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Experience with Multidisciplinary Design Projects at the US Military Academy

Peter D. Hanlon, Bryan S. Goda, and Lisa A. Shay
Department of Electrical Engineering and Computer Science,
U.S. Military Academy, West Point, NY 10996
{peter.hanlon/bryan.goda/lisa.shay}@usma.edu

Abstract - *The intent of Senior Design Capstone Projects at the US Military Academy is to provide cadets with a challenging engineering problem that requires them to integrate key concepts from several previous EE courses. Multidisciplinary projects add to that challenge because the students who participate in cross-disciplinary projects have to also learn the capabilities and limitations of other disciplines. While more challenging, a multidisciplinary project provides the students with a better perspective of real-world engineering projects. This paper addresses some of peculiarities associated with these multidisciplinary projects by describing the formation, monitoring, and evaluation of cross-disciplinary teams. Solutions to some of the common problems that are normally encountered such as scheduling, grading, resource allocation, and control of the group are discussed. Group dynamics and the unique results of what a cross-disciplinary team can produce are also discussed. The group's faculty advisor must play a key leadership role to ensure that the group stays on track, interacts well within the group and amongst the other departments, and ensures steady progress is made towards project completion. A series of design reviews throughout the year gives the group waypoints to measure progress as well as practice presenting in front of an audience. Some unique features not normally found in a senior design course such as peer evaluations, guest lecturers, and project's day have been implemented and will also be discussed. As illustrations of our findings and recommendations, this paper describes several group projects such as a digital controlled train with gantry crane, a project with EE, CS, and ME majors; Battlebots: a project with EE and ME majors; and the Autonomous Shadow: a project with ME, EE, and CS majors. Documenting this multidisciplinary process in preparation for the ABET evaluation visit is also discussed.*

1. Introduction

In this paper we describe our experience with several multidisciplinary (electrical engineering, mechanical engineering, and computer science) senior design projects. We start by describing how the projects have grown from individual design, to single discipline group design, to multidisciplinary group design projects. Then we make some general observations about some of the issues that have to be addressed when undertaking these multidisciplinary projects including: selecting the design team members, project administration (schedule, grading criteria, and project resources), design reviews, the role of the faculty advisor, and documenting these projects for ABET evaluation and certification. To illustrate some of these observations, we describe three examples of multidisciplinary design projects and then end with the lessons that we have learned over the several years of conducting these projects.

2. Growth of Design Projects

An important component of undergraduate engineering education is the solution of design problems. These problems require the student to not only to use fundamental concepts and equations, but also to understand the flexibility of the design space and iterate their design until an acceptable solution is found. The increased flexibility and level of difficulty require a deeper level of understanding from the students and thus these projects have become an essential part of an undergraduate engineering education.

The scope and difficulty of design problems progress as the student progresses through his education. Individual design problems emphasize and amplify the engineering skills addressed in classroom lectures and readings. While typically assigned as homework problems to allow students to reflect and iterate on their design, in the interest of time and efficiency many students work together to complete these problems. Group projects have grown from the realization that significant learning comes from group interaction and discussion. These group projects occur in lab exercises of various courses and culminate with a senior design project where a group of students spend a whole semester working on a design that incorporates much of the course work throughout their undergraduate education. As more engineering disciplines adopted these senior design projects, it was a natural evolution to move to design projects that involve multiple disciplines to broaden the student's education into those other disciplines.

Feedback from both faculty and students has pointed out several advantages of these multidiscipline design projects. First, they more closely model real work engineering projects where no group of engineers from a single discipline could actually affect a design because of the depth and complexity of the design space. Second, they require the students to develop a greater breadth of working knowledge that crosses into the other disciplines. Lastly, they give the students a greater appreciation of the other disciplines' contributions to solving engineering problems.

3. Conduct of Multidisciplinary Design Projects

While these multidisciplinary projects unquestionably broaden the student's engineering education, they do require some extra attention and coordination to smoothly conduct the project. Some of these areas are formation of the multidiscipline team, administration of the project, coordination of the design reviews, team evaluations, the role of multiple faculty advisors, and documentation for ABET accreditation.

Selecting the appropriate members for the team requires considerably more thought that single discipline projects for several reasons. Senior design projects are quite successful when the team members have previously worked together, which often occurs with single discipline projects. However, multidiscipline projects usually end up with students that likely have not even heard of each other, much less worked together before. The team member selection process must include an evaluation of the various team candidates that includes several important aspects such as their level of interest in the project, their level of interest in the other engineering disciplines, their leadership capabilities, and of course their ability to conform to a team consensus. These aspects are important for single discipline projects, but their importance is obviously much greater for multidisciplinary projects. The selection of team members at USMA is accomplished through an evaluation process where the team members are first selected within each discipline, and then the faculty advisors from the different disciplines meet and assess if the team member selections will produce an acceptable team. This process has generally worked well, as we will describe below when we discuss specific examples of multidisciplinary projects.

