An Interdisciplinary Student Design Project Involving Electrical And Mechanical Engineering

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Abstract:

A "capstone" design project has long been a central part of the engineering curriculum at the University of Alabama at Birmingham. Traditionally, these projects have been performed within a single department, within the area of specialization of the individual student. In the fall semester of 2006, the mechanical engineering students were in the second semester of a two-semester effort to design and construct a Formula SAE racecar for the student competition of the Society of Automotive Engineers. The electrical and computer engineering students were assigned the task of designing and implementing an instrumentation package to measure various mechanical quantities in the Formula SAE racecar. The mechanical quantities measured included engine RPM, transmission gear, and shift point. In this paper we present a case study of this interdisciplinary design effort, with observations of educational benefits and lessons learned.

Background:

Every undergraduate engineering student at the University of Alabama at Birmingham (UAB) is required to complete a "capstone" design project. This senior design project has long been a part of the requirements for an engineering degree at UAB. In addition to satisfying the requirements for accreditation by the Accreditation Board for Engineering and Technology (ABET), the faculty and our advisory boards generally agree that this project is an important learning exercise, requiring the students to use material learned in previous courses in an integrated manner. Since almost all work in industry and academia involves collaboration, a shift was made several years ago from individual projects to team projects.

Traditionally, each department has conducted this team project as a stand-alone effort. Students have been given assignments that are narrowly focused within their specialization.

The mechanical engineering department offers a two-semester senior design series, twice each year. In the first semester, a variety of topics such as scheduling and material selection are reviewed in a once a week lecture format during the first semester. Assignments for these lectures are related to the second semester of the project in an effort to establish mini-deadlines for the project. By the end of the first semester of the sequence, the students are required to have completed the design of the project, including all of the calculations and drawings. The second semester requires the student to build and test the apparatus. Periodic updates are required for the project in an oral presentation format. One of the mechanical engineering projects in Summer 2006 was the design and construction of a 1/3 scale Formula car. The Society of Automotive Engineering (SAE) sponsors the Formula SAE competition, which is an international competition involving 120 teams from as far away as Japan and Australia. This is the first year that UAB has competed in the competition. The competition allows the use of an engine up to a 600cc with a 20mm restrictor on the intake. The competition encourages the students to design and select a wide variety of the materials and mechanical aspects of the car. The design portion of the competition focuses on innovative design so the rules are intentionally left open ended on most systems. The UAB summer senior design task was to complete all of the mechanical aspects of the car and convert the carbureted engine into fuel injection by December 2006. The fall first semester senior design group was responsible for the completion of design for and fabrication of the carbon fiber chassis, the nose cone, and the side pods as well as the tuning of the engine. In the first semester of each senior design series the teams are given a set of design parameters at the beginning of the term. For this team, it is a set of rules published by the SAE that govern the design and construction of the vehicle as well as the competition events. This team included four mechanical students with varying educational and industrial experiences.

The electrical engineering senior design sequence has two tracks: a one-semester team project, and a two-semester team project. The one-semester option requires the students to design, build, and test an apparatus in one semester. The two-semester option is similar to the mechanical design series, without the lectures. The student are assigned a project during the first class meeting and expected to complete a design with drawings and calculations by the end of the first semester. For both the one- and two-semester options, weekly updates are required and the students are required to keep updated design notebooks, which are checked periodically by the faculty. The construction of the project and testing are conducted in the second semester. Traditionally, the project assigned for the two-semester team project in the electrical engineering department has been the design of an entry for the Institute of Electrical and Electronics Engineers (IEEE) Southeastcon robotics competition. The projects for the one-semester senior design projects vary from semester to semester. Both the one- and two-semester projects include a preliminary design review (PDR) and a critical design review (CDR) as a central requirement. The one-semester project has PDR early in the semester, and CDR at midterm. The two-semester project has PDR at the midterm of the first semester, and the CDR at the end of the first semester.

The Project Assignment:

In the Fall of 2006, electrical engineering students who registered for the one-semester senior design series were given an assignment to design and build an instrumentation system for use in the Mechanical Engineering department's Formula SAE car. The design requirements for the electrical system were that it should display the following items: shift up and shift down indication, engine RPM readings (tachometer) with at least three digits of decimal precision, and the gear in which the transmission is currently operating. In addition the student design was required to survive and operate within the environment of the Formula SAE car, and to not interfere with the operation of the car in any way. In order to insure that the module did not interfere with the operation of the car, it was required that the car must be able to operate with or without any of the modules installed.

Twelve students registered for this design project. The students were split onto three teams of four members each. All of the teams were given the same project, and at the end of the semester, an informal competition was to be held to determine the best design.

The students were assigned into teams by the instructor. At the start of the semester, students were required to fill out a survey of their skills and time commitments for the semester. The answers given by the students were central to selecting which students formed teams. A special effort was made to ensure that all teams had members with a wide variety of skills.

