Lessons Learned from Teaching Industry-Based Senior Projects

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I. Introduction

A two-semester senior engineering design course sequence has been used at Lake Superior State University (LSSU) for more than a decade to develop ties with industry and to give our graduates a taste of real-life project engineering. Over the past five academic years, nearly 220 multidisciplinary engineering seniors have completed 36 projects, controlling budgets totaling approximately $1.1 million.

This paper describes our continuing effort to involve industry with engineering education. The projects are proposed, funded and ultimately delivered to industry. An industry contact person is the leader in determining the goals, the acceptance criteria, and the project requirements. Communication between faculty, industry contact person and students is vital to ensure success. The faculty advisor is a coach, consultant, and evaluator of the students. The students will not graduate until they meet the criteria specified by the customer, i.e. the industrial contact, as well as the educational criteria set forth by the Senior Project Faculty Board (SPFB). In the setting suggested here, failure is not an option, and the student team must deliver[1].

The authors of this paper have either coordinated and directed student teams, or have acted as industrial contacts for one or more teams. The guiding philosophy behind our industry-based capstone senior design course sequence includes industry origination, a business setting and the teaching of non-technical (soft) skills. Industry projects demand real solutions, as well as provide actual budgets and definite time constraints. To set a business tone, we provide all of the teams with a shared office space (cubicles, computers, phones, etc.), fostering a common work environment and sense of community. Non-technical skills such as team building, communication, project planning and creative problem solving are key components of the first semester of the course. While each project includes technical demands, it is usually the non-technical issues that make or break projects[2].

This paper discusses the structure of LSSU's two-semester course sequence and the timing of team assignments from September project initiation to May project completion

– a realistic timeframe for meaningful projects. An effective teaching tool has been the creation of a fictitious faculty project (a university walkway project) that mirrors the student assignments. Regardless of other desired outcomes, the final project completion remains the most critical part of each project. Students are given explicit instructions to enable them to create clear, measurable acceptance criteria that govern the implementation and completion of their projects. The LSSU faculty uses the project process and results to quantify the competencies of our graduates, and to improve the course.

II. Philosophy and Course Organization

Three fundamental principles provide the framework for setting directions and making decisions in the organization and implementation of industry-based senior projects. These principles are industrial project origination, professional setting for the course sequence, and incorporation of soft skills. These principles provide a philosophy for the faculty as they deal with the projects and students, and also set the stage for successful transition to industry by the graduates, planting the seeds for lifelong learning and successful careers.

The first principle is that projects are originated with industry or business. For a successful project and a quality student experience, there must be a real need for the project outcome, with a budget and a timeline. These are common to all industrial projects. While the project outcome may be research, prototype, production, or process, the more tangible and measurable the outcome, typically, the better the project. Industrial projects also have design criteria, product/process specifications and management constraints that graduates will encounter in their careers.

Another key factor associated with industrial origination is that the student teams must deal with a real customer that is outside of the academic environment. They must learn to interface and deal with professionals that have different norms, environment, and expectations than the faculty. They are forced to learn about satisfying a customer that is not perfect or always right. Most industrial based projects also result in the students dealing with vendors. Thus, they become customers in a professional setting.

Finally, industrial based senior projects are often multidisciplinary in nature. Students work with other disciplines to learn about areas and problems outside of their curriculum, and often the students are responsible for technical aspects of their project that are not taught in their particular curriculum.

The second fundamental principle involves a professional environment for the students. The SPFB has used internal and external funding to provide a facility on campus called the Engineering Design Center (EDC) for design-and-build testing equipment, improved computer networking capabilities, and a professional office setting for the seniors. By instituting a fee for the projects performed by our students, we have continued to upgrade this facility. The common office space also facilitates interaction between the various project teams, and promotes some healthy peer pressure.

Another need within a business setting is to emphasize that all communications, both written and oral, are professional. Meetings with students have a business format, with written agendas, action items and due dates. The emphasis is on accountability. This means that student assignments and tasks are completed when an acceptable level of performance is achieved, not just a passing grade. In business, “C” work is usually not acceptable. More often, a task is redone until it is done correctly. The same must be true in industrial based senior projects. Ultimately, the project outcomes must be met and the Acceptance Criteria satisfied. Students are told that unfinished projects may require student teams to stay after graduation until completion – and this has happened.

Another issue that is interwoven in the business setting is that students should graduate feeling confident and successful. Thus, the faculty members strive to help the teams succeed. Failure should not be seen as an option. For the faculty, this means walking a fine line between coach, evaluator, and consultant. Like a coach, the faculty must set standards and also provide encouragement and advice on problems. The faculty also needs to act as a consultant, help set direction and sometimes make decisions as a leader. The faculty must use their expertise to define and limit the project scope so that student success is a challenging but reachable goal.

