2007: INTEGRATING EXTERNAL, CLIENT-BASED ENGINEERING SENIOR DESIGN PROJECTS INTO A CAPSTONE CLASS

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Integrating External, Client-Based Engineering Senior Design Projects into a Capstone Class

Abstract

One of the most challenging aspects of coordinating an engineering capstone class is assuring that course learning objectives are met. Regardless of the type of senior design project undertaken in the class, whether competition, service, or client-based, each choice presents certain challenges. However, the most difficult scenario occurs when truly open-ended, client-supported projects are integrated into the curriculum. Having taught the engineering senior design class in a multidisciplinary context for the past ten years using several different project approaches, I find the one consistent unknown from semester to semester remains the quality of the client student interaction in externally-based, client-supported design experiences.

Therefore, this article discusses the value associated with, as well as the challenges in integrating external client projects into the engineering senior design curriculum. Several methods for 1) identifying external projects, 2) qualifying projects, 3) defining client roles and responsibilities, 4) assessing the experience from both the client and student perspective, and 5) communicating successful results will be presented. In addition, several strategies for maximizing the students' experiences in these partnerships are included in the article.

Introduction

A number of factors have influenced a transition in the conceptualization and implementation of engineering senior design courses. Foremost among these factors is the influence of the outcomes component of engineering accreditation. Secondly, feedback from employers, alumni, advisory boards and engineering professional societies has additionally served to impact both the manner in which senior design courses are offered and the desired student learning outcomes. We have seen large scale movement from engineering senior design projects best characterized as discipline-specific and department/faculty generated, to projects characterized as multidisciplinary and externally client focused.

With over twenty years teaching senior design courses, and with the past ten years coordinating and teaching multidisciplinary engineering senior design classes, I feel confident in my claim that I have seen both the very best and absolute worst experiences that these courses can generate. Fortunately for all those involved, the successes have far outweighed the challenges.

When designed properly, the engineering capstone course has the potential to offer significant rewards for all those involved. Some of my students have jointly filed patent applications with their project clients, published their work in journals and conference proceedings and won awards in prestigious international competitions. All of these

accomplishments have raised the visibility of the school in the eyes of prospective students, alumni and accrediting bodies.

To provide context for the discussion that follows, Roger Williams University's senior engineering design course is offered as a six credit, two-semester class. The courses are described in our catalog as follows:

> *Senior Design I provides experience in integrating math, science, engineering and computer science principles into a comprehensive client-based design project. This course incorporates open-ended problems emphasizing a multidisciplinary approach to total system design that provides multiple paths to a number of feasible and accepted solutions meeting stated performance requirements. Design teams will generate alternatives, make practical approximations, perform appropriate analysis to support the technical feasibility of the design, and make decisions leading to an optimized design.*
>
> *A continuation of Senior Design I, Senior Design II students will be expected to develop a working prototype. Working closely with various constituencies, student teams will conduct periodic review presentations for their client ensuring the design meets the clients' needs and expectations. The course objectives include the delivery of a successful project to the client by the end of the semester.*

Students should expect that the projects offered in the capstone class will parallel those commonly found in industry; projects defined by participation of cross-functional employees that share a range of specializations (e.g., various disciplines within engineering, writing, science, management and marketing). Furthermore, the class provides students with a forum for the synthesis and application of knowledge and skills acquired over the span of college studies in engineering and outside.

Student learning outcomes for the two semester sequence of the class encompass the following. Students are expected to:

1. Gain practical experience in a multidisciplinary design and development team
2. Understand and then transform a client's needs into a tangible project design
3. Apply the formal engineering design process with emphasis on concurrent engineering
4. Practice defined processes and effective team (and client) communication during conceptualization, production and delivery of a product or system
5. Develop proficiency in preparing, reviewing and validating all components (notes and writings, sketches and drawings; simulations and models; vendor relations; budgeting, economic analysis, materials selection, etc.) related to a completed project design
6. Synthesize information and develop effective communications explaining the results of the design process in informal and formal reports and presentations to technical and non-technical audiences
7. Recognize value in alternative ways to approaching issues, thinking critically, managing team members, and problem-solving

8. Experience the value of early starts, careful planning, team interaction, and positive interpersonal communications under tight deadlines
9. Participate in at least two external events where the successful project and research will be showcased
10. Create the foundation for a successful career or graduate studies.

Capstone class organization

The organizational and structural model that I use for the capstone design class is the client team approach. Having taught the class using different models and approaches, the client team structure best assures a successful end result. With this model, each student team relies on both an internal support team and the external client.

