project (unmanned flying vehicle for AU VSI competition) involves electrical, mechanical, and computer, plus computer science, computer science engineering, and marketing, with assistance from design technology.
- The Formula Car (SAE competition) consists of mechanical, electrical, plus design technology and marketing.
- The Biomedical research projects (partly funded by an NSF grant) combine biomedical, electrical, mechanical, computer, and materials joining.
- The Avionics Event Logger (proposed by Rockwell-Collins) involves electrical, with computer science.



Figure 1. The LeTourneau Phoenix Project Team 2004-2005

Team leaders are either appointed by course faculty with input from students and faculty or chosen by the team members with guidance from faculty. Interdisciplinary teams are typically organized along one of two structures: (1) a concurrent engineering model, in which all disciplines are equal partners in a complex project under a single team leader, or (2) a subcontractor model, in which students of one discipline receive project specifications from another discipline. In the Formula Car project, students in the electrical concentration develop

such components as dashboard display and traction control, which students in the mechanical concentration will later assemble into the vehicle.

One of our project teams is uniquely organized according to a corporate model. The biomedical research team structure is based on a business model of modular components. Students and professors are both an integral part of this modular structure, with students involved at various levels, including management. Each component is treated as an individual hierarchy with its own set of goals, yet responsible to the overall management structure and project objectives.

Current projects include the Intelligent Artificial Arm (a prosthetic arm with anatomically-oriented muscles controlled by processed EMG signals) and the LEGS project (an inexpensive leg prosthetic for developing countries). A large project team (up to 25 students) is broken into a number of specific task-oriented sub-teams (often electrical, mechanical, and computer), each with a leader. This structure gives the faculty member (P.I.) (RVG) a reasonable number (3 to 5) of student leaders to mentor and teach. The team leads then provide a modified version of mentoring to their fellow classmates in their sub-groups. Junior members are mentored by senior team members in specific areas of the research. The faculty member (P.I.) acts as the CEO, and students are assigned as overall Project Manager (PM), Engineering Leads (EL), and Individual Contributors (IC). The P.I. selects the PM with input from the likely ELs, who themselves are usually selected from the prior well-performing juniors on the team. In an extreme situation of negligence or incompetence, a student leader could be “fired” from the leadership position (demotion) by the CEO. This team structure allows clear lines of distinction between various responsibilities and the direction of how information and responsibility flow within the team.¹⁰

(2) Provide early involvement in senior project teams to introduce ongoing projects, team structure, and design philosophy.

It is important that students be informed early of the emphasis placed upon design projects and the nature of various ongoing projects. The expertise of seniors will be combined with the future team members at the sophomore and junior level in ongoing projects like the Formula Car and the Phoenix Project. Student ASME and IEEE meetings are ideal vehicles for seniors to introduce their team members and their projects. Group meetings with advisees allow faculty to discuss various student opportunities, including involvement on design teams. Freshmen and sophomores are welcome to participate as “free labor” on the senior teams, while juniors can earn one to three credits of technical elective and prepare for a leadership role the following year by effective participation.

(3) Provide training in teamwork, beginning in the freshman year to formally introduce teambuilding concepts.

Some formal training in teamwork begins in the Introduction to Design course taken by all freshmen and continues at a higher level in capstone design courses. A number of good resources have been developed to assist in this area, including the BESTEAMS material¹¹ and The Team Developer text and software.¹² The Foundation Coalition has prepared several monographs on team development and overcoming dysfunctional teams.¹³ The intent is to develop effective functional teams.

Katzenbach and Smith suggest eight key approaches for building high performance teams:

1. “Establish urgency, demanding performance standards and direction.
2. Select members for skill and skill potential, not personality.
3. Pay particular attention to first meetings and actions.
4. Set some clear rules of behaviors.
5. Set and seize upon a few immediate performance-oriented tasks and goals.
6. Challenge the group regularly with fresh facts and information.
7. Spend lots of time together.
8. Exploit the power of positive feedback, recognition and reward.”¹⁴

In comparing engineering student teams with professional sports teams, military squads, and rapid-time-to-market industry teams, we conclude that those teams which are most successful have

- Well defined goals and intermediate goals
- Clearly defined time framework
- Clearly defined roles for each team member
- Clearly defined expectations for the team and for each member
- Competent leadership
- Awareness of individual skills and differences
- Appreciation for the contributions of each team member
- Strong team unity and pride
- Defined actions for resolving conflicts

At the senior level we have discussed the following topics with design students: team formation, communication, ideal team members, roles within a team, motivation (ideally, a sense of accomplishment, not just a grade) and conflict resolution. As the team develops, individual accountability for each student needs to move away from the faculty member and towards the team and its team leader. In addition to individual technical tasks, our student team roles typically include a team leader, secretary/scribe, treasurer/accountant, fundraising contact, and webmaster. Team communication takes a much different form from the formal communication of project proposals and report writing. Most is electronic, informal, and minimal. It is essential that all team members receive the emailing, that the content be understandable, and that the tone is not rude. In addition, a training briefing for team leaders was held early in the semester. Topics discussed dealt with responsibilities, organization, motivation, and handling problems.

(4) Require a course in Engineering Project Management as preparation for upper level team design.

All engineering students are required to complete a course in Engineering Project Management, scheduled during the junior year in preparation for use in capstone design courses. Implementing various tools of project management insures that all team members are in agreement in terms of expectations of deadlines, milestones, and responsibility. These tools of project management include the work breakdown structure, Gantt chart, and formal budget.