The administration of multidisciplinary projects can be more extensive than single discipline projects, but it does not have to be if faculty advisors closely coordinate between disciplines. Not surprisingly, we found that different engineering disciplines have had different approaches for tracking the project schedule, different criteria for project grading, and different sources of project funds. These differing approaches were initially quite cumbersome because each discipline laid their requirements on the team, thus requiring twice the amount of administration at times. Faculty advisors have worked with each other to come to a common approach for these multidisciplinary projects that incorporates the requirements of both disciplines. In some cases this involved one discipline changing its requirements to conform to the other discipline, such as using Microsoft Project for schedule tracking instead of a PERT chart. In other cases, both disciplines retained their requirements but applied them only to their students, such as only requiring the electrical engineering students to perform peer evaluations as part of the grading criteria. We have also found that a diverse approach to funding, such as each discipline funding different parts of the project, has been particularly successful and in many cases has reduced the overall cost of the project.

Just as different approaches to the administration of the project have to be mitigated between disciplines, so also does the philosophy behind the design reviews and team evaluations have to be defined and agreed upon between the faculty advisors. Three crucial milestones in a project are when the candidate designs have been evaluated and one candidate has been chosen, the next milestone is when the design has progressed to the point where the team is ready to order parts, and yet another milestone is when the project has been built and it ready to be entered into competition. Each of these milestones requires a design review presentation to a board of faculty members to ensure the team has met that milestone. Terminology caused confusion between the disciplines in that these design reviews were referred to as an "in progress review," "preliminary design review," and "critical design review" by one discipline and as a "preliminary design review", "critical design review," and "final design review" by another discipline. This caused significant problems when both disciplines agreed to have a preliminary design review before the winter break, with one discipline expecting to order parts over the break while the other discipline had just completed selection of the candidate design. Resolving these differences often requires close coordination not only between the faculty advisors for the project, but also the program directors and department heads.

Yet another potential source of difficulty is differing project philosophies and the role of the faculty advisor between the disciplines. One department's approach to senior design projects is to scope the project so that the team has a high probability of successfully completing the design, fabrication, and testing of the project, while another approach is to challenge the students so that they have a fair probability of failure in the testing phase. Subsequently, the role of the faculty advisor also differs in that one department encourages advisors to be intimately involved with the team to the point of leading them to a design with a high probability of success, while the other approach is to have the advisor allow the team freedom in the design and simply monitor the team's progress. These philosophical differences must be worked out very early (even before the inception of the actual design projects) and may even require department head involvement.

4. Objectives and Outcomes

One of our program objectives (long term goals) is to have our graduates apply disciplinary knowledge and skills to develop and implement solutions to applied problems individually and in diverse teams. This objective is linked to three outcomes (things students should be able to do at graduation): being able to draw progressively from more complex design-test-build experiences, engaging in design efforts in a team setting, and being able to apply math-science-engineering knowledge relevant to specific problems.

Our multidisciplinary projects are the culminating result of a cadet's educational program. In order to measure effectiveness, assessment is done at a variety of levels. Each course has an end of course survey linked into the academy-wide course administration software. Results are complied at the course, program, department, and academy level. Graduating seniors and graduates after three years are surveyed about the program's effectiveness. Faculty also participate in assessment by preparing course assessment reports, serving on goal teams, and monitoring outcomes. Each of the seven engineering programs maintains an advisory board to provide feedback on program effectiveness and objective accomplishment.

Our graduates have provided useful feedback in improving our program. Over 85% of our graduates respond with a very positive outlook from their undergraduate experience. Graduate input has helped link the math program closer to the engineering programs, helped create a more realistic design environment, and become an integral part in updating our program objectives. The USMA EE program is rated #8 in the latest US News and World Report survey of undergraduate EE programs. Our August 2002 ABET visit was also a tremendous success.

5. Examples of Multidiscipline Projects

<u>Marklin Digital Train</u> – The Marklin digital train set is a state of the art model railroading system which easily permits the integration of hardware and software. Each train has an on-board microprocessor that can independently set the train's speed and direction. A PC serial port connects the control interface box to the trains, sensors and switches. The flexibility of the Marklin system made it an ideal starting point for a multidisciplinary project.