As course director, it is presumptuous to assume that I possess all of the cross-disciplinary technical knowledge needed to mentor the various teams and their projects each semester. Therefore, each group has at minimum, three separate clients with various roles and responsibilities in supporting the student team. My role as course director is that of facilitator and coach. I see myself as a general manager keeping students on schedule and budget, counseling them on group dynamic challenges,[a] marketing their accomplishments through press releases and newsletters, assisting them with fund-raising, coordinating logistics, and often stepping in to assist them in addressing insurmountable technical issues when they have run out of other options.

The second member of the client team is an internal faculty member. This individual is selected for his or her technical background and expertise as it relates to the problem statement of the project. In most cases, students will assemble their own group of faculty members across departments and campus as their team of internal experts. Once selected, I meet with these faculty members to explain expectations and responsibilities associated with the course. Fortunately at Roger Williams University, each faculty member designated as a semester long technical matter expert for student teams receives a stipend for his or her efforts.

Last, the third member of the client team is the external project sponsor. Once again, I encourage students to build a network of external experts if agreed to by the industrial sponsor. The agreement may come in the form of an explicit permission if working with a company to the case of a competition project where guidelines for external collaboration with vendors, suppliers and others are very well articulated. Even though an industrial client or competition may sponsor the project, students often times find many sources of expertise throughout the world. I urge the students to call and write these individuals and groups with specific questions if needed for the project. A section of the team's final design binder is dedicated to documenting all of their external contacts and communication for the project.

With this model, each member of the client team has formal designated roles and responsibilities that students understand. The internal and external technical matter experts focus solely on the technical aspects of addressing the problem statement and the

course director/project manager works on all other areas that bring the project to a successful conclusion.

How to identify external projects

Industry

Most years, I have at least three times as many potential projects as there are student teams. One successful tactic for identifying potential industry projects involves working with engineering department industrial advisory boards, school alumni, donors and professional societies. We regularly include a question on our alumni survey and an appeal in our newsletter that specifically asks our past graduates whether they would like to participate in the senior design class. This participation may take on a number of different roles such as providing a particular expertise that we might require for an individual project, financial support or submitting a company sponsored design project. At each advisory board meeting, one item on the agenda includes a presentation of the accomplishments and recognition achieved by the senior design teams as well as an invitation to participate in the future.

For those companies and individuals interested in submitting a potential design project, a package of materials that includes course objectives, mentor expectations and examples of past successful projects is provided. Also, a survey that walks the potential provider through the process of articulating his or her problem statement, constraints and anticipated deliverables is also included.

The geographic distance from a project provider has never posed significant challenges in my experience. My students have participated in very successful "distance" projects with engineers at Boeing, completed senior projects with General Motors in Mexico and when considering competition projects, most are undertaken in a geographically distant mode. In fact, with a well-defined project, distance rarely impacts the experience negatively. Since this is the case, the potential market from which to draw projects is virtually unlimited.

Competition Projects

There are mixed opinions concerning the incorporation of competition projects into capstone design classes. Earlier in my career, I was only a lukewarm supporter of using competition projects as the focus of capstone classes. Today however, some of the best student experiences are realized as a result of competition projects. As engineering senior design classes have evolved, so too have engineering competition projects.

When evaluating competition projects, just as with industry projects, it is important that a written report, oral presentations, bench-scale or physical demonstration of the product or system, and a well-defined set of rules, guidelines, evaluative criteria, and rewards are present. One of the best multidisciplinary competitions incorporating all of the above and more is held annually in New Mexico. Having just concluded the 17th Annual

International Environmental Design Contest, The Institute for Energy and the Environment at New Mexico State University has a solid track record of each year offering seven to eight industry/government sponsored design tasks for teams to pursue.[b]

Each task is best accomplished with a team of engineers possessing different specializations. In addition to engineers, many teams enter the competition with members from computer science, environmental science, chemistry, technical writing, business and marketing. All of the tasks in this competition focus on some aspect of energy and/or the environment and require a comprehensive approach to solving one of the industry or government sponsored design problems. This is one of the few competitions that historically has provided teams traveling to New Mexico with travel stipends for offsetting costs.