The final principle that provides the framework for the senior projects at LSSU is the integration of soft, or non-technical, skills into the projects. It is the belief of the faculty that a graduate’s successful career will be determined as much or more by their soft skills as their technical skills. The projects do require that students use their technical skills, but these are not seen as the focal point. Soft skills such as teamwork, communication, project planning and management, creative problem solving, and ethics are given major emphasis throughout the yearlong experience. Student teams are given instruction and complete exercises in all of these areas throughout the year. Faculty advisors coach and mentor their team’s soft skill development throughout the project.

LSSU’s senior engineering design course sequence is organized as a two semester six-credit (three each semester) lecture/lab. Stated course outcomes are that students will:

- be capable of giving an effective oral business presentation.
- be capable of writing a clear, concise project proposal that flows from general to specific.
- demonstrate effective writing of short business memos.
- be capable of explaining the principles and issues of ethical behavior in engineering and professional fields.
- be capable of using creative problem solving techniques for solving business and technical problems.
- be able to create and use timelines and responsibility charts for project planning.
- be able to complete effective performance evaluations of team members.
- be able to explain the approach for performing a literature search.
- demonstrate that they are effective team members.

During the Fall semester, students are primarily defining their project requirements, exploring solution options, and learning soft skills. Students are provided with the necessary instruction and lab activities to develop these skills. The final requirement of the semester is a comprehensive project proposal document approved by both the industrial contact and the SPFB.

In the Spring semester, the teams are actively implementing their projects, purchasing components and services, constructing or overseeing construction of their projects, and competing testing and final documentation. Significantly less time is spent with lectures during this semester.

Table 1 – Course Activity Outline shows the time frame for major activities by the teams, and some of the instructional topics covered. The most recent course syllabi are on the LSSU website at http://engineering.lssu.edu/senior.

Timing	Principle Instruction Topics	Major Team Activity
Late August	SPFB selects projects/teams and meets with Industrial Contacts	
Mid September	Team Building, Norms and Expectations	Project Concept Statement
Mid October	Presentation Guidelines, Project Planning, Timelines	Scope Presentation
Mid November	Design Review Guidelines, Peer Evaluations, Written Proposals	Design Review
Mid December		Project Proposal
Late January	Timelines, Safety Review	Final Project Proposal, Design Review
Late February	Formal Update Guidelines	Formal Update Presentation
Late March	Project Documentation	Project Testing Plan Review
Early May	Project Completion Responsibilities	Final Presentations and Reports

Table 1 - Course Activity Outline

III. Industry and School Commitment

Each team requires both university and industry support for the completion of their project. Realistic projects will lead to realistic frustrations for the students. Our aim is to minimize those frustrations that can be controlled. The fundamental role of a faculty advisor is to act as a coach and evaluator for his team. However, this role fluctuates between team consultant, allowing potential leaders to emerge within the team, to a greater role of leadership on the team.

Industry-based senior projects require considerable time and commitment from the faculty. A recent time survey by the SPFB revealed that faculty who are involved in senior projects spend approximately seven hours per week for each course load hour compensated. The activities include weekly team progress meetings, time with the students discussing project details, lecture and lab preparation and grading, and weekly SPFB meetings.

The standard compensation of the university for teaching time does not adequately reward or recognize the time and effort provided by the faculty. Thus, commitment from the faculty as well as an understanding of the department and the university are essential to the success of such industrial based senior projects.

The University, via the EDC, provides a designated office space for each team and space to conduct team meetings and reviews. Each team has its own computer with internet access and necessary software (business and technical), phone, and e-mail accounts that allow for scheduling with faculty members. Teams are given extended access to this facility during evenings and weekends. University purchasing personnel are often used to acquire necessary project components, and a lecture covering proper purchasing procedures is given to the students in the Fall semester. As projects enter the construction and testing phases, teams may ask for a certain area in the workshop to be devoted for their senior project, or for access to existing laboratories and equipment to conduct certain tests or use certain equipment.

Interaction with the industrial contact is perhaps the key to project success or failure. Close communication with a limited – ideally just one – number of company contacts is greatly desired. Projects with active industrial contacts typically proceed more smoothly than projects with hard-to-reach contacts. To emphasize the importance of this relationship, the industrial contacts for projects that are selected meet with the SPFB in August, before classes start. They discuss the project and meet the faculty advisor assigned to the project. The industrial contacts are expected to participate in the Scope Presentation (October), Design Reviews (November and March) and the Final Presentation (May), as well as other team activities as the project dictates. The industrial contacts are also expected to review and comment on the written Project Proposal, and to approve the Project Acceptance Criteria.

