Expanding and Improving the Integration of Multidisciplinary Projects in a Capstone Senior Design Course: Experience Gained and Future Plans

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Expanding and Improving the Integration of Multidisciplinary Projects in a Capstone Senior Design Course: Experience Gained and Future Plans

Abstract

Over the last several years, the multidisciplinary capstone Senior Design Project program implemented by the departments of Mechanical Engineering, Electrical and Computer Engineering, and Industrial and Manufacturing Engineering at the FAMU-FSU College of Engineering has continued to expand and improve, in terms of the number of multidisciplinary, interdepartmental project teams, the degree of coordination between different departments, the rigor of the structured engineering design process, and the excellence of the project outcomes.

Important features of our interdepartmental Senior Design program include: (1) a two-semester structured engineering design sequence, with regular design-review checkpoints at which students receive feedback on their written reports, oral presentations and demonstrations from multidisciplinary groups of faculty reviewers; (2) the inclusion of many projects sponsored by external clients/customers, including established industrial firms, new entrepreneurial ventures, and research institutions (both government agencies/labs and academic science departments); (3) international collaborations through student exchange programs and partnerships with foreign universities in several countries; (4) ongoing participation in regional, national, and international engineering design competitions.

Several new milestones in the evolution of our program have been attained in recent years, including a first-place victory in a regional design competition (SoutheastCon), the success of several of our industry-sponsored teams in developing viable commercializable products, the development of several international exchange partnerships, and the expansion of our multidisciplinary program to include students from an increasing number of different departments, with several students from the Civil and Environmental Engineering and Computer Science departments newly participating on our multidisciplinary teams this year.

In this paper, we review the development and present structure of our multidisciplinary program, discuss some of the administrative challenges faced and lessons learned in the course of our interdepartmental collaboration, and present our vision for making this program even more successful and well-integrated in the future, through enhancements such as improved synchronization of schedules and standardization of assignment requirements between departments.

Introduction

Increasingly today, many undergraduate engineering schools and colleges are striving to more extensively integrate multidisciplinary capstone design experiences into their Bachelors' degree program curricula, impelled in part by the requirement[1] from the Accreditation Board for Engineering and Technology (ABET) for Bachelors' degree programs to prepare their graduates to attain certain student outcomes, such as, in particular, the following two, highlighted here:

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints…

(d) an ability to function on multidisciplinary teams

These two outcomes can be quite naturally attained by interdepartmental student teams in the course of working on capstone design projects in a well-structured engineering design process.

Therefore, both to better satisfy this ABET requirement, as well as to more generally improve the quality of the degree programs at the FAMU-FSU College of Engineering (a joint college of Florida A&M University and Florida State University), several departments at our College have been collaborating interdepartmentally in recent years to organize, coordinate and advise teams of students from multiple engineering departments to work together on multidisciplinary Senior Design projects. (In addition, on some projects, we strive to even involve disciplines outside of engineering, as appropriate; we will discuss this facet of our program in a later section.) The coordination of interdepartmental senior design projects helps our program to synergistically train our students towards attaining both ABET outcomes (c) and (d) simultaneously, and potentially several other ABET outcomes as well.

However, although interdepartmental collaboration on Senior Design projects is generally regarded as an activity that ends up being greatly beneficial to our students, and to the overall strength of our undergraduate program, implementing this kind of collaborative effort does present a number of significant administrative challenges, arising largely from disparities between the course structures and schedules and expectations that are placed on the students by the different departments that are participating in interdepartmental projects.

In this paper, we review the history of our interdepartmental collaboration at our College on our Senior Design program, discussing how it has evolved to its present state, reviewing what the major challenges are at present, and describing some of the recent accomplishments of our program, such as its integration of international and entrepreneurial aspects, and its increasing success in the realm of academic competitions, as well as in the development of useful artifacts, including scientific instruments for academic research, and also practical commercializable products for industrial and entrepreneurial sponsors.

We conclude by discussing some ideas and plans for improved methods of organization and administration of our interdepartmental Senior Design program that will hopefully help to make it even more successful and better-integrated in the future.

History of the Interdepartmental Senior Design Collaboration at Our College

Prior to 2006, many failed attempts had been made in our College to adequately integrate cross-disciplinary teams of engineering students in the senior capstone design projects. One of the main reasons for these earlier difficulties was the disparity between capstone design curricular structures between the different departments. Until 2006, the Mechanical Engineering (ME) department was the only engineering department at our College with a two-semester-long capstone design course, and so it had only been able to involve a few non-ME students in its multidisciplinary projects in an ad-hoc manner. Other departments, such as Electrical and

Computer Engieering (ECE), had capstone design projects that were "multidisciplinary" in the sense of involving students from multiple majors (*e.g.*, both Electrical Engineering and Computer Engineering) on projects, but these projects were not multidisciplinary to the extent of being interdepartmental, since both majors are taught within the one department.

The situation changed when both the ECE and Industrial and Manufacturing (IME) departments at our College modified their capstone design courses into a two-semester project format, compatible with the format already being used by ME. This has allowed a substantial expansion of our interdepartmental collaboration on multidisciplinary projects. In the rest of this section, we briefly review the evolution process of our efforts to foster a systematic integration of more multidisciplinary projects to enhance our College's senior capstone design curriculum.

Curriculum Modifications. Several major changes in the capstone design curricula in both the ECE and IME departments have enabled better integration of the multidisciplinary design experience at our College.