Another well-defined competition is the ASCE (American Society of Civil Engineers) Concrete Canoe Competition. This year marks the 20th year that the competition will be held. Once again, this competition incorporates a significant written report, oral presentation, product design category for construction evaluation and canoe races. In contrast to other competitions, the concrete canoe competition is generally not as expensive as the mini-baja, underwater autonomous vehicle or solar racer although this is not always the case. In one recent concrete canoe conference competition, one university's total budget exceeded $35,000 for the canoe build, excluding any logistics costs for 20 person team or canoe transport.[c]

Service or Non-Profit Projects

Another good source of capstone projects depending on the background of student groups is museums, financial institutions and non-profit organizations.[1] My students have participated in some very challenging projects with hospitals, designing tracking systems for medical equipment, simulation optimization products for patient flow analysis and new facility design for hospital expansions.

Museums, especially science museums, also can provide a number of technically challenging projects. One project in particular undertaken by my students required the design of a ceiling and floor support structure for a 45 ton sperm whale skeleton in an aging museum gallery. For this project, the museum facilitated the introduction of the students to the professional engineering company hired for all of the museum's structural work. As is the case with many non-profits, there is usually a long "wish-list" of projects waiting for funding. Some of these projects provide excellent capstone design opportunities for students.

Qualifying Projects

What exactly qualifies a project for a capstone design experience? For the purposes of meeting course objectives and student learning outcomes, by my definition, a qualifying external project is any project that meets the following requirements. First, there must be an identified external client that provides some degree of a developed problem statement.

Initially these problem statements may be presented in many different forms. For example, an entrepreneur might propose a simple one paragraph statement requesting proof of concept for an engineering invention still in conceptual form. Alternatively, an engineering competition project often includes over one hundred pages of rules, constraints and specifications in articulating the design problem. In any case, (again for my classes) the final problem statement must be robust enough to provide a basis for identifying alternatives to answering the design question.

Furthermore, the nature of the problem statement should allow for the inclusion of students from at least three different majors or specializations.[2,3] Although some engineering programs still deliver capstone courses to an audience of students from a single major, neither the design problems nor the team dynamics generated in these venues are realistic with respect to what a student encounters when entering the engineering profession. The opportunities for incorporating other majors from within and external to engineering only enriches the experience for all.[4,5,6]

Another requirement for qualifying the capstone project is that the problem statement should allow for students to physically create something, i.e. a prototype, working model or integrated system. Therefore, projects that involve only research into technological trends or innovative practices much like a thesis paper are not acceptable for my senior design classes.

From the client perspective, a requirement for frequent interaction is essential, whether face to face, electronically or through a listserv or other forum as is the case with many competition projects. In addition to the design binder and my written class requirements, the design project must at minimum include a significant written technical paper suitable in whole or part for publication as well as the production of a poster series. This eliminates projects where a client has required students to sign confidentiality agreements that preclude them from presenting, discussing or disseminating their work with outside parties.[d]

Defining client roles and responsibilities

As important as it is for students to recognize and fulfill their roles and responsibilities with respect to class deliverables, it is even more important for the client to agree to his or her "deliverables" in the capstone design experience. Student evaluation of the project is significantly correlated with the participation, mentoring, and support by the external client.[e] When undertaking projects with industry participants, individuals in the company identified as the "client" or contact person must have support from upper management to not only participate in the activity, but to be rewarded for the activity. In many cases, contact individuals in industry serving as the students' client, are undertaking this role in addition to their daily workload. Therefore, without recognition of this role by superiors, there is no accountability for either the success or failure of project. In two different cases, I have had individuals acting as the capstone industry contact person leave the country on assignment for three months without informing the students. In these cases, no one was designated as a replacement. For these reasons, the

necessity of having the course director and the university technical faculty mentor as members of the client team is critical for students to meet deliverables. With the extended client team approach, occurrences such as non-responsive clients can be turned into learning experiences for the students.

It is the responsibility of the course director to outline the desired behavior with respect to student interaction and communication for the client. This includes the methods and amount of communication expected between client and students on a weekly basis, the anticipated number of face to face or video conferences, the manner in which, and speed that the client is expected to respond to students, the number of formal presentations, and a plan for how the students' work will be used by the client. One simple strategy to assure that an open line of communication is maintained between the students and the client is to require students to submit electronic weekly progress reports to the client.[4] A second useful strategy is to include all members of the client team on the course management system as participants in the students' group.[f]

Another area requiring discussion with clients as well as faculty mentors are issues associated with the disposition and ownership of intellectual property generated by students. Without well-defined guidelines for the client and the faculty mentor, the treatment and disposition of inventions and discoveries made by the students during the course of the capstone class can become problematic. This is especially the case when university research policies and procedures fail to take into account inventions by students generated in a class setting, supported by external clients, and perhaps not created in campus laboratories. The issue of intellectual property and the rightful owner/s should always be discussed and documented in client discussions in the early stages of the project. This is equally applicable for the internal faculty technical mentor as well.

