Project Based Learning at the Graduate Level

Joe Tanner
University of Colorado

Scott Palo
University of Colorado

Graduate Projects is a two-semester course sequence designed to introduce interdisciplinary Masters and Ph.D. students to project management and systems engineering while working a complex aerospace engineering sciences project. Students are organized in project teams of a minimum of 6 and a maximum of 15–20 students. A department professor or instructor works directly with each project team, acting as an adviser, and frequently, customer for the project. The teams are structured with all of the personnel positions normally found in a government or industry project team. The team members themselves select the two leadership positions of Project Manager and Systems Engineer. The teams must plan their work within typical budget and time constraints common to all projects. They are required to prepare and present decision gate reviews using presentation methods of their choosing. They are also required to maintain accurate and thorough documentation of their activities and design choices. The students are also introduced to intellectual property protection, technology transfer considerations and entrepreneurial opportunities for new and innovative designs. All project students attend a weekly lecture covering these topics with the major focus on learning project management and systems engineering skills that may be applied directly to their project work.

Content

The Graduate Projects course is designed to give graduate level students experience in a structured aerospace engineering project team environment. The students learn and develop such skills as communication, cooperation, and teamwork. They also learn to accept the responsibility that comes with working on a team where every individual's contribution is necessary and important to project success. A primary course completion goal is to prepare students for the type of project management processes and team dynamics they will encounter in government and industry, making them more competitive and effective in today's job market.

Entry into the Graduate Projects two-semester course sequence is allowed either in the fall or spring semesters of the academic year. Each team will most likely be comprised of a mixture of first-semester 5000 level and more experienced second-semester 6000 level students. The experienced students provide project continuity from one semester to the next, and, in effect, help teach the new students as will be discussed in more detail in the following paragraphs. Each project is assigned a highly knowledgeable department faculty member to teach the technical aspects of the design and monitor team activities. The faculty member typically stays with the project to completion as the more complex projects may require more work to satisfy the customer requirements than can be completed in two semesters.

Each student is expected to contribute in two significant areas of their project work: technical excellence and teamwork. The design challenges are of sufficient magnitude that no one student can master all of the technical details. They, therefore, must learn to work effectively in a team environment. Successful development of teamwork skills is one of the primary learning objectives of this course.

Lecture

Every project team student attends a weekly fifty-minute lecture period structured to provide course content continuity for each team and team member regardless of the team's project phase. The lectures are normally given by the course coordinator or occasionally by guest lecturers. The topics cover a variety of subjects related directly or indirectly to project management and systems engineering. The lecture period also gives teams the opportunity to share information of mutual benefit by way of team status reports.

Every student benefits from the lecture information even if not functioning in one of the key leadership positions. If a student already knows he or she does not

desire a professional career as a manager, understanding what it takes to be good leader will help the student be a better team member in the academic setting and a better employee after entering the working world. Having experiential knowledge in project management and systems engineering on their academic record may also help all of the students be more competitive and successful in their search for the right job and salary.

The lecture period serves another valuable function, as it may be the first exposure for some of the students to the project team concept. Those entering graduate study course work from the University of Colorado Aerospace Engineering Sciences undergraduate curriculum have had extensive experience in project based learning through the required Senior Design capstone course. Students entering from another department or university may not be similarly prepared. The lecture material may be their first introduction to project and teamwork concepts.

The final factor worthy of note in the lecture pedagogy is the opportunity for second semester students to present lecture material to the rest of the class. Second semester students are encouraged, in fact, expected to team with the course coordinator to present a portion of the material. This concept has been popular, especially with the presenters who all agree they learn the material more thoroughly when preparing for a presentation. Unfortunately, the number of lecture session periods is limited. Not every second semester student has the opportunity to present a lecture topic. All students do, however, have an opportunity to practice their presentation skills before the entire lecture class during two short team status reports scheduled during the semester.

The textbook used as a framework for the lecture material is Visualizing Project Management[1] . Topics not covered in this textbook are also presented as appropriate to address the course learning objectives. Examples of additional material include entrepreneurship, intellectual property and technology transfer issues, as well as valuable real world experiences presented by guest lecturers.