First of all, starting in the 2006-2007 academic year, the ECE department adopted a new two-semester, six-hour capstone design sequence for both its electrical engineering and computer engineering Bachelors' programs. This new structure for the ECE senior design sequence made it possible for all projects involving ECE students to be coordinated by a single faculty coordinator who was could ensure that all design projects included realistic design constraints and sufficient depth for a capstone design experience, and that when possible, the design projects could also be made multidisciplinary in nature. After a few pilot projects, a sustainable, collaborative model began to take shape.

Further improving the opportunities for interdepartmental collaboration, starting in Fall 2008, the ECE department's Senior Design schedule became regularized so that all projects begin in Fall semester and finish in Spring, which is synchronized with the ME department's schedule—whereas, in the past, some of ECE's year-long projects were out-of-phase (started in Spring semester), which complicated course coordination and interdepartmental collaboration. The new arrangement matches well with the existing ME format allowing top-down coordination between coordinators early in the project solicitation and team recruitment process.

Also in 2008, the IME (a.k.a. IE) department, as well, came to the conclusion that their prior mode of conducting the senior projects over one semester was also outdated. In order to better fulfill customer design requirements, and to bring the IE department in line with other departments, the course schedule was modified to mandate a two-semester, Fall-Spring sequence, synchronizing with ME and ECE. In addition, the IME capstone design program reoriented its engineering design process to embrace the full six-sigma (6σ) methodology[2] by dividing projects into five reporting phases[3] such as Define, Measure, Analyze, Improve, and Control (DMAIC), with a gate (checkpoint) review at the end of each phase. This process can also be retrofitted as needed so that it interlaces well with either ME or ECE design sequence.

More detailed descriptions of the above changes were given in a previous conference paper[4] by some of the authors and so they will not be further elaborated upon here. However, as a result of these changes, it is now possible to match up the senior design project sequence between all three departments, and roughly coordinate expectations for design-review deliverables between them.

Organization of Multidisciplinary Projects. Formal collaborative efforts between the ECE and ME departments began in 2009 based on the concept of exchanging senior design students between courses to form multidisciplinary design teams in either department. A total of five interdepartmental projects were arranged in 2009-2010 to involve 17 ME and 15 ECE students, as shown in Table 1, below. Several iterations of schedule accommodations had to be made so that the two programs could carry out the collaboration more smoothly. Discussion of some of the challenges faced and overcome during this process will be discussed in a later section of the present paper; some of these experiences were also mentioned in our earlier paper.[4]

Table 1. Historical growth of our College's multidisciplinary (MD) senior design program, showing the progression for each department, in subsequent academic years, in the number of students from that department participating on interdepartmental MD teams (and the number of such teams that the department is involved with).

Academic Year	MD Project Students (Teams) in Each Dept.			
	CEE	**ECE**	**IME**	**ME**
2009-10:	0	15 (5)	0	17 (5)
2010-11:	0	18 (7)	9 (4)	25 (9)
2011-12:	0	32 (11)	14 (5)	37 (13)
2012-13:	3 (1)	24 (8)	0	22 (7)
2013-14:	3 (1)	42 (17)	14 (6)	52 (17)
TOTAL:	**6 (2)**	**131 (48)**	**37 (15)**	**153 (52)**

Both ECE and ME departments started to also include IE students on projects during the 2010-11 academic year, when nine IE students participated in four projects. Another 14 students joined six projects in the following year. For the first two years, the IE students assigned were operating as "subcontractors" on the design projects, rather than as full members of the design teams. In this mode, the IE students provided design, construction and integration support for the design projects to aid the teams in meeting the requirements for the project, while also reporting directly to the IE department to fulfill departmental mandates.

Since 2009, a greater emphasis has been placed into selecting and assigning multidisciplinary teams from ME, ECE and IME departments each year. The following table depicts this evolution based on certain quantitative metrics. The columns in Table 1 show the total number of students from each engineering department that were involved in inter-departmental multidisciplinary projects over the time period Fall 2009-Spring 2014. The number in parentheses indicates the number of interdepartmental project teams that those students were distributed over. For example, within the Mechanical Engineering program, a total of 153 students (or 40% of all ME students) were involved in multidisciplinary projects over the past 5 years.

Note that overall, the number of multidisciplinary projects in most departments has been increasing each year except in 2012-13, when the IME program was unable to participate as a result of low graduating senior enrollment. The percentage of all projects that are multidisciplinary has gradually increased as well. Overall, 45% of all of the ME-involved projects over this period were considered multidisciplinary, with the participation of one or more non-ME engineering students. Likewise, the percentage of ECE-involved projects that were multidisciplinary has steadily increased, up to a level of 77%, or more than three-fourths of the projects that involved ECE students in the current year. The trend has been similar in other departments.

More information about the present year's multidisciplinary projects is provided later in this paper.

Current Structure of the Senior Design Course

At this point in the evolution of our multidisciplinary collaboration, the various Senior Design courses making up our program (from the various departments) have converged to the point where they all have largely the same overall structure, albeit still with many differences in details between them. Here, we are referring to the three engineering departments that are currently most heavily involved in our multidisciplinary program (ME, ECE, and IE). But, in each course, students in each department enroll in a two-semester sequence (under a course number in their home department) for their main work on their project; each such two-semester sequence starts in Fall semester, and ends in Spring.