Assessing the capstone design experience

One of the real advantages of integrating a multidisciplinary capstone design course into the engineering curriculum is that, if properly designed, all of the "a through k" ABET outcomes are addressed. Since this is the case, a well-defined assessment plan for the class is required to take advantage of the numerous assessment opportunities.

From the student assessment perspective, instruments or processes that I use each year in evaluating not only students' learning but also the class format, design and delivery include the following.

1. *Student skill and learning gap assessment conducted in the first weeks of the semester.* This instrument assesses areas where students perceive gaps in their skill set and knowledge base as they enter their senior year of studies. Along with the assessment, students also submit their resume to date. Having both the skills assessment and resume allows me to create a personalized plan for each student with respect to areas where a student may need more experience or exposure. This personalized plan may evolve over the two course sequence yet is initially developed in conjunction with the student in a private thirty minute ice-breaker meeting at the beginning of the semester.

2. *Team evaluation surveys.* Each month, every member of each team completes an evaluation of every other group member. Since most student work is conducted in groups, this survey allows me to assess individual student performance in a team setting and intervene when and if necessary. At the end of each semester, students complete a more comprehensive evaluation of each other's performance and assign a grade to each other for the semester's work.

3. *Oral presentation assessments.* Each week each team gives a five minute presentation in class on their progress during the previous week. During these presentations, I complete a simple evaluative instrument assessing the performance of the group as well as documenting the oral group dynamics. During the preliminary and final design reviews, students make a thirty minute formal presentation to the class as well as their client constituencies. During these reviews, every audience member completes an assessment of the presentation. Periodically, special audiences will request presentations by all or some of the teams. For example, the American Society of Civil Engineers (ASCE) regional chapter requests a presentation from the concrete canoe team for one of their professional meetings each year. Once again, members of the audience are asked to evaluate the presentation.

4. *Written work assessment.* The students' design binders as well as final technical reports are judged and evaluated by their client, internal faculty mentors and others according to an assessment rubric.

5. *External validated assessment.* Perhaps the single most important assessment practice for student groups is external recognition and validation by outside experts. As will be discussed in the following section, every possible method available to externally validate students' work is incorporated into the assessment plan each semester depending on the nature of the projects. Therefore, each year students will enter their design projects into the ASEE student poster and bench-scale competition held at the regional ASEE meetings each April. In addition, students participate in a University research showcase each year requiring once again the creation of posters, presentations and demonstrations. For those students participating in competition projects, rankings and performance as compared to other institutions is measured and reviews are incorporated into future teams' deliverables. Students also enter their work in the Council for Undergraduate Research (CUR) conferences and poster sessions. Last, when appropriate, I encourage students to submit their work to journals, trade publications and for patent applications. As important as internal assessment is to the refinement and delivery of the course, external assessment that validates student performance through competitions, publications and patents is extremely beneficial not only for the experiences provided to students, but also for engineering program recruiting, visibility and accreditation.

Assessment of the client is designed as a triad approach. First, each semester, student teams assess their client in areas such as support, mentoring, availability and knowledge. Clients assess their own performance with respect to their interactions with student teams and last I assess the client's contributions to a successful team project. My assessment of the client is a dynamic process that is ongoing throughout the two semester course and formalized at the end of each semester with a written report. If required, client mentoring and intervention may be necessary.

Finally, as is required for all courses in engineering at Roger Williams University, a comprehensive assessment summary and discussion incorporating the findings of all assessment instruments and processes is delivered to the Dean shortly after the conclusion of each semester. This report normally totals twenty to twenty-five pages of material.

Communicating successful results

As presented previously, at Roger Williams University we work to maximize the capstone design experience as it serves many purposes with respect to recruiting, accreditation, program visibility and providing a differential advantage for seniors when interviewing for jobs or applying to graduate school. To effectively accomplish the outcomes associated with the class, communication of student accomplishment is a critical component of the plan.

It is essential for the course facilitator to have a close relationship with the University's public relations and communications department to facilitate the dissemination of student accomplishments in terms of projects, publications, presentations, awards and competitions. This department coordinates with local media outlets and appreciates opportunities to highlight the institution. Alternatively, external sponsors such as competitions, professional societies, non-profits and industry will also have public relations departments that are very interested in publicizing or writing stories about specific projects.

