Yearlong Client-Based Team-Oriented Senior Design Projects: The Rose-Hulman Approach

Dr. Barry J. Farbrother[1] and Dr. Daniel J. Moore[2]

[1]Professor & Head, Department of Electrical and Computer Engineering, Rose-Hulman Institute of Technology
Terre Haute, IN 47803, USA. http://www.rose-hulman.edu/~farbroth/
Tel: (812)-877-8414 Fax: (812)-877-8895 E-Mail: barry.j.farbrother@rose-hulman.edu
[2]Associate Professor, Department of Electrical and Computer Engineering, Rose-Hulman Institute of Technology
Terre Haute, IN 47803, USA. http://www.rose-hulman.edu/~moore1/
Tel: (812)-877-8410 Fax: (812)-877-8895; E-Mail: daniel..j.moore@rose-hulman.edu

Abstract: This paper describes a required yearlong senior project design sequence for computer engineering and electrical engineering majors at Rose-Hulman Institute of Technology. The ten quarter hour sequence of courses, provides a realistic team-based design experience for students. Project topics span the breadth of electrical and computer engineering and are provided by a variety of clients located across the USA. The Myers Center for Technological research with Industry - a 42,000 square foot facility designed to promote university-industry interaction, provides engineering workspace for student teams. We believe that this course sequence fully meets the requirements for a culminating upper level design experience as defined by ABET Engineering Criteria 2000.

Student teams negotiate the product design specification (PDS) with the external client, organize and operate their team activities, undergo a series of design reviews, and provide a comprehensive report and presentation at a spring quarter design symposium. The course director identifies clients. Rose-Hulman's President Dr. Samuel F. Hulbert's goal is to have every Rose-Hulman student experience the thrill of engineering before graduation. This experience provides as realistic an engineering design experience as is possible in an academic environment, and meets our institutional goal *to Parallel the Workplace*. Three ECE faculty members each *mentor* 6 – 9 student teams. This effort (considered 50% of a teaching load) requires students take ownership of their project and manage the work effort. Members of the ECE faculty are available to student teams (as subject experts) on a consulting basis. The demands of the projects have required that students learn how to access information and that they learn how to learn as the need arises, thereby promoting a level of preparation and independence previously unattainable in conventional classes. Some administrative aspects are described along with examples of what has worked and what has not.

1. Background

The electrical and computer engineering (ECE) department of Rose-Hulman Institute of Technology has developed a required three year "Engineering Design Thread". The course sequence is intended to provide all ECE majors with an understanding of engineering ethics, professional development activities, professional societies, various design methodologies, team organization and management, project design specification development, general engineering economics, engineering decision-making processes, and oral and written communication skills. The sequence culminates in an externally sponsored 9-month (three-quarter) industrial project during the senior year.

2. Senior Design Project Sequence Overview

All projects are solicited from external industrial sponsors, with brief summaries of typically 20-30 projects being given to students the first day of the class in the fall. Each student must submit a "project assignment application" the following week. The application requires the students to indicate the three projects in which they have the most interest and to provide a brief synopsis of any "non-standard" course(s) or related experiences and capabilities that may be needed for the project. They are also allowed to list up to three names of students they prefer not to be assigned to the same team. They may not, however, pre-form teams or request specific members for their team. The intent of the application process is to allow the greatest flexibility in assignments, as generally done in industry, while recognizing that a project is unlikely to be successful if serious personal conflicts or knowledge skill deficiencies exist. The 3 to 5 member teams are determined by the course faculty, based on their understanding of the project, the student applications, and the individual student' s capabilities the project teams are announced. By the end of the 2nd week and provided with sponsor contact information and assigned a faculty mentor. The faculty mentor IS NOT a member of the design team but rather a resource for questions and problems encountered during the project.

Additionally, each team receives a "project resource kit" containing a long distance phone access code, a photocopy account code, lab space assignment, sample timesheet, and 9 hours of "faculty consultant credits". These consultant credits are intended to be used when a team requests help from the faculty or qualified expert not directly associated with the senior project course. Each team is required to use some of these credits in an effort to insure the teams discuss their design options with experts. The process helps the students recognize the importance of scheduling, preparing questions, and organizing before the consulting session in order to maximize the results. The "consulting process" also provides the faculty with an instrument they can use to reduce random questions and inquiries from multiple teams and/or team members.

Furthermore, the teams must request, and justify, any auxiliary items needed. These auxiliary items may include specialized test equipment and computers. Standard items such as power supplies, dual trace oscilloscopes, function generators, and multi-meters may be checked out without justification or mentor approval. The sponsor and the faculty mentor in advance of placing the order must approve both project-specific purchases of parts and/or test equipment.

