STRATEGIES TO ENGAGE CAPSTONE DESIGN COURSE SPONSORS IN HIGH-PRIORITY, CLIENT-FOCUSED PROJECTS

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ABSTRACT

Capstone design courses are a mainstay in undergraduate engineering education worldwide. With an increasing awareness by students of sectors such as disability, sustainable development and technologies for developing countries and an increasing attraction to these priority areas, instructors are responding by developing industrial and community service contacts that have a clear human-need component. This paper describes strategic factors in developing contacts within and outside the university environment. By generating a professional environment to attract projects in priority areas, the Department of Mechanical Engineering is operationalizing its commitment to providing education in areas students find most relevant to their future.

KEYWORDS

Undergraduate engineering education, capstone design course, community service learning, sponsored design projects

INTRODUCTION

The capstone design course, a central component of most undergraduate engineering curricula worldwide, leads student teams through a complete CDIO experience over the course of a half or full academic year. Sponsor financial involvement and university resources vary substantially by university and world region, and evolve over time at each institution as well [1, 2]. In addition, the types of projects that sponsors offer range from critical-path engineering problems to side-interest, high-risk areas to small-scope, limited exposure mini-projects. Depending on the sponsor, projects may have a specific person as the client or may respond to an identified need of the sponsor organization. With an increasing awareness by students of sectors such as climate, disability, sustainable development and technologies for developing countries, and an increasing attraction to these compelling areas, instructors are responding by developing industrial and community service learning (CSL) contacts to satisfy student interests.

The implementation of CSL activities in engineering design courses is becoming well accepted in the academic teaching and learning community. For example, the Engineering Projects in Community Service Learning (EPICS) [3] project was initiated at Purdue University in 1995 and has been expanded to at least fifteen other North American universities. CSL is an excellent vehicle for meeting the demand for a number of outcome competencies for our students around engineering accreditation criteria in North America [4,5], and its pedagogy and outcomes compare favourably with the recommendations set by the Boyer Commission [6]:

1. an ability to formulate or design a system, process, or program to meet desired needs
2. an ability to function on multidisciplinary teams
3. an ability to identify and solve applied science problems
4. an understanding of professional and ethical responsibility
5. an ability to communicate effectively
6. the broad education necessary to understand the impact of solutions in a global and societal context
7. recognition of the need for and an ability to engage in life-long learning
8. a knowledge of contemporary issues.

CSL also provides opportunities for practical, hands-on experience in a societal context beyond what students would normally experience in a conventional university-based capstone design project. A recent survey of communities of interest, including employers and industry leaders, done by our colleagues in the UBC Civil Engineering Department, sent a strong message that our students need to be prepared to enable the public to make informed decisions. Survey respondents underlined the importance of engineers understanding the social context of their work and appreciating their role in developing and communicating sound public and private policy agendas. In addition, by working on CSL projects related to issues such as local food security, energy or water systems, and material recycling, engineering students have the opportunity to construct an individualized understanding of sustainability in a highly social context. On the recruitment side, CSL can be promoted as an attractive program initiative that portrays engineering as a socially responsible career with a positive impact on local and global communities.

CSL-based projects have been introduced within the capstone design course of the Department of Mechanical Engineering at UBC. This paper will present the course structure as it is currently implemented, will describe the increase in CSL sector projects in recent years and present some strategic factors in developing contacts within and outside of the university environment to promote this growth.

DESCRIPTION OF THE CAPSTONE UNDERGRADUATE PROJECT DESIGN COURSE

The Mechanical Engineering capstone design project course constellation at UBC, known as MECH 45X, is comprised of the following offerings, from which all graduating students must choose one:

- MECH 457 (general track and thermofluids),
- MECH 458 (mechatronics),
- MECH 459 (biomedical engineering), and
- APSC 496 (interdepartmental capstone course within the Faculty of Applied Science).

The course commitments include weekly lectures, meetings (weekly one-hour meetings with the team's faculty supervisor and monthly meetings with the sponsor's liaison) and a series of deliverables (approximately one per month).