The stated goal of the design team was to create a computer controlled gantry crane (figure 1). The crane should move in the X-Y plane and possess a moveable electro-magnet to carry metallic weights. The project required the combined skills of electrical engineers (DC motors, optical sensors), computer scientists (programming and graphics), and mechanical engineers (gantry crane design, mechanical movements). The electrical engineers used the Marklin switching signals to turn the DC motors off and on in the appropriate direction, while carefully placed openings on rotating disks attached to the motors simulated the signaling for the Marklin track sensors. Thus precise movements in all directions could be accomplished. The computer science students developed a graphical interface and control software that allowed the user to select where cargo would be picked up and delivered and then output the appropriate commands to the motors. The mechanical engineering students developed the frame structure and gearing necessary to interface with the motors, support the specified load weight and permit the full range of motion across the loading dock and all three tracks shown in Figure 1. The final demo for this project involved the software maneuvering 3 trains into the loading bay and the operator dragging and dropping the desired cargo from the loading dock onto any flatcar using the GUI. The software controlled the crane which picked up and deliver the cargo in accordance with what was selected on the GUI. The project proved to be an outstanding example of each discipline working together to accomplish the design specifications.

Figure 1. Marklin Train with Gantry Crane

Battlebot – The Battelbot project is a very popular joint Mechanical and Electrical Engineering project that consists of two to three cadet teams that design, build, test, and compete a middleweight, non-stomping BattleBot according to the rules of the national competition (www.battlebot.com). This past year, the project culminated with a BattleBot Tournament and Final Rumble (Figure 2) between two cadet teams and two faculty entries. The popularity of the project is due primarily to its destructive nature and a fair amount of freedom of mechanical design. Many cadets enjoy the brain storming phase of the project and trying to gather intelligence on the designs and plans of the other teams. The cadets frequently complain that the faculty have the advantage in the competition since we have complete access to the team's designs and will thus capitalize on that knowledge. This complaint is completely unfounded!

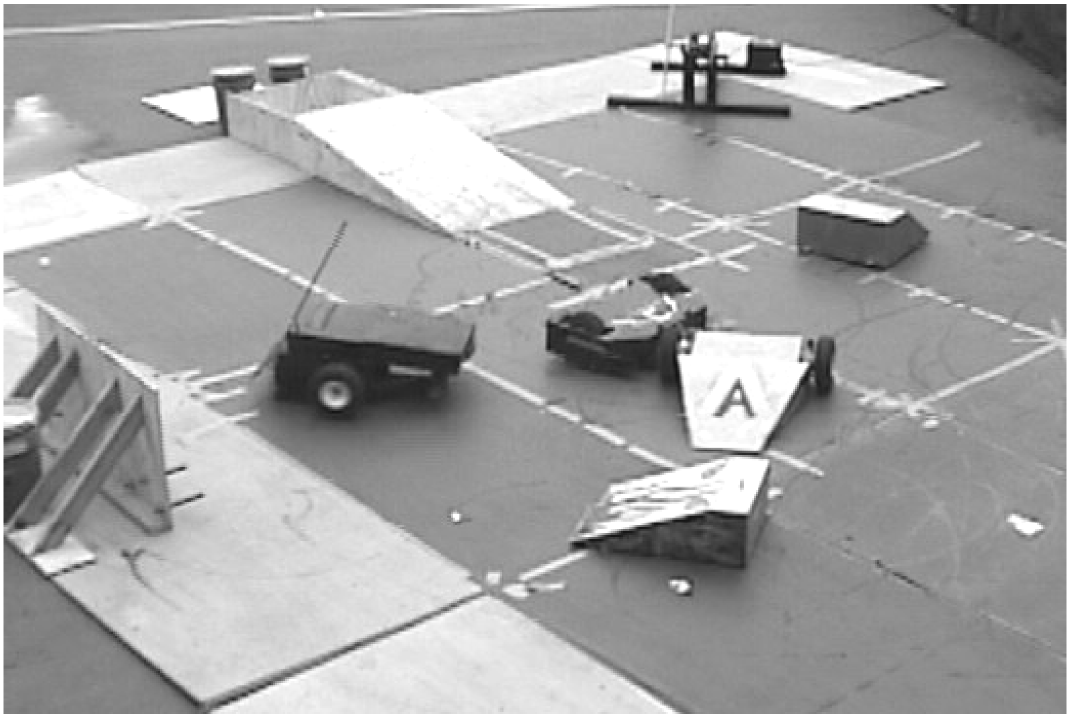

Figure 2. Battlebot Project - Final Rumble Competition.