Whenever external industrial clients are involved, expect also that the development department of the institution will become involved. In some cases, the development department can also provide excellent leads to individuals representing companies that may propose projects.

From the student perspective, each of my student capstone groups is responsible for several marketing deliverables. Each group prepares a three fold brochure on their project, a series of posters with one of an appropriate size for framing and hanging in our engineering building, a one page marketing flyer that overviews the project and is used primarily for inclusion in our recruiting packets and for hand-outs at open houses, and a team fund-raising packet used to raise additional funds for their project. Although we undergo many iterations of these items, each year I am continually amazed at the professionalism and creativity of the final marketing materials.

Last, I work each senior throughout the year in assuring that his or her personal plan for seeking employment or applying to graduate school is met. In each of these cases, time is spent incorporating the capstone design experience, publications and awards on resumes, letters of recommendation or graduate school applications.

Conclusion

When initiating client-based senior design projects, it is impossible to precisely define the outcome of an open-ended design problem. Ultimately however, our responsibility as faculty in directing and mentoring these experiences is to guarantee an optimal quality experience for all participating parties. With proper planning and a course structure that builds in accountability and assessment, the capstone design experience can provide all those involved with many rewards. As our seniors prepare to enter the workforce or attend graduate school, the capstone design course serves as the vehicle moving them into the next phase of their lives. It is our responsibility to enthusiastically assure that the journey is both exciting and enlightening.

Bibliography

[1] See: Linda Ann Riley and Edward Pines (2000) "Where the Money Is: Teaching Design with Financial Institutions," published at: http://spacegrant.nmsu.edu/NMSU/2000/index.html, Las Cruces, NM.

[2] See: Patricia Wojahn, Linda Ann Riley, and Young Ho Park (2004) "Teaming Engineers and Technical Communicators in Interdisciplinary Classrooms: Working With and Against Compartmentalized Knowledge," *Proceedings of the IEEE IPCC Annual Conference*, Minneapolis, MN.

[3] Linda Ann Riley, Patti Wojahn and Young Ho Park (2003) "Multidisciplinary Courses: Facilitating Win-Win Opportunities Across Departments and Colleges" 2003 Science, Technology and Education Conference, published at: http://spacegrant.nmsu.edu/NMSU/2003/index.html, Las Cruces, NM.

[4] Julie Dyke Ford and Linda Ann Riley (2003) "Making Room for Communication in Engineering Education: Letting Past Research Inform Future Pedagogy," *Journal of Engineering Education*, October 2003, Vol. 92, no. 4.

[5] Young Ho Park, Linda Ann Riley and Patti Wojahn (2002) "Senior Design Classes: Teaming Engineers with Technical Documentation Specialists to Enhance Students' Learning Experiences" 2002 Science, Technology and Education Conference, published at: http://spacegrant.nmsu.edu/NMSU/2002/index.html, Las Cruces, NM.

[6] Patti Wojahn, Julie Dyke, Linda Ann Riley, Ed Hensel, Stuart Brown (2001) "From Classroom to Multidisciplinary Team: Envisioning Transition for Engineers and Technical Communicators," *Technical Communication Quarterly*, (Spring).

Endnotes

[a] The majority of challenges with students in the first semester of the course are almost entirely group dynamic related. At this point, students are not completely comfortable with their roles in the group and often have difficulty delegating workload as well as getting group members to contribute equally. By the second semester, many of these issues are worked out.

[b] See details of the WERC Annual Design Contest at: http://www.werc.net/contest/index.asp

[c] The $35,000 canoe budget was present by Laval University of Quebec at the New England Conference Concrete Canoe Competition. For information on the 2007 Concrete Canoe Conference Finals, please see: http://content.asce.org/inside/nccc2007/

[d] I learned this lesson the hard way as one semester I had a senior design team working on a National Laboratory project. The confidentiality agreement didn't permit the group to submit even one written document over the course of the semester. Each week during their progress report presentation, they stood up in front of the class and proclaimed, "We are making good progress on our project, but are not at liberty to discuss the details."

[e] As demonstrated through student evaluations of the course as well as student evaluation of their client.

[f] I have used both Blackboard and WebCT as the course management tool for the capstone class. Each group has their own private project site where their client is included as a member of their group. In this way, clients can upload files to the site to share with students, as well as have visibility to all of the daily communication and work of the team.