"Real-World" Aspects of the Project:

An attempt was made to bring as many "real-world" issues as possible into this project. Both authors have many years of industry experience, and a clear understanding of the differences between actual engineering practice and academic exercises. Particularly in design projects, the authors feel that it is important to expose students to the environment and types of issues that they will face in industry.

Not all aspects of a project in industry can be applied to a student design project, but many can be brought into the course. After the requirement for a working project, the primary influence on an industrial design is often the parts budget. Students in the electrical team were constrained to a parts budget of $600. All projects in the real world are constrained to certain interfaces, and in this project as well, the students had to meet certain mechanical and electrical interface requirements, so that their projects could operate in the car. In order to help insure a successful outcome for both departments, the instructors collaborated early in the semester to produce a clean mechanical interface specification, and simple electrical interface.

In the real world, information is often incomplete, and part of the engineer's job is to perform research to determine the needed specifications, whereas, in academic projects, the students are usually handed a complete set of specifications at the start. Another common problem in industry is a changing set of specifications, and misinformation from various sources. The students in this project were intentionally given incomplete specifications, with the requirement that they should find out the needed information on their own. Also, while there was no intentional attempt to mislead the students, the engine computer behaved differently than the specifications indicated, and a fairly major change in the designs was required late in the semester. These issues are discussed in detail, below.

Some purely academic issues remained. Although all customers in industry are extremely concerned with schedule issues, there is often some degree of flexibility on the final delivery date. Because this project was completed as a single-semester course, there was a hard deadline for completion, at the end of the semester. Nonetheless, students were encouraged to use industrial scheduling techniques, to insure a timely completion of their work.

Issues Encountered During the Project:

It soon became clear that most students had very little prior interdisciplinary experience. The first major challenge to the students was their exposure to an engineering problem that required knowledge beyond their area of specialization. Most of the electrical engineering students reported that they had spent most of their first week researching how an automobile works, and what the transmission actually does. Similarly, the mechanical engineering students spent a significant amount of time understanding electrical issues, including the interfacing requirements for the engine computer.

The students were given several areas to research on their own. The electrical engineering students were told to collaborate with the mechanical engineering students to determine the actual gear ratios for various transmission gear selections. All groups were able to accomplish this task, although they required instructor guidance to fully understand the system-level implications of other gearing ratios in the car.

Despite the fact that considerable effort had been put into specifying an electrical design project that was not commercially available, two groups of students found commercially available packages that satisfied most of the project requirements. The instructor denied them the use of the commercial packages, so that the students would be required to demonstrate their own ability to complete a design.

Another area, which the students were instructed to research, was the electrical interface to the engine computer. The mechanical engineering students had already selected the HALTECH E6X computer to control the engine. This computer provided an output signal that could be mapped as a tachometer output, to indicate engine-speed. The HALTECH documentation stated that this output was a Pulse-Width Modulation (PWM) signal. It was left to the students to determine the exact electrical characteristics of this signal.

By the midway point of the semester, none of the students had reported any believable information in this area, and it became apparent that more guidance was needed. When a search of the documentation did not turn up sufficient information, a test was arranged to determine the actual electrical characteristics of the tachometer signal. The electrical engineering instructor, along with one of the mechanical engineering students who was more familiar with the engine management system, set up a test bench and measured the HALTECH signals while simulating various engine conditions.

It was determined that the tachometer signal was not a PWM signal as stated in the documentation, but instead consisted of one pulse per engine revolution. The duty cycle of this pulse remained fairly constant over the operating range of the engine.

This signal was clearly different from the interface standard that had been discussed at the outset of the project. All groups of electrical engineering students had developed designs that expected a PWM signal, based on information in the HALTECH documentation. Two of the three groups had taken a design approach that could be adapted to accommodate the new interface requirement. The third group had a different design approach, and required additional circuitry to interface to the new signal specification. Substantial help was provided to this third group, because of the lateness in the semester when this change in requirements was discovered.

This late change in interface requirements was not planned. Most academic projects are clearly specified at the outset, and do not change. It is the authors' experience, however, that interface requirements often change during the course of an engineering project in industry. The late discovery could have been perceived as a problem, but was used instead as an opportunity to teach.

This change was used to emphasize to the students the importance of being adaptable in their design work. The change also served as a strong indicator of the importance of a clear interface specification. The need for a clear interface specification had been stressed to the students early in the semester, and the point was made that they should have been more proactive in determining the actual requirements, rather than assuming things based on unclear documentation. Despite the difficulty imposed by this late change, all three groups of electrical engineering students were able to successfully adapt their designs to work with the actual signal provided by the HALTECH computer.

Another key issue that was encountered during the development effort involved the selection of other electro-mechanical sensors. There were many approaches that could have been taken to determine the gear selection of the mechanical transmission. After investigating several different approaches, all three groups of electrical engineering students decided to measure the speed of the car and compare this speed to the engine speed.

The instructors felt that it was important for all of the electrical designs to be interchangeable. To make this more practical, all three designs were constrained to use the same sensor for the car speed. The students were required to research available sensor options, and submit proposed solutions. The instructor then worked with local vendors to provide one sensor that would work with all of the student designs. Mechanical and electrical issues were both vital in selecting a sensor that performed the needed function.