IV. Design Reviews and "Brick Paths Unlimited"

The SPFB seeks to provide students with exposure to true-to-life engineering projects, and instruction in a variety of project management topics that can be used as tools to guide the future course of the projects. In order to assure that the teams are on track, during the Fall semester the SPFB gives assignments to verify:

- a good understanding of the project (Project Concept Statement, Scope Presentation)
- a means to evaluate and update the status of the project (Timeline assignment)

- an understanding of the technical challenges and decisions for the project (Design Reviews)
- an appreciation for the realities of acquiring necessary components and materials (Purchasing assignment)
- and a well organized plan for the total project execution (written Project Proposal)

The Design Reviews are the most important activity above and present the students with the most uncertainty. The Design Review guidelines (which are also available at http://engineering.lssu.edu/senior) stress that the major purpose for design reviews is to:

- Communicate Proposed Designs/Plans
- Solicit input on Design/Plans
- Finalize Design Issues

The Design Review meeting must be conducted in a formal fashion with a written agenda and plan, and formal handouts. The teams must select a meeting facilitator and designate key people to lead parts of discussion and to document the discussion. We have evolved a system of "green" – "yellow" – "red" light evaluations to indicate projects that are OK, in need of minor additional design work, or halted for immediate design revisions. Team status is posted in the EDC for all teams to see.

Two or three hour design reviews provide the teams with the most intense, but useful input of the semester, and while the SPFB rarely gives a team a "green" light evaluation, there are also very few "red" lights. The November Design Review provides the team with a good springboard to complete their written Project Proposal, while the March Testing Review focuses the team on the tasks needed to complete the construction and secure final approval of their projects.

The students are uncomfortable with some of these activities, and constantly ask the SPFB for examples of what we expect. There is some reluctance to providing this, since we do not want to see copies of our examples, however the creation of a fictitious project – named Brick Paths Unlimited (BPU) – has been a success for us and well received by the students. BPU is given the task of researching and installing a walkway on the LSSU campus, complete with lighting, handicapped access, etc. The SPFB has created a Scope Presentation, Design Review, and Formal Update Presentation for BPU that SPFB faculty members present at the respective lectures. The SPFB also documents other BPU activities that mirror team assignments, such as the Project Concept Statement and Timelines. An indication of the effectiveness of these examples has been improved team performance for these activities, as well as student questioning following some of these presentations – the students at the sample Update Presentation often grill the SPFB presenters. The BPU presentations are available at http://engineering.lssu.edu/senior. (To our dismay, the University partially installed "our" walkway last year, however we have invested too much effort into BPU to invent another project!).

V. Lessons Learned

The SPFB continues to learn valuable lessons during the evolution of the design projects. This section will draw upon those experiences and attempt to share some of the more important faculty, student, and project issues that need to be addressed when initiating multidisciplinary, industrial-based projects.

The formation of productive teams is a critical and difficult task. An important factor used to allocate the students onto teams is the faculty members' knowledge of the technical, leadership and interpersonal skills of the students – formed during the years of interaction with each student. To better quantify student abilities and thinking style, in the Spring semester preceding their enrollment in the senior projects course sequence, students are surveyed for project preferences and complete a simplified thinking-preference questionnaire patterned after the Hermann Brain Dominance Instrument[3]. The purpose of the thinking-preference questionnaire is to ascertain the students' propensity for the following four thinking styles: (1) analytical and logical, (2) planning and organizational, (3) interpersonal and intuitive, and (4) conceptual and holistic. Student team formation is guided by the results of the questionnaire, with the intention of creating "whole-brain" teams (teams of students that exhibited all four thinking styles). This procedure has been helpful in avoiding teams that lack some fundamental component of project execution. The SPFB meets in August to select teams, attempting to address technical needs for a project, balance leadership attributes of all teams, and foster interpersonal team dynamics.

Individual student grades in a predominantly team setting poses another challenge. Higher education provides a highly structured learning and working environment. Most standard courses and labs use clear instruments to evaluate student achievement (exams, quizzes, homework, etc.). In industry, the evaluation process is not as clear and is composed of both subjective and objective methodologies. To address this difference in the evaluation processes, the senior project course sequence has been designed to serve as a transitional period between the university and industry. Unlike other courses, a student's performance in these senior design courses will be judged using subjective and objective measures. Points are given for both written and oral exercises, and typically these exercises are team based. The evaluation of individual student performance, which represents 20 to 25 percent of the final grade, is subjective. To allow some consistency in this evaluation a set of standards for grading has been created by the SPFB. The following student traits have been defined:

- Demonstrated Leadership
- Initiative
- Professional Behavior
- Commitment to Project
- Actively Pursuing Solutions
- Measurable Technical Contribution
- Measurable Class Assignment Contribution
- Demonstrated Team Focus
- Enables Teammates

A student's subjective grade is based on the number and extent of these traits that they demonstrate. A subjective grade in this type of team-based course must be sufficiently large to avoid all team members from getting the same grade, regardless of contribution.