3. Philosophy Underlying Senior Design

The senior design project course is based on a multifaceted approach designed to address pedagogical, design, and management issues. Externally sponsored projects are intended to "stretch" the students in terms of applying their engineering skills and knowledge base. The projects are, in many cases, those they might expect to be involved with as new graduates. Teams are given complete autonomy to address the project and the needs of the sponsor. Additionally, they are expected to look at multiple aspects of the project – societal impacts, ethical issues, cost constraints, marketability, manufacturabilty, and salesmanship. Emphasis is placed on the faculty mentors NOT being a part of the project team. Students are responsible for the complete project – management, direction, design, and completion – the mentors are there as a resource not as a manager. The year long duration of the program provides time for the teams to succeed while still allowing them to make false starts, go down "dead end paths", and to discover the problems related to putting off decisions. The strong emphasis on teamwork, individual responsibility, work distribution, and design strategy(ies) help reinforce the importance of the skills presented and used in the earlier design sequence courses. The importance of seeking help when necessary, and of investigating concepts not covered in earlier coursework, as the project develops are aspects designed to reinforce the necessity for lifelong learning. The underlying philosophy is therefore, to provide the students with realistic engineering design problems and projects while still providing a strong educational and knowledge base support structure.

4. Project Team Operation

Each project team works with their sponsor during the second two weeks of the fall term, to develop the Product Design Specification (PDS). The PDS includes details related to the project scope, design constraints, and project deliverables and serves as the "contract" between the student teams and the project sponsor. The teams and sponsors generally schedule face to face meetings or videoconferences during the development of the PDS. The teams are required to have the proposed PDS reviewed by the faculty mentor before submitting it to the sponsor for final approval. Since the PDS is an agreement between the team and the sponsor, the faculty mentor is not a signatory unless specifically requested to do so by the sponsor. When the sponsor approves the PDS, the team begins the conceptual design phase of the project, which is expected to be completed no later than the end of the fall term (late October/early November). A critical design review (CDR) is conducted in mid-October for all project teams. The faculty mentor and at least one other faculty member is present for the CDR and encouraged to ask questions and provide suggestions following a brief oral presentation by a randomly selected member of the project group. Project sponsors are invited with many participating via conference phone. Project timelines are thoroughly reviewed and critiqued as part of the CDR process. A second CDR is held in mid-January and a final CDR is held in late March.

The teams begin the prototype, implementation, and/or final design phase, as specified in the PDS, by the beginning of the winter quarter (early December). Teams are required to maintain contact with the sponsors during this phase of the course and effectively function as an "engineering consultant group" by responding to feedback from the sponsor. A design symposium in late April, about three weeks before the end of the school year, is where project teams make 15 – 20 minute oral presentations and answer questions related to their designs. The symposium is open to the project sponsors, interested faculty and students, potential project sponsors, and interested members of the campus and local community. Attendees receive a book of executive abstracts for all the projects. The individual sponsors also receive formal final project reports and any other deliverables by late May for the specific project(s) they sponsored. Additional course details may be found at: http://www.rose-hulman.edu/~moore1/EC-460/.

5. Administrative Issues

The administrative overhead is an area that must be addressed as well. Management of a student team can take a disproportionate amount of a faculty member's time. A typical four credit hour senior project course traditionally might involve a faculty member in one or two meetings with team members each week. This time commitment necessarily limits the number of teams a single faculty member can supervise especially if team members regard that person as the primary source of expertise. In the model used for each of the design sequence courses, the faculty member is a mentor rather than a subject matter expert. Therefore it is possible for a single faculty member to supervise a larger number of teams. For each of the last two years, three faculty members have mentored twenty-four student teams. Supervising eight senior project teams is considered a one half teaching load and the actual workload varies from quarter to quarter. The heaviest load occurs in the winter quarter as the teams struggle with the major design portion of their projects. The stated credit hours for both faculty and students are four, four and two (fall, winter, spring).

The course director workload, while measured the same as the other faculty mentors, in fact is higher in both the fall and spring quarters. The director is responsible for soliciting the projects, assigning teams, interfacing between the teams and sponsor as they develop their related PDS, arranging for team space and equipment needs, organizing the design symposium, and providing the general organizational management of the course. These tasks are in addition to the mentoring of the project teams. The department head has been able to help address these extra responsibilities by assigning the director to courses that have been taught recently by the director in an effort to minimize preparation time and to keep the extra course load to one per term.

The need to have someone directly responsible for developing and maintaining project sponsors is currently under discussion. This person would be different from the course director but would, of necessity, work closely with the course director especially during the spring term. Another item under discussion is supporting the course director for a month in the summer so the projects can be finalized before the director's 9-month contract starts in late August. Both of these ideas are strongly supported by the ECE advisory board.