On the multidisciplinary projects, students are exchanged between departments as needed to fill a specified number of positions in given disciplines. Students from a given department are appointed to available projects by the Senior Design course instructor for their home department. These appointments are based in part on students' expressed project preferences, but the final appointment decisions are ultimately made by the course coordinators, to ensure that all projects' staffing needs will be adequately met, insofar as possible. In the IME department, students are assigned to projects by collating data on GPA, race, and gender. A class average GPA is used to assign high, medium, and low scoring students to each group. This variability is introduced in conjunction with race and gender considerations to mimic the diversity of the workplace.

Once the teams are assembled, each project is thenceforth coordinated primarily (albeit with cooperation as needed from other coordinators) by its designated "lead" department, which is generally whichever department first solicited sponsorship and/or advising commitments for the given project, although occasionally a project will get handed off between departments in subsequent years, if that happens to be called for due to the changing technical needs of, or faculty interest in, the given project. The department that leads a project in any given year has primary responsibility that year for that project's funding, advising, and general coordination, although oftentimes, multidisciplinary projects will receive some funding through multiple of the departments that are involved in that project. Also, generally, one or more faculty adviser(s) from each department that is participating on a given project will be appointed to help advise the student team on matters relating to that department's engineering discipline, although levels of involvement in project advising tend to vary greatly between different faculty members. Most projects have a single main faculty advisor from the project's lead department, who is largely responsible (albeit with help from course coordinators) for spearheading the project and steering it to best meet the needs of the particular sponsor/client (or competition effort); although, occasionally, a project will be co-advised by faculty from multiple departments who wish to collaborate together.

One particularly important point that we feel should probably be made clear to all students at the start of the academic year, to avert certain kinds of conflict (a.k.a., “power struggles”), is that the question of which department is designated as the “lead” department on a given project is primarily just an administrative matter to facilitate an appropriate division of responsibilities at the course coordinator level, as well as to determine which department’s particular schedule of major design-review checkpoints the specific project team will follow. In particular, the “lead department” designation should not be interpreted as necessarily dictating the division of authority or leadership roles among the students on the team. Generally, teams are permitted to determine their own organizational structures for themselves. And certainly, students from other departments outside the project’s lead department are fully expected to contribute equally to the project work, including to the preparation of all major project deliverables, as well as to the team’s decision making, as full and equal members of the team. Teams should be made aware that their members from other departments are not necessarily expected to necessarily adopt a role that is subordinate to the students from the project’s lead department; in fact, not infrequently, one sees that students from other (non-“lead”) departments, depending on their personality or leadership skills, will end up leading their team’s efforts.

After team formation, over the course of the two-semester class sequence, the project teams proceed through a structured engineering design process, during the course of which they must pass through periodic checkpoints (formal design reviews and/or demonstration events). These checkpoints give all of the stakeholders who are involved with each project an opportunity to review and give feedback on the students’ progress on their design efforts, to hopefully help the students resolve any problematic issues that may arise as early as possible in the design process, as well as to assess the students’ progress for purposes of grading and departmental self-assessment. The list of stakeholders on any given project includes the course coordinators from all of the departments that are involved in that project, and any of their delegated teaching assistants; as well as the project’s main faculty advisor(s), and any other faculty reviewers that may have been assigned to help review the project by its lead department; and also any external technical advisors that may have been appointed by non-lead departments participating on the project; and finally, also, the project’s sponsor or client, for those projects that are externally sponsored by some interested party outside the Engineering school (such as a non-engineering academic department, an industrial firm, a government agency, or a private entrepreneur). We don’t expect that all of the various stakeholders on a given project will necessarily be able to attend each and every design-review event that is scheduled, but we generally do try to ensure that at least several (3 or more) qualified evaluators attend each review in person (perhaps with some others watching later by video), and that several of the reviewers contribute evaluations for each oral presentation and/or its accompanying written report (if any). The course coordinator for the project’s lead department (or their delegated TA) then averages together all of the different evaluations received in order to determine the overall team and individual scores on the assignment(s) corresponding to that checkpoint.

In addition to going through these major checkpoint events, which typically occur at a rate of roughly one every month or so (varying somewhat depending on the schedule of the project’s lead department), the student teams also meet with their main project advisor(s) and course coordinator(s) to review their progress even more frequently, at least once every two weeks in between the major checkpoints. In a typical project's timeline, most of the high-level design work will be completed in Fall semester, with some subsystem assembly/testing work having started, and Spring semester is (ideally) spent finalizing the remaining design details and completing full system prototype construction and testing. Usually, teams will hold two or more demonstrations of their prototypes at various stages of development during the Spring semester, concluding with the annual (ECE) Design Fair and (ME) Open House events in April, at which members of the public and external project sponsors have the opportunity to view the (hopefully) completed prototypes on display, and interact with the student teams.

At the end of each semester, the complete grade information about each student's project work on their major project deliverables (as defined by the lead department, and evaluated by all contributing stakeholders) gets communicated from the lead department's coordinator back to the coordinator for that student's home department, who then assigns the student's final overall course grade based on this information and other factors, such as peer review data and various smaller, department-specific assignments that may be associated with each individual course.

Current Year's Interdepartmental Projects

Table 2 below lists the Senior Design projects this year that involve students (and faculty coordination/advising) contributed by multiple engineering departments at our College, out of the set: Civil and Environmental Engineering (CEE), Electrical and Computer Engineering (ECE), Mechanical Engineering (ME), and Industrial and Manufacturing Engineering (ME); the engineering departments that are currently involved in each project are indicated with an 'X.'