Within reasonable boundaries, students will perform at a level that is consistent with the SPFB expectations. The SPFB works hard to help the student groups develop as teams, and to convey their expectations regarding professionalism to the students, individually and as teams. Examples range from the basic techniques of running a professional meeting to tactful but clear communication with their industrial contact. It is important that the SPFB convey their expectations and help each student team develop a culture and environment that will foster project success.

Occasionally, the behavior of an individual or group of students might be detrimental to the success of a student team and therefore the project. When this occurs, the team's faculty advisor and the SPFB must take immediate, appropriate action. Although sometimes awkward and painful, the swift discipline of a team, or the removal of a student from a team or the entire course sequence, is necessary to ensure a healthy environment for the success of all the student teams

Regardless of the team composition, the success of a team's project can be traced to the existence or development of several key characteristics of the project itself. Following the axiom that a problem that is well defined is a problem half-solved, the industrial sponsor must be able to clearly define the problem and establish clear outcome expectations. The project outcome must be important to the company, and the company must be willing to provide financial support for the project. Although all design projects evolve over time, it is the reasonably defined projects with fairly static delivery timing that work best in an academic setting. The student team will become discouraged if the sponsor's need is vague or their interest is lacking, they will have trouble dealing with changing criteria or fluctuating delivery dates. However, a student team is highly motivated when the industrial sponsor is interested and places a high value on the project outcome.

The contact person who represents the industry plays a key role in the project's success. It is important that this person is knowledgeable about the project, responsible for the success of the project, and available to regularly communicate with and generally support the student team. While our recent graduates will return to offer projects for consideration, it has been our experience that a somewhat seasoned contact person with some level of authority is also very desirable. Being able to conduct a project is easier than being able to guide a student team to do the same.

From the student team's perspective, a desirable project must be challenging, yet of a manageable, size and scope. The breadth and depth of the project will determine the number of students the faculty places on the team, yet the project must be one that the team can complete during the academic year. Although it is likely that the students will need to acquire new skills that are unique to the project, they will still need a foundation of engineering skills and methods that will support the success of the project. It is also important that the students' success can be clearly measured with the implementation of a prototype or final product that includes hardware, or software, or both. Generally speaking, the student team must be placed in a position where they can succeed, given a challenging yet realistic goal, and clearly know when they have reached that goal.

From a faculty or administration aspect, the nature of the project should relate in some manner to the interest or background of the faculty advisor. The faculty advisor is not serving as a consulting engineer, yet he/she should be able to advise and coach the team to success. The nature and scope of the project should also be consistent with the resources that the university can dedicate to the project.

The operational challenges relate to the normal communication, coordination, and financial challenges of the project. There must be frequent, clear communication between the faculty, team, industrial contact, and faculty advisor. The activities of the student team must be coordinated with the constraints of the university and appropriate to needs of the project. Finally, a process must be defined for the industrial sponsor to meet the financial needs of the project. Purchasing difficulties present one of the harshest introductions to the real world of project engineering. Steering the students through this is essential in light of their graduation timing. In general, student teams follow the purchasing requirements of the industrial sponsor such as obtaining competing bids for major purchases. Petty cash funds are also used for smaller (and unexpected) purchasing.

During the spring semester, a group of current senior projects students give a Lessons Learned Presentation to the juniors enrolled in the next year's senior project course. The focus of the presentation is to pass on the mistakes and successes as seen through the students' eyes. This presentation was incorporated in response to a suggestion from the Industrial Advisory Board and helps to close the loop as the students prepare to graduate.

VI. Conclusion

The implementation of industry-based senior projects has been a challenging but successful endeavor at LSSU. There are many lessons we have learned from the execution of the senior engineering design course sequence over the years. We have refined the selection of teams, the evaluation of projects, and the involvement of industry contacts. The presentation of soft skills material has been improved through a fictitious faculty project called *Brick Paths Unlimited*. Increased emphasis on a structured design review format and timing has aided the teams in the execution of their projects. Improved facilities for the teams have resulted in improved interactions within and between teams. Student evaluation methods have been made more consistent, and proper credit awarded for student efforts. Each year as we undertake a new set of projects, LSSU continually weighs the "costs" to the faculty and university against the benefits to the students and our industrial constituents from industry-based projects. Each year we feel positive about what we are doing.

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