Lab Sessions

Each project team meets in two one-hour fifty-minute lab sessions per week. The section professor and course coordinator typically attend the scheduled lab sessions. These sessions are where the real team development activity takes place though many hours of full team and sub-team activities are performed outside of these sessions. The team is required to conduct a more formal project status meeting during one of their lab sessions. The content is similar to what would be presented in a government or industry project team report to their management or customer. The presentation is limited to one hour and the section professor or instructor acts as the manager/customer.

The lab sessions are also an excellent forum for the first semester students to really learn about the project environment from the more experienced second semester students, lab section professors and course coordinator. The returning students are specifically charged with helping integrate the new students into the team just as they would new members joining their government or industry project team. The new students must read and understand all existing project documentation so they can “get up to speed” as quickly as possible on the details of the design progress. They also must learn as much as they can from the experienced team members. This partnership seems to build team cohesiveness quickly as is mandatory for team success in the short period of time available in one semester.

Teams

Enrolling students may choose from one of several established or newly formed project teams offered each semester. The project technical work falls into one of the following general topic areas: aeronautics and control, small satellite design and human rated spacecraft design. Four project teams were formed for the spring 2010 semester with forty-two students enrolled. The number of projects offered is dependant on the availability of faculty to teach the technical areas of the project, student interest, and available funding for a given project. Students are not restricted from switching teams in the first few days of the semester should they discover another team’s work more closely aligns with their interests. This does not happen often.

The team starts to form during the first lab session. The Project Manager is selected by the students from those among them expressing interest in that position. The candidates are usually 6000 level students in their second semester in the course sequence. The team quickly appreciates the importance of a strong yet not over-bearing manager to keep the project activities organized and on track. The other critical position on the team, the Systems Engineer, is selected in a similar fashion. The Systems Engineer is responsible for the technical aspects of the project. Most teams also select assistants for the two main leadership positions from among the first semester students. The assistants are preparing to be prime candidates for the key leadership roles in their second semester should they care to assume that responsibility. The other positions on the

team; sub-system leads, manufacturing engineer, safety engineer, financial officer, etc. are typically selected in subsequent lab periods as the students learn more about the project and each other's abilities and strengths. Figure 1 shows a typical team organization chart.

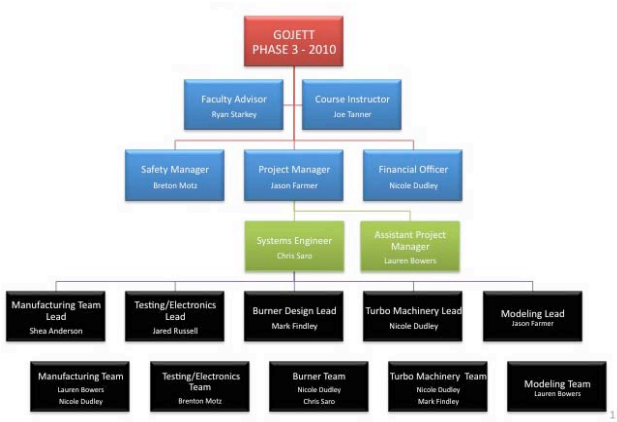

Figure 1: Typical project organization chart.

Students on a given project team may have varied academic backgrounds as Graduate Projects is open to multidisciplinary degree paths. The current small satellite (CubeSat shown in figure 2) team, for instance, has contained aeronautical, electrical, and mechanical engineering students plus an occasional physics student. This diversity is necessary given the technical complexity in a number of design areas of this project and, in fact, strengthens the team. The students learn from each other as a cooperative atmosphere develops of shared technical knowledge and problem solving strategies.

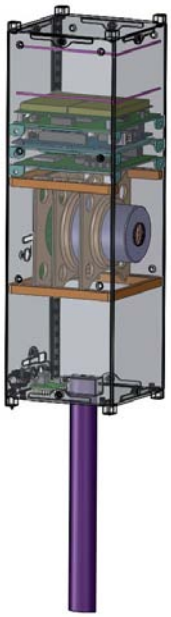

Figure 2: Solid model diagram of the Cubesat Project.

The teams are required to function as a project team would in government or industry. They must develop and keep to a detailed project schedule and budget. They perform in-depth technical analysis to justify their design choices and maintain complete and accurate documentation of their activities, both on the individual level through lab notebooks and the team level through project definition documentation. Finally, they are required to conduct two formal decision gate review or project status report presentations per semester.