The reader will note that currently, there is only one interdepartmental project that involves the Civil & Environmental Engineering (CEE) Department; this is because this department's involvement in the interdepartmental Senior Design collaboration at our College is a new aspect of our program which is was only recently introduced (in 2012) and is proceeding on an experimental basis. The current CEE-involved project is funded by one of the authors' National Science Foundation project on wind energy, and it will last for the next five years as a pilot program. Although traditional design problems in Civil Engineering had only a limited interdisciplinary aspect, we envision that emerging modern developments such as energy-efficient buildings or wind turbine structures will provide increasingly many opportunities for interdisciplinary collaboration. One challenge that we faced was the size of the final product in Civil Engineering designs. Since it was not possible within the project budget to actually construct the kind of full-scale (*e.g.* ~50 m tall) wind turbine that would be most useful for civil-scale power generation, the students were asked to instead design the full-scale structure, but construct only a scaled-down model that will test key features of the design. We expect that CEE's involvement with the multidisciplinary Senior Design program at our College may expand in future years as we gain more experience through this pilot project.

In addition to the projects listed above, there is one other currently active Senior Design project (RoboSub) that was interdepartmental between the ECE and ME departments during the three previous academic years (2010-11, 11-12, 12-13), but is currently only interdepartmental between the ECE department and Florida State's Computer Science department; that project is not included in the above table because it currently actively involves only one engineering department (although lab space for it is still being contributed by ME). There are no ME students on the team this year, because the bulk of the mechanical engineering work needed on the project was essentially completed last year.

Table 2. Current Interdepartmental Senior Design Projects at our College

Project Description	**CEE**	**ECE**	**IME**	**ME**
1. Autonomous Aerial Vehicle		X		X
2. Autonomous All-Terrain Vehicle		X		X
3. Bearing Bore Gauge Tester		X		X
4. Bridge Sensor		X	X	
5. Conformable Battery Pack		X	X	X
6. Friction Cone Penetrometer		X		X
7. Hand-Held Grinder			X	X
8. Hybrid Energy Storage for Off-Grid Zero-Emissions Building		X		X
9. Mars Lander Rover Recharger		X		X
10. Offshore Wind Turbine	X	X		X
11. Oil Spill Radar Testbed		X		X
12. Orthogonal Interconnect Testbed		X	X	X
13. Palm Harvester		X	X	X
14. Protective Baseball Gear			X	X
15. Solar Arcjet Thruster		X		X
16. Solar Car for Shell Ecomarathon		X	X	X
17. Indoor Quad-rotor Control		X		X
18. Robo-Ops Competition		X		X

There are also a number of other current Senior Design projects at our college, not listed above, that are at least somewhat multidisciplinary in nature, even though they may currently involve students (and faculty advisers) from only one department. For example, the SoutheastCon robotics competition effort normally requires electrical, computer and mechanical design elements, but our college's teams involved in this competition have not been set up as interdepartmental projects; only the ECE department has been involved in them so far. (However, it's possible that the ME department may choose to contribute students to some of the SoutheastCon project teams in some future years.) Likewise, there are similarly a number of projects that only have ME students on them, but which nevertheless involve at least a small amount of design work in the area of electrical circuits and/or digital control systems. However, not every project that has some multidisciplinary aspect presents sufficient challenges to adequately engage students and faculty from multiple departments; therefore, in deciding which of the projects are appropriate to run as full-fledged interdepartmental multi-discipline efforts, the course coordinators must use their judgment, and be somewhat selective.

Collaborations with Non-Engineering Departments

Over the years, a number of Senior Design projects at our College have also involved collaborations with departments outside of the engineering school, thereby further extending the multidisciplinary reach and scope of our program.

For example, for the last three years, two of our departments (ECE and ME) have engaged in a partnership with Florida State's department of Earth, Ocean & Atmospheric Sciences department, and two of its associated research laboratories, to have teams of our engineering students develop various new scientific instruments (or instrumentation platforms) that would be of utility in oceanographic research. The senior projects that have been carried out so far in this ongoing partnership include:

- **Robo-Boat** for automated, GPS-navigated collection of temperature/salinity data.
- **Coastal Drifters** for collection of current and temperature data in shallow coastal waters.
- **Oil Spill Radar** testbed for characterizing satellite radar response to oil slicks.

In addition, in some recent years, we have partnered with a laboratory within the Physics department of Florida A&M on a couple of projects to develop novel instrumentation for Cosmic Ray astronomy:

- **COSMICi** system for collection of directional cosmic-ray shower data.
- **Cosmic Cube**, a low-cost desktop system for distributed collection of cosmic ray shower data.

We have also collaborated with North Florida Community College's science and mathematics department on a project involving the design of an enclosure for a telescope mirror.

Also, we are working with Florida State University's Computer Science (CS) department to recruit upper-level CS undergraduates to participate in our senior engineering projects for special-topics credit. We had one CS student join a programming-intensive Senior Design project (RoboSub) starting in Fall 2013, and three more (including two graduate students) were added to other multidisciplinary projects (Oil Spill Radar, Penetrometer, Autonomous ATV) in Spring 2014. Hopefully, next year we will have even more participation from the CS department, and will work to recruit additional students from Florida A&M University's Computer and Information Science (CIS) department.

Finally, although this is not strictly a collaboration with another teaching department per se, in the general realm of academic/educational projects, we have had two projects in recent years that were sponsored by local science museums.

Entrepreneurial and Product-Development Projects

Fostering entrepreneurship, and technology commercialization more generally, has, in recent years, emerged as a major new focus area for our College and for Florida State University, both to prepare our graduates to be better able to "think entrepreneurially" (or innovatively) in their engineering design and/or program management work when they get out in their careers (regardless of whether they actually start their own companies), and also, to hopefully help increase our local region's economic development as new ventures started and/or staffed by former students increasingly "spin off" from the university.