Capstone Course Lectures

In the past, lectures were used primarily to repeat and amplify on design process tools that students were taught in previous years. This year, in response to student feedback that this repetition is unnecessary and, indeed, unwelcome, we have changed the focus to more forward-looking content and to more participatory formats in line with the general trend to participatory, team-based learning (TBL) strategies in our department [7], especially for lecture courses. Below we present the changes we have made to the lecture component this year.

1. Participatory workshops: In the two weeks prior to a major deliverable such as a report, the teaching team prepares a related assignment that all teams must complete and hand in on one sheet of paper (see Figure 1 for a sample assignment). The goal is to give the entire class a warm-up exercise so that there is a common understanding of the expected scope of the upcoming deliverable. In the lecture, four to five teams are selected at random to present an abridged version of their assignment to the class, using a document camera and the lecture hall projector. In the ten minutes allotted to each team, one of the instructors does a critique, poses questions to the team relating to the rationale behind the approaches presented and offers suggestions for improvements.

> This Thursday … we will have a participatory workshop to help prepare you for the Critical Function Prototype (CFP) deliverable. Please review the online CFP guide as well. For Thursday, we would like you to prepare on ONE sheet of paper your answers to the following 3 items:
>
> 1) Which key function you are contemplating prototyping?
>
> 2) What is the particular design risk you wish to reduce through the prototype? In other words, what is the knowledge you hope to gain from the prototype that will allow you to proceed with greater confidence?
>
> 3) What quantitative/qualitative testing will you conduct (deliverable)?
>
> As before, we will select several teams to present their ideas on the document camera for discussion. Since you have been thinking about your next deliverable already, writing down your first attempt at these 3 items should take very little time.

Figure 1. Assignment to the class relating to the Participatory Workshop prior to the Critical Function Prototype Report

2. Lectures by practicing engineers: Each term, two to four lectures by colleagues and industry-based professionals are organized to bring outside opinions that are immediately relevant to a particular phase of the project. For example, this year there was an early lecture on the development of the value proposition of a design for a client, a lecture and demonstration of rapid prototyping techniques and technologies in the middle weeks, a subsequent lecture on the power of engineering analysis in practice, and a final-month lecture on the regulatory landscape of products in Canada.

3. Reflection sessions: In CSL initiatives, reflection is an important constituent of the student experience to explicitly require them to analyze, discuss and write about their community immersion in terms of impact to the people in the implicated community and impact on their own views [8]. In each term of MECH 45X, there are two to three opportunities for students to have focus-group format reflection sessions with the instructors to address a short list of topics (see Figure 2 for an example). Split into four subgroups of about six teams each and one team per table, students address a short list of questions/topics on a flip-chart-size page with a marker. After ten minutes the responses are posted on the classroom wall for everyone to peruse for five minutes, and then each team presents one to two major points from its own sheet as a point of departure for an instructor-led discussion. Subsequently, the sheets from all sessions are collated and responses categorized by themes. The analysis is posted on the class website so students can compare their session's comments with those of the other three sessions, and the results will be used next academic year for course improvements.

The session will be organized as an advice-giving session - you will imagine that you have the ability to give advice to yourselves when you were just starting the last phase of the project. For 10 minutes, you will brainstorm with your team what advice you would give to yourselves and write out at least five suggestions that would have helped you if you had known this a few weeks earlier. The remaining 15 minutes will be a class discussion - each team will share in turn the best piece of advice they have and we will discuss the issues that arise. Our hope is to collect these pieces of advice and share them with next year's class, in hopes of making their experience even better.

Figure 2. Topics presented to students at the first Reflection Session, half-way through the first of the two terms.