Another issue associated with project work is the monetary cost. An additional benefit accruing from university/industry partnering is that most industrial partners are prepared to cover a portion of project costs. Student teams are provided with telephone and photocopier accounts making it possible to determine project related costs. Additionally, the project sponsor pays for the costs of some of the consumable items, such as prototyping. Very often computers, software and specialized laboratory equipment are loaned to the institute for the duration of the project or donated. Project clients are billed for project related expenses at the end of the spring quarter – an important factor for a small department in keeping a small project budget in the black. Apart from the financial assistance provided to the department, the provision of accessing specialized equipment makes it possible for students to undertake projects that would be impossible otherwise.

6. Industrial Project Development

All of the senior design projects are sponsored by external industrial or "not for profit" sponsors. The project sponsors range from small companies, under 100 employees, to multinational corporations and from local non-governmental organizations (NGOs) to state agencies. While the majority of the sponsors are located within 200 miles of Rose Hulman we have had sponsors as far away as all three coasts.

The course director begins the process of soliciting projects during the fall term with the major "push" conducted during the spring term. Each potential sponsor is contacted directly by the course director in order to explain the program in detail and to discuss the sponsor's commitments and obligations as well as the results they may expect. The most recent symposium abstracts are provided to new or potential sponsors and are available on the web. Samples of completed final project reports are provided when requested and if approved by the original sponsor. All sponsors are asked to effectively cover all "out-of-pocket" costs for their project(s). These costs include travel, long distance phone calls, special hardware and software, and prototyping parts directly associated with their projects. Project expenses have ranged from under $ 500 to over $ 50,000 with the average being well under $ 2,500. The sponsors are also asked to provide an engineering contact that will be available on a regular basis for interfacing with the team(s). Additionally, the director discusses the role of the faculty mentor and emphasizes that the projects are NOT run or directed by the faculty and, as such, are not "certified" projects that would include a PE endorsement. The director also discusses potential confidential and/or proprietary issues. Each sponsor is given complete authority over what material and publications are released, posted on the web, or presented in the public symposium. The sponsor may require the final report not be released but must work with the project team to develop the symposium abstract and presentation for public release. Projects with highly classified/proprietary issues are not accepted as part of this program but are referred to other campus organizations that are designed to handle these types of projects.

7. Sample Projects

More than 70 projects have been completed in three years. The majority have been successful (some very successful) with several resulting in the sponsor taking the project into production after review by company engineers. Two projects were not completed and resulted in the student teams being "fired" by the sponsor and therefore receiving a failing grade for the course.

One of the very successful projects involved the design of a wireless interface for keyless locks used in many hotels and by large industries. The interface was designed to allow the lock codes to be changed from a central location instead of having to take a laptop to each lockset to make the change. Some of the issues associated with the project were related to power consumption (the lockset operates on a 9 V battery), size restrictions (the sponsor did not want to change the lockset styles), and security (the sponsor did not want the code changes to be easily "caught" and/or changed by non-authorized personal). The final prototype was successfully demonstrated at the senior symposium and placed into the final design phase by the sponsor. The student design team was very impressed (and proud) when the company agreed to spend over $ 50,000 for equipment and parts based on their presentation after the conceptual design phase of the project in early December. Another indication of the success of the project was the sponsor's submission of a follow-up project the following year in an effort to make the antenna less obtrusive, increase the operating frequency, and increase the operating range.

Another project involved the design of both the hardware and software associated with an optical measurement/evaluation system for use by a biomedical sponsor in conjunction with moisture content in pharmaceutical production. The final design was reviewed by at least two pharmaceutical companies and selected for further development.

Another very successful project resulted in a patent application. Two teams completed a final design of a communication device for the hearing and visually impaired. The device is designed to allow the user to communicate over conventional phone lines and includes both Braille (Perkins) and QWERTY keyboards as well as both Braille and large character displays. The teams solicited input from the hearing and visually impaired organizations in Indianapolis and Terre Haute as part of the design process. The result is a device that at least one manufacture is very interested in producing. Additional projects have involved designs of various measurement systems for magazine processing, electric motor controls and displays associated with electric vehicles, computer image processing, robotic vision systems, offshore oil platform power management control systems, high voltage (> 20 kV) power supplies and probes, monitoring systems for high power (1000 MW) disconnects, a portable electronic stress (breathing) monitor, and high speed (GBit) fiber analysis and monitoring systems and displays.

There have also been a few "proof of concept" projects that resulted in the sponsor deciding to continue the design or, in at least three cases, deciding not to proceed with the concept based on the recommendation of the senior project team.