In line with this trend, we have been working to add an entrepreneurial component to our Senior Design program, both by inviting entrepreneurs to sponsor projects in which teams of engineering students develop prototypes or demonstrations of new products supporting that entrepreneurial venture, as well as by encouraging students to come up with their own ideas for new entrepreneurial ventures which they can then seek funding for (*e.g.* through business plan competitions) and develop prototypes for in their Senior Design project. We are also currently in discussions with FSU's business school, aimed towards the goal of integrating business school students into entrepreneurial engineering project teams in the future. For students who want to start their own companies based on their Senior Design project work, there are several local resources, such as business incubators, which can help students establish contact with the needed expertise to help them navigate through the difficult startup process. Also, even already-established companies can sponsor Senior Projects that are aimed at developing novel, commercializable technologies, fostering an entrepreneurial spirit within existing industry firms.

Some of the entrepreneurial and technology-commercialization-oriented Senior Design projects that have been pursued in recent years include:

- **Bridge Sensor –** Demonstrating a new technology for sensing structural fractures.
- **Electroluminescent Cap –** A baseball cap product with a flashing sports logo.
- **Grinder Tool –** Improving a handheld grinding tool for a local manufacturer.
- **Palm Harvester –** Developing a machine to aid in harvesting of tall oil palms.
- **Pedibus Development –** Designing a pedal-powered sightseeing bus for tourists.
- **Printer Cleaning Station –** Accessory to clean the print head on a fabric printer.
- **Self-Stabilizing Pool Table –** Student-led venture to develop this novel product.
- **Solar-Powered Phase Change Compressor –** Developing a working HVAC application of this invention patented by the project sponsor.
- **Turf Hardness Tester –** Design & development of a manufacturable product for a local manufacturer of turfgrass test equipment.

Several of us (the Senior Design course coordinators) also helped to organize and participate in an Entrepreneurship Kickoff Event (mixer and workshop) at our College in April 2013, in which experts from the local business community presented advice for student entrepreneurs, and students presented their ideas for new entrepreneurial projects that they wanted to pursue as Senior Design projects during the current academic year. One of this year's entrepreneurial Senior Design projects (Self-Stabilizing Pool Table) came to us as a direct result of last year's workshop, and we are striving to expand this aspect of our program in future years. We are seeking grant support to provide seed funding for student entrepreneurial projects.

Although our product-development oriented projects are ultimately run by the students, and the scope of what they can accomplish in two semesters is limited, we also encourage the external industry sponsors of our projects to provide the students with helpful feedback, during (live or teleconferenced) sponsor meetings, and during the Q&A periods of student presentations to which the sponsors are invited, to help our students better apprehend the real-world considerations that affect important business aspects of product commercialization, such as the manufacturability and marketability of their designs. This industry participation helps the students "keep their feet on the ground" and helps to ensure that their projects will be more than just an academic exercise that only looks good on paper – ideally, we would like their efforts to also have actual value in the real world.

Projects from Industry and Government Sponsors

External sponsorship of our capstone design program provides many benefits by exposing our students to real-world challenges and giving them the opportunity to engage with engineering professionals who serve as mentors. In addition, many industry-sponsored projects are intrinsically multidisciplinary in nature, which demands collaboration from engineers with diverse backgrounds. Over time, we have engaged many sponsors with consistent levels of sponsorship; these sponsors can, in many cases, provide solid mentorship through their appointed liaisons who help advise the students, as well as financial support towards the realization of prototypes. This sustained sponsorship has also provided strong incentives for departments to work together, and is one of the major reasons for our increasing multidisciplinary collaboration.

For many years, our Mechanical Engineering department, in particular, has been fortunate, with the participation of its Mechanical Engineering Advisory Council (MEAC), to cultivate many long-term industry and government sponsors who have provided high-quality real-world and engineering-relevant projects, encompassing more than half of our recently sponsored projects. Other departments in our collaboration have also been building up similar connections, which over time are further strengthening our cross-departmental design collaborations. In general, we have engaged with two types of sponsors:

1. Industrial sponsors from national/global companies such as Boeing, Cummins, Harris, Lockheed, and GE, along with a wide variety of local/regional companies;
2. Government agencies such as Air Force Research Lab, NASA centers, Department of Energy national laboratories, our state's Department of Transportation, *etc.*

This year alone, we have four global/national and seven regional/local companies as sponsors. Collectively, this year their support is funding a total of 14 projects (see Table 3, below), several of which (marked with asterisk "*") are currently multidisciplinary (or have been in past years).

In addition, typically a number of projects each year are sponsored or co-sponsored by government agencies. This year we have several projects that are primarily sponsored by government agencies:

- **Friction Cone Penetrometer –** Sponsored by the National Park Service.
- **Mars Lander Rover Recharger –** Sponsored by NASA Kennedy Space Center.

- **Indoor Quad-rotor Control** – Sponsored by the Air Force Research Lab (AFRL) and Eglin Air Force base (as well as co-sponsored by an industry sponsor).
- **Solar Arcjet Thruster** – Sponsored by the NASA Marshall Space Flight Center.