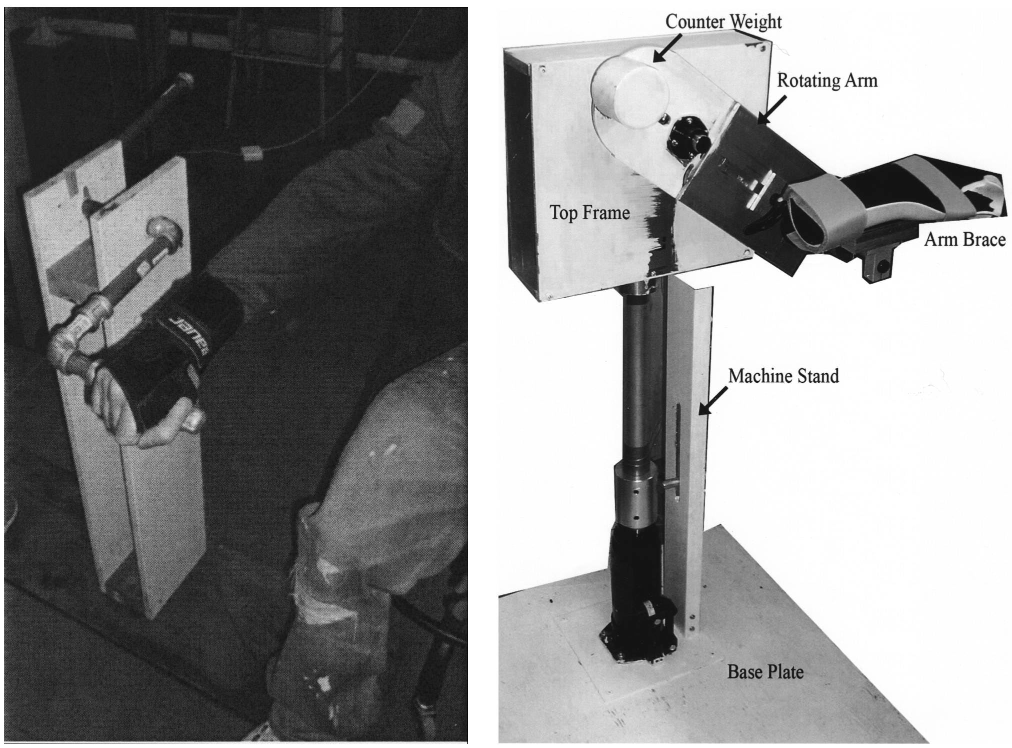
Course Meetings

Weekly one-hour team meetings with the faculty supervisor are team-led and driven by the team's written agenda, which has three categories of information: tasks accomplished the past week, breakdown of each student's tasks accomplished and hours spent (with cumulative hourly total as well), and the coming week's goals. Although some time is spent recapping the week's progress, the bulk of the time is devoted to the difficult issues to resolve in the coming week – in other words, where the supervisors are likely to have the most experience in assisting/guiding the team to focus energy and time, and where the questioning of design rationale is most likely to produce learning and insights.

The less frequent but even more crucial liaison meetings have as the primary goals to bring client-based and community-based expertise to the team and to render transparent the process of the project's design rationale. The two-way communication in these meetings is as important to CSL-type projects as to corporate-sponsor projects. Each project uncovers issues, opportunities, constraints and scope changes that were not clear, by students, sponsor or community stakeholders, at earlier stages. It is not uncommon to have two or three important midcourse "corrections", i.e., justifiable and necessary changes from the client's initial need statement emerging from the design process itself. Educating the client on the design rationale leading to the changes must be conveyed so that both parties remain connected and proceeding toward a common goal, even as that goal is redefined. These meetings are also opportunities for the client and community members to re-evaluate the status of the project and inject crucial additional information (values, resources, expertise, etc.) that may not have been deemed important or relevant earlier.

Course Deliverables and Student Assessment

Course deliverables include reports, presentations, prototypes and student logbooks. Reports corresponding to the major design-engineering and CDIO phases are: requirements definition, literature search and benchmarking, conceptual alternatives development, technical analysis, detailed drawings and prototype testing. Major presentation deliverables include a conceptual alternatives review in Term 1 and a final prototype review in Term 2. Prototype deliverables include an early "critical function" prototype (CFP) in Term 1 as the precursor to the final, fully functional device delivered near the end of Term 2. See Figure 3 for examples of both in one CSL project that involved the design of a novel arm exerciser for a disabled client with spinal cord injury. After final assembly, an evaluation plan is developed and implemented to show how the original design requirements map to prototype specifications: the final report includes results on this testing. The final prototype and report are delivered to the client.