As the semester progresses and the teams mature they realize the impact of good and bad team dynamics on team performance. Each student submits a peer evaluation on each of his or her teammates at the mid-semester point and at the end of the semester. The course coordinator gives individual feedback by passing the anonymous peer comments to each member of the team. The comments are frequently not a surprise to the individual but occasionally an unknown area needing improvement is identified. Many students have made significant changes in their behavior or work ethic during the second half of the semester based on these comments. The resulting improved team dynamics and productivity are noticeable.

Industry

Each team is encouraged to establish and maintain close contact with industry representatives relating to their project. In some cases, a company may be the sponsor of the project and, as such, is the approval authority for decision gate presentations. The company may, in fact, be the recipient of the design or technology developed by the team. In these cases, the company engineers are very much a part of the pedagogy of the course as they help teach the students design principles and best practices as well as giving students feedback on their work. In other cases, the customer may be a professor who is sponsoring the team through his or her research funding. Figure 3 shows an example of the Dream Chaser industry-sponsored project.

Figure 3: Dream Chaser project.

The students are encouraged to contact members of industry for help in advanced technology areas. Industry and government engineers have been very willing to help the teams as advisory board members, usually through email, phone contact or teleconferencing, but occasionally in person. The students have found this willingness to participate in their work very encouraging.

Outcomes

Each project team is required to make two formal presentations per semester, typically via PowerPoint. These presentations are satisfactory forms of project documentation but a more detailed recording of design specifics is also required in a paper or electronic archiving format. As a team's project design matures, there may be a need to prototype and test. These products and results may also become deliverables to the customer. Some teams have found it beneficial to mockup portions of the design to validate their methodology or design philosophy. These mockups have been very beneficial in allowing the students to visualize the effect of their design decisions and also quite effective in attracting new students to the project as they see tangible evidence of the team's work. The lunar ascent module mock-up as shown in figure 4 is an excellent example. The ultimate deliverable is, of course, the finished design product or process as requested by the customer.

Figure 4: Lunar ascent module mock-up.

Assessment

Project team success is measured by an on-budget, on-time design or product that satisfies the customer. Graduate Projects course success is measured by the quality of the students who finish the two-semester sequence; what they have learned in their technical area and the teamwork skills they have developed that will aid them in their professional endeavors.

Assessment is primarily an objective evaluation by the section professor or instructor of the team's overall performance. Individual assessments are influenced by verbal presentations, contribution to the written documentation, participation in team meetings and lecture periods and peer evaluations. Extra consideration for the 6000 level students is given for leadership, teaching and lecture presentations.

Continuous Improvement

The Graduate Projects course has been offered for three semesters at the University of Colorado. Feedback from the students on what they have learned about project management, systems engineering and teamwork has been very positive. Most of the teams have functioned quite well in the project environment with adequate leadership though all recognize the need for improvement. Having several students on a team from the previous semester has proven to significantly accelerate project start-up and new student integration in the first two weeks of the semester. The course coordinator solicits student feedback and suggestions at the end of every semester to make improvements to the course in general and the lecture in particular.

Project team success as measured by completion criteria has yet to be determined. None of the projects currently in work have matured to the point of completion due to the amount of design, build and test efforts required. On a very positive note, however, the National Science Foundation has selected one of project teams for a CubeSat secondary payload flight opportunity in the future with significant funding provided to complete the design and prepare the satellite for flight.

Conclusions

Project based learning has been an integral part of the undergraduate curriculum for many years in the Aerospace Engineering Sciences Department at the University of Colorado. It is now quickly gaining popularity in the graduate curriculum as well. To meet degree requirements, Masters of Science students may write a thesis, complete course leading to specialty certificate, or complete the Graduate Projects course sequence. The number of students choosing the Graduate Projects course option has increased every semester from a start of two teams with less than twenty students to the most recent semester with four teams and over forty students total. The College of Engineering also sees the benefit of this type of learning opportunity as the Mechanical Engineering Department is developing a similar course. The future of project-based learning is very bright as faculty members, students, and administrators appreciate the benefits of hands-on team based education in preparing quality engineers for the challenges of a highly competitive world market.

References

1. K. Forsberg, H. Mooz, H. Cotterman, Visualizing Project Management, Third Edition, Wiley 2005.