*Table 3. Industry-Sponsored Projects in 2013-14. *Multidisciplinary projects.*

#	Project Title	Industry Sponsor(s)
1	Solar Car for Shell-Ecomarathon (Competition Effort)*	Boeing
2	Biaxial Tensile Test Fixture for Uniaxial MTS Testing	Cummins
3	Mechanical Dump Valve	
4	Turbocharger Compressor Casing	
5	Phase Change Transient Heatsink for Power Semiconductor	GE Aviation/ Unison Industries
6	SoutheastCon Mobile Robotics (Competition Effort)	Harris
7	Orthogonal Interconnect Concepts for Phased Array Antenna*	
8	RoboSub (Competition Effort)*	
9	Indoor Quad-rotor Control*	Jabil
10	Grinder/Battery Development	King Arthur's Tools
11	Automated High Volume Bearing Bore Gauge*	Koyo Bearing
12	DTC Magnet Insertion Process	Turbocor
13	Turf Hardness Impact Tester	Turf-Tec International
14	Shuttle Valve Design	Verdicorp

International Engagement

Our Senior Design program has increasingly many international facets. These help to expose our students to the kind of diverse, multinational environment that is the context for many real-world engineering projects in today's increasingly globalized economy.

For example, we have a successful ongoing collaboration with two Brazilian universities as part of the Fund for Improvement of Postsecondary Education (FIPSE), a program of the U.S. Department of Education which encourages international education collaborations. In this program, we alternate, in different semesters, between sending some our students to Brazil, and having some Brazilian students come here to study. During part of each year, the teams in this program are split between the two countries (with some team members in Brazil, and some in the U.S.), and during this period, the students must leverage teleconferencing and other technologies to collaborate effectively on their project. For example, in Fall 2013 semester, the American student on one team who was in Brazil delivered his portion of the required design-review presentations in the form of a pre-recorded video, which was integrated into a PowerPoint presentation that was delivered live by the rest of his team.

Our College recently also started up a new exchange program with the Federal University of Technology at Akura (FUTA) in Nigeria; as part of this program, some Nigerian exchange students on a BS+MS track are participating in our Senior Design projects this year.

Our College is also in the process of starting up several new international exchange programs in partnership with the Tianjin University of Technology (TUT), Anhui University, and the University of Macau (all in China); in these programs, similarly to the Nigerian one, a number of Chinese students will finish their B.S. degrees and earn their Masters degrees at our College. As a result of this program, we expect to have an increased number of Chinese students participating in our senior projects starting in the 2014-15 academic year.

Finally, one of our universities (Florida State) has a branch campus in Panama with a Computer Science department there, and we in discussions with them about collaborating to start up a new international, multidisciplinary Senior Design project next year, with one of our former students working on that project to finish his degree remotely.

Ongoing Particpation in Engineering Competitions

Despite the increasing number of projects in our Senior Design program that are aimed at developing practical products for science and industry, another continuing facet of our program remains our ongoing participation in regional, national, and international engineering design competitions. In recent years, competitions that our students have participated in (or at least, worked towards participating in) at some level include:

- The American Astronautical Society (AAS) and American Institute of Aeronautics and Astronautics (AIAA) sponsored CanSat competition (rocket-launched payload).
- The American Solar Challenge competition (solar car road race).
- The Association for Unmanned Vehicle Systems International (AUVSI) sponsored Student Unmanned Air Systems (SUAS) competition to develop autonomous unmanned aerial vehicles (AAVs/UAVs).
- The AUVSI-sponsored RoboSub (robotic submersible vehicle) competition.
- The Institute of Electrical & Electronics Engineers (IEEE) sponsored regional SoutheastCon student hardware competition (mobile robotics competition)
- The National Aeronautics and Space Administration (NASA) sponsored Revolutionary Aerospace Systems Concepts – Academic Linkage (RASC-AL) Robo-Ops (planetary rover) competition.
- The Shell Eco-Marathon Challenge (energy-efficient vehicle competition).
- The Society of Automotive Engineers (SAE International) sponsored Formula Hybrid (gas-electric and all-electric racing vehicles) competition.

Overall, our College's performance in these kinds of engineering competitions has been improving in recent years; for example, in the last two years, our student teams won 1st and 3rd place trophies at one competition (SoutheastCon), and last year one of our multidisciplinary teams won 5th place in another competition (Robo-Ops).

Environmental, Social and Sustainability Considerations

In the course of their projects, our students address and are taught how to consider the impact of their designs on the environment, safety and health hazards, product life cycles and lifetime cost of ownership, reliability, risk analysis, and how to analyze probabilities in their designs. Statistical analysis is particularly important when not enough data is available, or the final product is used in uncertain and poorly defined conditions, and may be likely to be abused or misunderstood by the user. Our students must write Users' Manuals for their products, and provide other documents that can help address all of these concerns.

Our students work closely with their sponsors/customers, and they implement midcourse changes on an as-needed basis. Sponsors' evaluation of project progress and accomplishment is an integral part of the senior design grading process, to ensure that the customer's input has weight with, and is respected by, the students.

Other Aspects of Senior Design Course Content

In the lecture content of our departments' Senior Design courses, we focus not only on design approaches and project planning, but also on teaching our students the basics of professional conduct, including team-building, engineering ethics, oral and written communication skills, and other basic skills that they can adapt to think critically and to learn how to be creative and innovative. Although our basic approach has been to focus on problem definition, needs analysis, development of design concepts, and evaluation of such concepts and overall project-related needs, we also address the tools and methods that students need to think quantitatively and carefully, and to analyze all possible scenarios, risks, and limitations of their designs and implementations. Those tools include decision theory, analytical hierarchy process[5] (AHP), quality function deployment[6] (QFD), basic creativity[7,8] and innovation[9] techniques that students can build and enhance to improve on what they traditionally do, as well as effective time management, and conflict management/resolution[10,11] strategies. Those approaches were derived from numerous experts' writings (articles, books, papers, workshops, and others) that have screened those tools to determine the ones that best enhance the learning process and students' critical thinking skills, and help students avoid impeding cultural, personal, and other social and self-limiting habits and performance barriers.