(a) (b)

Figure 3. (a) A Term-1 Critical Function Prototype (CFP) and (b) a Term-2 final prototype of the same arm exerciser project. The CFP embodies a key functionality the prototype must have to satisfy client requirements, but one that the students are least sure of being able to complete successfully. CFP testing will either validate a design choice or steer the design away from a solution that turns out not to be viable.

PROJECT IDENTIFICATION AND SELECTION BY COURSE INSTRUCTORS

Each year, six to seven instructors whose interests collectively span the department's specializations are involved in the capstone design courses, with each instructor responsible for 4-5 student teams of 4-6 students each. Over time, instructors have developed professional relationships with local companies, research labs and community organizations. Each year, instructors contact liaisons at these entities and solicit project ideas. In an ad hoc manner, potential new sponsors are also contacted.

A number of general strategies have been found to be instrumental in successfully soliciting projects from returning sponsors and developing new sponsors.

- Communicating clear financial and collaboration expectations on the part of sponsors for their involvement in the project for the duration of the academic year,
- Developing official mechanisms through the University Industry Liaison Office (UILO) that allows companies to retain intellectual property rights to student project work,
- Encouraging students to submit their projects to design award competitions to boost visibility for both students and sponsors,

These mechanisms lead to the presentation of clearer project abstracts upfront by the client, and to projects that can more easily be scoped to fit into one full academic year. The following sections develop the community service learning (CSL) component of the course.

COMMUNITY SERVICE PROJECT INCLUSION IN THE CAPSTONE DESIGN SERIES

Opportunities and Challenges

Effective inclusion of CSL pedagogy into the capstone design series clearly requires efforts beyond recruiting non-commercial sector sponsors. The ideal CSL project incorporates, from the work of Cone et al. [9]:

1. Characteristics of the learner
2. Academic and pragmatic issues
3. Service experience - disjunctive from the student's everyday experience
4. Holistic reflection - intellectual as well as emotional, written and oral
5. Mentoring

In our current model, the academic and pragmatics issues of a capstone design experience, as well as mentoring, are handled through the lecture materials and weekly team meetings with instructors. We have incorporated the reflection component for all of our projects, although the main focus is on the design process generally, and does not always relate directly to the service aspect of the students' work. However we do see that students who are service-oriented are attracted to CSL projects and in some cases will have a continuing involvement with the CSL project sponsor following completion of the capstone project.

Furthermore, when working with community sponsors, as opposed to corporate or internal project sponsors who often have engineers to assist with developing the project specification and mentoring the students, the capacity to guide a CSL project from the client side is often insufficient. Therefore faculty mentoring and guided student reflection on these types of projects can require extra attention. A plan to provide both additional training related to working with community organizations in a service-related role, as well as student credit for a "service portfolio" may help to expand the benefits that students take away from doing a CSL capstone project in the future. Current efforts at UBC to develop an integrated CSL curriculum plan with related supports are underway and can help to address these issues.

We can view the progress on CSL-type projects from two perspectives: domain priority area and sponsor type. These are presented below.

Project Review by Priority Area

A major recent catalyst to increasing the number of CSL projects in our curriculum has been the establishment of two priority areas for the UBC Faculty of Applied Science (APSC) and our department: biomedical/assistive technologies and sustainability. An incentivizing budget has been allocated to promote research and instruction in these areas, independent of the type of project sponsor (corporation, community organization or research lab). As this relates to the capstone courses, we are encouraging companies and local organizations to identify and sponsor projects in these areas even if they cannot support them financially; the department contributes funds to complete the student projects.

A further impetus was provided by the 2009 Canadian National Science and Engineering Research Council (NSERC) award to UBC Profs. Philippe Kruchten and Antony Hodgson of a 5-year Design Engineering Chair to promote interdepartmental instruction, initially focusing on capstone-level expansion of biomedical and rehabilitation projects and thereby enhancing the ability to attract new sponsors. These factors have promoted offerings of projects that fall in the Community Service sector.