The mechanical engineering students also needed a sensor to interface between the engine camshaft and the HALTECH engine computer. The instructors worked with the students, and determined that the same sensor could be used for both functions.

As the end of the semester neared, it became apparent that it would not be possible to perform integration and testing with the actual SAE formula car. The semester schedule required the electrical students to demonstrate a working design before the car would be finished. In industry, one is usually required to complete integration and testing before receiving payment for design work. However, in this case, grades had to be submitted before the car would be ready. To allow the electrical engineering students to receive their grades on time, final acceptance testing of their designs was performed on a test bench that simulated the car, electrically. No actual testing was performed of the mechanical or thermal ruggedness of the designs.

Observations:

The mechanical and electrical instructors both observed that most students struggled with system integration. In some cases it was the first time students had been exposed to an open-ended problem that required system integration. Almost all of their academic careers to date had been spent learning to compartmentalize knowledge in each course and learn how to execute the task or knowledge needed for that course without outside considerations. Even though the students had been well trained in component and subsystem design, they initially struggled with system integration and the application of knowledge to real-world problems. By the end of the semester, most of the students showed substantially improved abilities in these areas.

It was also observed that students had at least as much difficulty with integrating components within their electrical or mechanical designs as they did with interfacing between the complete electrical portion and the full mechanical design. Again, it is believed that this is evidence that students are very compartmentalized in their knowledge.

Students are now making full use of the Internet as a resource, but it seems that they may be almost too dependent upon it. Many students seemed almost incapable of doing any design work without first performing a search on Google. Some of the more creative electrical engineering students found and used technical message boards on the Internet to consult with professionals working in the field. This seemed to be also true for the mechanical engineering students.

Time management by the student teams was a minor issue for the mechanical department but the electrical students did quite well in this area. The importance of effective time management had been stressed to all students in both departments. The instructors felt that two main factors were responsible for the problems that were observed in this area: the scope of the mechanical project, and the lack of participation by a major portion of the group members. The student teams that did not distribute workload evenly experienced the most difficulty with this issue. Incorrect shipping dates supplied by vendors also created scheduling issues for the mechanical and the electrical teams. The mechanical students were also faced with a very large labor-intensive build cycle.

Selecting student teams with a good mix of skills proved to be of substantial benefit for all of the students involved. The electrical engineering department had made a concerned effort to make sure that each team had a person with "hands-on" knowledge on each team. The mechanical team did not assign groups, so the presence of a "hands-on" person was not intentional. However, both the electrical and the mechanical faculty observed that the effectiveness of the teams was greatly enhanced by the presence of at least one "hands-on" student. Another factor that contributed to the effectiveness of student teams was the presence of students on each team that had some years of work experience.

A central problem for both departments was effectively evaluating the unequal distribution of responsibility among team members. The electrical department requires the students to document their design process in design notebooks and therefore the unfair distribution was easily identified and appropriate grade penalties could be applied. On the other hand, the mechanical department relied on student peer review and instructor observation to determine participation.

However the peer review was not an effective measure this time, since the group chose not to disclose enough information. Instructor observation did not count for a high enough percentage to deter the behavior. Also, it could not serve as documented proof. The mechanical department is discussing the use of design notebooks for the next design cycle.

One major issue shared by the mechanical and electrical senior design projects is the creation, maintenance and quality of drawings produced by the students. The students seemed to feel that drawings are not really necessary to the design process and view them as a waste of time that is distracting them from what they feel is the actual design process. The drawings are rarely finished on schedule, and are almost never updated when design changes are made. In the past, submitted drawings have not included drawing titles, dates, author, or revision comments. The few drawings that were produced were often used for their conceptual value, instead of serving as a key part of the documentation package for a finished design. In several cases, the mechanical parts produced during the build phase did not mesh, due to the drawings being approximations of location instead of an exact placement.

In an effort to correct some of these issues with engineering drawings, the mechanical engineering department has implemented intermediate drawing deadlines, and has emphasized the drawing requirements in earlier courses. In addition several of the drawing/fabrication issues from earlier senior design projects were shown to the class. The electrical engineering department has brought in critical design review (CDR) drawings from industry and stressed the completion of drawings. Small improvements have been observed but more is still needed.

Conclusions:

This interdisciplinary, team design experience appears to have been beneficial to all students involved. The students were exposure to a wider range of engineering issues than they would normally face in a more traditional design project. By the end of the project, the students demonstrated greatly improved skills in system integration, scheduling, documentation, and teamwork skills. The students did not always enjoy the experience, and some of their lessons were learned due to long hours, perseverance and much heartache. The difficulties they encountered were in the areas where it was most beneficial for the students, and they are better prepared for industry because of the work they did to complete this project. Overall the experience was positive, and the authors enthusiastically recommend interdisciplinary projects whenever possible, as a means of enhancing the quality of engineering education.

References:

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