One of the key features of our approach is that we require evaluation and feedback from our students on the relative performance of themselves and their team members (self-and-peer evaluation) and review this information periodically, and take necessary steps to implement any needed correction measures. This usually saves time and helps our students focus more on ensuring project success and on having every member contribute as effectively as he or she can.

Challenges in Interdepartmental Senior Design Project Coordination

Over the years, we have found that working on multidisciplinary projects is a very rewarding experience for the students, as well as for ourselves. Working closely with our colleagues in other disciplines helps us all to gain an appreciation for our sister disciplines and to more effectively see and understand the "big picture" of engineering as a whole. Students, too, will benefit from this experience when they get out into the real world of industry, in which many, many real-world projects are highly multidisciplinary, and engineers from many backgrounds are expected to work effectively together. For these and other reasons, we feel that the multidisciplinary aspect of our program is invaluable, and is well worth the challenges.

Nevertheless, one does encounter difficult challenges in administering and coordinating such a program. Many of these arise from the relative newness of the multidisciplinary program, and from the historical tendency of many academics within particular engineering specialties to stay within their "silos" and not interact very much with their colleagues in other fields. Because of that history, we, as a faculty, are not always extremely familiar with the kinds of tools, techniques, methods, diagrams, analyses, *etc.* that would be expected to be seen from students in other disciplines, and sometimes this leads to "surprises" during the evaluation process, wherein a faculty member may be asked to help evaluate a team's written report or oral presentation, and they get exposed, during the course of the review, to a type of technical material that they are not familiar with, and do not know how to appropriately assess. However, these kinds of problems can be expected to diminish by themselves over time, as the growth of our multidisciplinary program gradually helps to expose more of our faculty, over the years, to content material from other disciplines, and as a result, over time, this material becomes more familiar to them.

Other problems are more administrative and structural in nature. One classic source of tension in the interdepartmental projects at our college arises from the differing class schedules and meeting scheduling procedures used by the different departments. These in turn relate to (still) somewhat differing credit-hour structures for the course sequence in different departments. For example, at our College, currently there remains the following disconnect:

- In our Mechanical Engineering department, students take a 3 credit-hour Engineering Design Methods course their Junior year, in which they receive most of the lecture content of Senior Design. During Senior Year, they take Senior Design for 3 credit hours in both the Fall and Spring, and 3 hours/week worth of class periods are set aside for this purpose, but, since they have already had the lectures, this time can be used mostly for project meetings and presentations.

- In our Electrical and Computer Engineering department, students also take 3 credit hours for Senior Design in Fall and Spring of their senior year, but there is no separate Engineering Design Methods course in the curriculum; instead, students receive that lecture content during Fall semester of their Senior year, at the same time that they are starting work on their projects. As a result, those class periods are not available to use for team meetings and presentations; instead these events must often be scheduled at times outside of students' normal class hours.

Probably more than anything else, this difference in these two departments' credit-hour structures, and the resulting difference in the use of class periods, is the main problem that, in recent years, has led to recurring tensions between students (and occasionally also faculty) from different departments who are involved with the interdepartmental projects, since it makes it rather difficult to schedule meetings and presentations for projects at times during which both Mechanical and Electrical/Computer students are available, and, in recent years, the number of these projects has been increasing. However, because ultimately this particular problem arises from differences in departmental curricula, this is not the kind of problem that can finally be solved by the Senior Design course coordinators acting on their own; instead, it must be resolved by decision-making bodies at the departmental and college level.

The scheduling problems tend to be especially painful during the first weeks of Fall semester, during which the team members from the various departments are not yet finished coming together to comprise a well-coordinated and high-functioning team. (The importance of this team development process is well summarized in, *e.g.*, chapter 9 of Ford & Coulston's text.[5]) In the past, we have found that the mismatched course schedules can all too easily turn into an excuse for students to take a long time to establish their team cohesion. In response to this experience, we have developed several instruments (short assignments) which we hope will facilitate a smoother, more rapid and effective team development process during the first few weeks of Fall semester:

1. "Team Contact Information" and "Team Meeting Planner" forms, to force members of multidisciplinary teams to exchange contact & schedule information with each other immediately (within a few days) after team assignments are made.
2. "Meeting Scheduling Checklist" form, to push teams to also schedule all required meetings (team meetings, meetings with project advisor/sponsor, coordination meetings with course instructors, *etc.*) as early as possible in Fall semester.
3. "Code of Conduct" assignment (an agreement to be composed and signed by all team members), to force teams to sit down with each other and plan out the basic outlines of how they are going to work together, and what their responsibilities to each other are.

The instruments in item 1 above have been applied, on an informal trial basis, by the ECE department to all of the ECE-involved projects, and have been found to be very helpful; the ECE department will be including these assignments (as minor graded items) on its official course syllabus starting in Fall 2014, and they are also recommended for adoption by other departments.

The instrument in item 2 above was just developed this year, albeit too late to be used by all teams, but it will also be introduced as a formal requirement in the ECE course starting next Fall. It, too, is also recommended for adoption by other departments.