8. Assessment and Recommendations

The first complete design sequence, sophomore through senior, was completed during the 1998-1999 academic year. Feedback was solicited from students, course instructors, departmental faculty, industrial sponsors, and potential employers of our graduates. While much of the data presented here is still preliminary and based on two offerings of the complete sequence, it is significant and has resulted in adjustments to the program. The overall feedback from all constituents has been very positive and supportive. One indication of the positive impact of the program is that we may not be able to accept projects from all interested sponsors and/or may have to restrict sponsors to a single project.

A major change in the junior level course was a result of some of this early feedback. The initial offering of the course required the teams to build a prototype. The short duration of the actual design/prototype cycle (8 weeks) led most student teams to immediately pick an approach that "might" work without spending time looking at, and reviewing, alternative approaches. The students were therefore not prepared for the conceptual design phase required in the senior year. Teams now address project designs in the junior level course by focusing on the various potential alternatives and developing and justifying a recommended design without trying to have a working prototype. This new approach allows more difficult projects to be addressed and has better prepared the students for the conceptual design phase of the senior course. Comparisons between the 1997-1998 and the 1998-1999 senior project course clearly illustrate the benefit of the change in the junior course.

Another important change in the 2000 – 2001 offering will be the possibility of an entrepreneurial team(s) project(s). Students in the junior year course may submit a project proposal to be reviewed by an external team of experts in the area of new concept development and entrepreneurial projects. Strong reviews and support of these proposals may result in the author's developing/designing the proposed project as part of their senior design program. Accepted projects must meet the same requirements as all other projects including having other students assigned to the team. Projects deemed to have a high potential for personal financial gain would not be accepted as part of the senior design course. These project proposal authors will be directed to other campus organizations designed to provide support for innovative and entrepreneurial projects including venture capital support if needed.

The level of project related responsibilities assigned by their employers to the recent graduates, as well as the initial offers to our 2000 graduates, provide another point of reference that the current structure of the design sequence is preparing the students for more immediate integration into the engineering field. Several corporate recruiters have commented that the students participating in the new sequence, especially the seniors, are very self confident and proactive in indicating their strengths, their experience in working in teams, and other project related capabilities. Additionally, several of the students have joined their sponsor fulltime upon graduation. As a side note, a number of students have also discovered they would not like to work for the sponsor of their project and turned down employment offers. Feedback from the ECE advisory board has also been very positive and helpful in refining the scope, management, and objectives of the sequence.

The general organization and format associated with the junior and senior level courses (minimal use of traditional lectures, strong emphasis on teams, faculty mentors, external sponsor interaction, and peer evaluations) has resulted in strong student "ownership" of their education, especially by the seniors. The students recognize, usually before the CDR in mid-October, that they are not going to be told how, when, or what, they need to do to complete the project. They also discover that their success, or failure, lies with the TEAM and effective teamwork and resource (especially time) management.

Junior and senior level courses are graded based on the team performance. Course grades are assigned based on the TEAMS' performance with each member receiving the same grade unless there is a significant reason to do otherwise. Different grades have been assigned to fewer than 10 % of the students in these courses.

While the initial response has been overwhelmingly supportive, adjustments to the program are continuing and additional assessment data being analyzed. One change under consideration is to involve Master level students in the senior program. The idea is to have the Master student serve as a project manager/chief engineer overseeing two projects by the same sponsor.

There are some downside issues. The incorporation of this major design experience has caused some faculty members to have concerns over the reduced number of hours available for senior level elective courses. The senior design program is equal to 2 ½ elective courses not taken, the number rises to 4 ½ when the other design sequence courses are included. Further exacerbating this situation is the fact that each student team is required to "consult" with ECE faculty on an "as required" basis, which is interpreted, by some faculty as an inefficient process of getting the material to the students. Using an idea currently under discussion and review it may be possible to address both of these concerns – elective courses and workload issues – by eliminating some, or perhaps all, traditionally taught senior level electives. Using this paradigm, senior level topics would be taught on a just-in-time basis using the short course model so widely utilized in industry. Student teams would contract with an individual faculty member to provide a 2 to 5 day short course on a particular topic, which may be attended by students from one or more teams. Faculty would then be "credited" with an appropriate workload equivalent for the course(s). Obviously it would be necessary to design and implement a new procedure for tracking these courses, assessing the level of faculty work effort, adjusting possible tuition charges, and assigning credit toward graduation. Another major factor that would have to be considered relates to the way such courses would be reported for accreditation purposes. The traditional method measures courses in credit hours and the variety of short course formats would therefore make describing program content a more challenging task.