After project teams are formed each team presents a formal design proposal which includes requirements, technical approach, management plan, schedule, and budget. All team members

should be involved in the writing of the proposal and agree to the items it contains. Defining Requirements (primarily from the client) insures that all team members are working with the same specifications and constraints. The Technical Approach section defines the approach that all team members will use. Primary roles and tasks of each team member are defined in the Management Plan. The Schedule outlines the key tasks and dates with which all must comply. Each proposal also includes a Budget that establishes the major expense areas and their ceilings. Proposals must be approved by the lead faculty member and are submitted to the project sponsor or client. Weekly oral and written progress reports track tasks planned and accomplished, areas of difficulty, and hours logged by each team member. Progress reports are also delivered to the project client and serve as an additional means of accountability.

(5) *Require multiple items of feedback to determine the contribution of each team member.*

One of the most difficult areas for any faculty member working with team projects is deciding how best to grade a project, and, particularly, individual contributions within the project. While the success of a project and the quality of presentations and reports should directly affect the grade of each team member, the most difficult aspect of assigning grades for any team project is to differentiate the actual contribution of each member. Student satisfaction in the project is also related to proper recognition of one's efforts.

A major portion of the grade will typically be based on the quality of the final demonstration (which should include test results and verification of meeting requirements), final report, and final presentation, with smaller weight given to the proposal and progress reports. These portions will be identical for each team member. Individual performance should also account for a portion of the grade (reasonably 10-20%). Contributing factors may include: (1) the number of hours the individual student worked on the project, (2) faculty member's (and client's) observations of student work, (3) self-evaluation (personal assessment of effort by each student), and (4) peer evaluation (assessment of every team member by each member.). An alternative grading format, used in some courses, multiplies the total team score by an individual weighting factor determined for each student from peer and self-evaluations. A number of evaluation criteria for individuals in a team have appeared in the literature.^{15,16}

Now that conscious efforts are being invested into teambuilding and performance in our program and many others, the next step is to evaluate how successful the teams actually are, not simply as designers but also as teams. Part of the course grade should include team performance. If we are instructing in teamwork with effective teams as our goal, we need also to assess teamwork. This is nearly as difficult as assessing individual performance. Industry visitors to final design presentations indicate that they are readily able to judge and comment on design ability and communication skills but usually cannot judge the effectiveness of a team.

Candidate areas for assessing a team might be organization, communication, decision making, team unity, and ability to resolve conflicts. Li et.al. have chosen six performance metrics: individual time spent, time spent in meetings, individual action items completed, team milestones achieved, peer evaluation of team members, and private comments to the instructors.¹⁷

Conclusions

Five tools have been put into place to enhance interdisciplinary teamwork in our engineering courses. In a survey involving capstone design students, 71% responded that they were well-prepared for team projects and 86% that they were comfortable working as part of a team. 71% indicated that their teams were functioning well. The areas most needing improvement were found to be team communication and organization. Future efforts will be directed towards those areas and towards assessing the overall effectiveness of the teams.

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APPENDIX A

Personality Extremes in Project Design

I have encountered some form of each of these personalities in various design classes and am not surprised if some of these “clash” on a team. A good dose of respect and project management tools can bridge many of the problems.

Peter Perfectionist

Peter is bright and has high standards - so high, in fact, that they are unreachable. As a result, if a report or design can't be “perfect” it doesn't get submitted at all. Peter needs to learn that if a project has met all requirements and safety standards it needs to proceed to the next step, even if it isn't “perfect.”

Sammy Shotgun

Sammy is not a linear designer. His approach to a project is random “hacking” or “tweaking” until something seems to work. His designs are never optimized and barely work if they work at all. Sammy needs to learn a systematic approach to design that includes concept generation, concept analysis and selection, and preliminary design.

Polly Procrastinator

Polly runs the risk of delaying the start of a project until it is too late. Often it isn't laziness that causes her delay but rather “analysis paralysis.” Polly needs to select the most promising potential approach and begin to develop it.

Carl Cautious

Carl is the opposite of a risk-taker. He is unwilling to commit resources to any project until he is guaranteed of success. Carl needs to fit into a project team and accomplish his assigned part, expecting that the whole project will come together.

Dolly Driven

Dolly has a single focus—get the task done as quickly as possible. If other team members are not working fast enough she may take over their tasks. Dolly needs to learn to break down the task into manageable parts and assign each task to a given group.

APPENDIX B

Suggestions for Interdisciplinary Teams Involving Multiple Disciplines and Faculty

1. Faculty must meet together beforehand and on a regular basis to agree on the scope and areas of responsibility of the project.
2. Expectations in terms of reporting and effort as well as grading policies need not be identical but must be similar for the different disciplinary teams.
3. Faculty and students must agree on the organizational model (concurrent, subcontractor) used for teaming students of different disciplines.
4. It is essential that all team members agree on the project goals.
5. It is essential that a lead faculty sponsor meet regularly with the team.
6. Students must agree on a few key inter-discipline milestones for the team (upon which they will be graded), typically related to interfacing electrical and mechanical components or hardware and software integration.
7. All team members must define their participation in terms of the success of the larger team.
8. All members of competition teams must be willing to accept a grade of “incomplete” until the competition has taken place.
9. Complete teams must meet at least once a week to determine the current tasks and responsibilities.

APPENDIX C

Guidelines for Team Interaction (based on Biblical principles)

1. Each team member is valuable and plays a unique role in the team, like parts of a body. None can be ignored. Respect for each team member is essential. Work on understanding the unique gifts and skills of each member and how each fits into the whole. (I Corinthians 12)
2. The ideal leader is a servant who cares more for the well-being of the team members than for his/her own glory. There is no place for a dictator in a healthy team. (Matthew 20:20-28)
3. Try to handle conflicts person-to-person before involving others. Don't confront an individual in front of a group. Begin privately and try to resolve the issue. Gossip is never allowed. If individual resolution fails bring in one or two others to try to resolve the problem. (Matthew 18: 15-18)

Biographies

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