This is the third year of the project, so many of the initial problems have been worked out. The mechanical and electrical teams are formed at different times (about six weeks apart), but this project is fairly easily compartmented by discipline. Thus each team can initially pursue an independent path. Project schedules and design reviews are established early by the advisors, along with resolving a common terminology for those design reviews, and initially a chief advisor was established as a single decision authority to negotiate and resolve any differences between other advisors. Since the same faculty advisors are on the project from year to year, we have found that the chief advisor is no longer necessary. Budgets are split between the two departments and project grading criteria are also separated by discipline. This project is easy to compartmentalize between disciplines, with the exception of timelines and competition rules, so it more closely resembles two distinct design projects with multidiscipline integration issues.

<u>Autonomous Shadow</u> - The Autonomous Shadow project was a proof-of-concept test of a space toolbox that would allow an astronaut to control the separation distance between himself and a floating toolbox. To prove the initial concept, the cadets designed a platform that would maintain a prescribed distance from a target using pneumatic reaction control jets that would fly in the weightless environment of NASA's NKC-135 weightless laboratory (Figure 3). An ultrasound range sensor was used (just for the proof-of-concept since this would obviously not work in a space environment) with two reaction control jets to maintain the proper distance. A computer simulation was developed so that various control algorithms could be tested. The

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project was flown with some success on the NKC-135, but some problems were encountered with the underpowered reaction control jets and friction from the constraining cables.

Figure 3. Autonomous Shadow Project During Flight Testing.

This was an intensive, highly integrated, joint mechanical and electrical engineering project that required cadets with backgrounds in control theory, microprocessors, mechanical structures, thermodynamics, and computer modeling. The project scope and timeline was established by the electrical engineering and computer science aspects of the project since those were the project's critical path. A primary electrical engineering faculty advisor was established to develop the project requirements, grading criteria, and design reviews. Budget was shared between the disciplines allowing multiple sources to be used. The project was highly integrated between the disciplines because it required the cadets from all three disciplines to share a lot of design information and iterate all aspects of the design several times based on the simulation results and then modify the simulation based on component testing results.

6. Lessons Learned and Conclusions

Our experience with multidisciplinary projects has shown that they are well worth the extra time and effort because they give the students a much better perspective and appreciation of the complexities of real-world engineering projects. We have found that they do require frequent coordination between the project advisors and may even require philosophical coordination at the department head level. This coordination must occur from the inception of the project to clearly define the scope and level of integration of the disciplines within the project. The requirements and selection of the team members must also be clearly defined early in the project definition. Administration of these projects is difficult because a common project timeline must be worked out between the disciplines, including defining when specific design reviews occur and exactly what is expected of the project team at those design reviews. Despite these potential problems, there are advantages that outweigh these difficulties. One secondary advantage is that the cost of these projects can be shared between the disciplines. The extra involvement by the faculty members generally produces a much better leaning environment for the project teams, who in turn are more motivated to work on these projects which produces a more satisfied experience for all involved, including the faculty members. The primary advantage of these multidisciplinary projects is that it better prepares the students for the kind of engineering projects that they will participate in after graduation.

To capitalize on these perceived advantages, we recommend that these projects should be carefully developed, executed, and evaluated. The philosophical groundwork should be coordinated between the various departments even before the specific projects are initiated. We recommend that the disciplines brainstorm several project concepts and then assign prospective faculty advisors to begin defining the project framework. Once this framework is coordinated, then the specific project details can be coordinated such as timelines, design review definitions, team member requirements, scope of the disciplines, budget constraints, etc. Lastly, these projects need to be evaluated in both the short term (end of the semester feedback from the students) and intermediate term (three year surveys from the graduates) to make sure they are enhancing the students learning and engineering experience. We also foresee the requirement to conduct long term feedback from alumni to evaluate the perception that these projects give the students a better perspective of real-world engineering.

Authors

PETER D. HANLON is an Assistant Professor in the Department of Electrical Engineering and Computer Science. He holds a B.Sc. degree in Engineering from the University of Central Florida and M.Sc. and Ph.D. degrees in Electrical Engineering from the Air Force Institute of Technology.

BRYAN S. GODA is an Associate Professor in the Department of Electrical Engineering and Computer Science. He holds a B.Sc. in both Electrical Engineering and Computer Science from United States Military Academy, an M.Sc. in Electrical Engineering from the University of Colorado, Boulder and a Ph.D. in Electrical Engineering from Rensselaer Polytechnic Institute.

LISA A. SHAY is an Assistant Professor in the Department of Electrical Engineering and Computer Science. She is a graduate of the United States Military Academy with a B.Sc. in Electrical Engineering. She also holds an M.Sc. degree in Electrical Engineering from Cambridge University and a Ph.D. in Electrical Engineering from Rensselaer Polytechnic Institute.