Regarding item 3, the Code of Conduct, we feel that this document is very important for giving all team members a sense of accountability to their team, and for establishing procedures to be followed in case a team member is not doing his or her part. On occasion, we have found that there have arisen disconnects between departments regarding the detailed expectations for this assignment, but we believe that such disconnects can be prevented in the future based on some new guidelines for this assignment that we have developed to standardize expectations for this assignment between departments; we plan to begin implementing these guidelines next year.

Finally, a third area of challenge arises from differences in course syllabi and evaluation rubrics between the different departments. The expectations and timing for major deliverables (project reports and presentations) are roughly similar between the different departments at our college, but are not identical. This sometimes leads to confusion among the students as to what the expectations are for their particular project, and among the faculty evaluators as to what standards they should be using to evaluate a given document or presentation. However, these problems can be alleviated somewhat by simply doing a methodical job, within each department, of providing clear assignment schedules to students in advance, and clarifying in writing (*e.g.*, through written evaluation rubrics) what the expectations are for that department's deliverables, and providing that information in advance to the students as well as to all faculty (from every department) who are asked to help evaluate a given project's deliverables.

However, sometimes the lead department's evaluation rubrics, if they were overly narrow in scope, might not be adequate to encompass appropriate evaluation of student contributions from a different engineering discipline. To mitigate this problem, course developers should strive to compose their rubrics using language that is broad and flexible enough to allow evaluators from other departments to adequately express their assessment of the kinds of content that they expect to see from the team addressing aspects of the project that are important to his their (the evaluators') own fields.

To some extent, over time, the various departments have also been borrowing ideas from each other's evaluation rubrics and report/presentation guidelines to include in their own department's materials. Eventually, we may see some degree of standardization of assignment materials arise between departments; certainly, there are many commonalities already. However, due to departments' differing pedagogical interests, this is bound to be a gradual process.

Towards an Integrated, College-Level Senior Design Project Course

In the near term, we expect that our scheduling problems will be somewhat alleviated next academic year (2014-15), because our College will be adopting a new class schedule in which all engineering classes will be taught only two days a week (either Monday/Wednesday or Tuesday/Thursday). This means that Fridays should theoretically be available, for students from all departments, as a time during which they can hold team meetings or design-review presentations for Senior Design, since none of our students should have class conflicts on those days, except for the occasional student who may happen to be taking a course from another college that meets on Friday during their senior year.

However, despite the near-term alleviation of scheduling pressures that we expect this change may afford us, in the longer term, it may nevertheless be advisable for us to continue to work, at the departmental level, to better synchronize the schedules of the various departments' Senior Design courses, because there may not be enough time on Fridays alone to satisfy the scheduling needs of all projects.

One idea that has been floated is to create a separate course number, managed at the college level (not by any single department), and put all of the multidisciplinary projects under that course heading, so that all students working on those projects will have the same class periods set aside for Senior Design during the week, and so, during any of the reserved class periods, on weeks when there are no lectures scheduled in the course calendar, it will be guaranteed that every member of each multidisciplinary team will be free during that time period to meet as a team, or with faculty, about their project.

However, to implement such a change would still require significant coordination between the departments, to make sure that that new course were designed to adequately satisfy the curricular needs of all of the participating departments. And, in some cases, accomplishing this may be quite challenging; for example, the ABET criteria for Civil Engineering mandate that only a licensed P.E. may teach the capstone design course. Also, having a separate course for the multidisciplinary projects might introduce additional delay and confusion at the start of the Fall semester, since students would not even know which course number to register for until they knew whether they had been appointed to a multidisciplinary project or not. So at this point, this path is still only one of several possible solution approaches that we are considering. But, as we said, any solution anyway requires buy-in from several departments' curriculum committees, and it may also impact other parts of the curriculum (*e.g.* if it changes the number of credit-hours dedicated to Senior Design), so it will be likely be administratively difficult to implement. Therefore, we remain the lookout for creative new solutions to these kinds of challenges.

Conclusion

Over the years, we have found that to interdepartmentally coordinate multidisciplinary Senior Design projects has been a challenging, but very rewarding experience. Usually, by the end of the year, each team has gained an enormous amount of practical engineering skills and knowledge, as well as having learned valuable lessons on how to work on a diverse team, address real-world needs, and resolve conflicts arising from students' differing backgrounds and work habits, while also addressing unpredictable challenges that arise externally due to changing requirements from clients, occasional sponsor unavailability due to government shutdowns, *etc.* Frequently, our past students have expressed to us, after completion of our program, that they learned more in the course of their Senior Design projects than in the rest of their engineering curriculum put together. This type of feedback encourages us that we are on the right track. Although the administrative tasks involved in successfully coordinating >300 students and ~60 faculty from five departments (including, now, Civil & Environmental Engineering and Computer Science) on several dozen multi-disciplinary projects are complex and difficult, we nevertheless feel that the rewards for our students, and for the quality of our program, are substantial and well worth the effort. Every year, we learn new things about how to effectively manage this collaboration, and as a result, each year our coordination processes become more streamlined and effective, despite the increase in complexity resulting from an ever-increasing number of multidisciplinary projects. This allows increasingly many students each year to benefit from the multidisciplinary team experience, while having a better experience overall in Senior Design. Fortuitously for us, next year's change in our College's class schedules may alleviate some of our long-standing meeting-scheduling headaches. Further improvements in the interdepartmental synchronization of the capstone design course may also be possible. In future years, as word of our program's successes continues to spread, and more new external (industry, government, and entrepreneurial) sponsors jump on board, we anticipate that the number of interesting, practical, well-funded and successful projects developed by multidisciplinary teams of senior engineering students at our College will only continue to grow.

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