Project Review by Sponsor and Project Type

Three strategies that have further increased the quality of CSL projects are:

- Seeking sponsors from university research labs and other internal (to the university) community service units locally,
- Seeking sponsoring external community organizations that innately have a clear link to the departmental priority areas of sustainability and biomedical/rehabilitation engineering, and
- Suggesting to potential company sponsors to formulate a project idea that fits with our departmental priority areas.

The strategies above relating to departmental priority areas are often those that focus the project on a human client need rather than a corporate engineering need. In these projects especially, students spend a significant amount of time with their clients, observing activities such as medical interventions and querying domain experts, for example at the UBC Farm, a university facility that has strong ties to programs in developing countries and is dedicated to research in sustainable agriculture practices. In the reflection sessions of the course, students explicitly credit these exploratory activities as seminal to the discovery of innovative approaches and concepts: the human element is a key component to the success of these projects.

While much of the design and engineering learning is in class, a substantial component of the CSL occurs when students meet the project sponsor, interact with the community and begin to understand the client need that has been identified and proposed for their project. The first major design step, converting a client need to an engineering design proposal, is an intense identification and scoping process that brings the community back to the classroom.

Since instituting these priorities several years ago, the types of projects have evolved in the capstone design course (Figures 4 and 5). This year (2009-2010), 50% of the 42 project offerings responded directly to priority areas, as were 50% of the 28 projects ultimately selected by students, an increase from 33% in the preceding year. When divided according to sponsor type, there has been a trend toward more projects from internal and external CSL sources than corporations over the past nine years. Viewed from a departmental priority perspective, the number of projects in the biomedical/rehabilitation and sustainability domains has increased significantly over the past nine years, and most notably over the past three years.

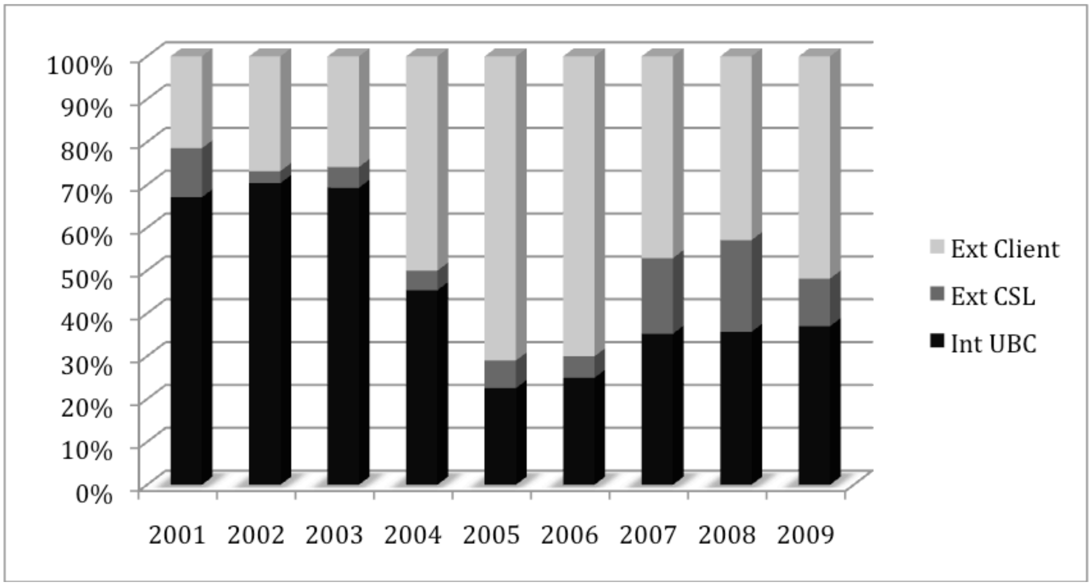


Figure 4. Inclusion of community-service learning (CSL) projects in MECH 45X over the past 9 years. Internal-UBC projects from within the MECH department dominated the first 4 years. In 2005 the course was re-organized to increase the number of external sponsors. Starting in 2007, we began an explicit program to increase the number of CSL sponsors from both inside and outside the university.

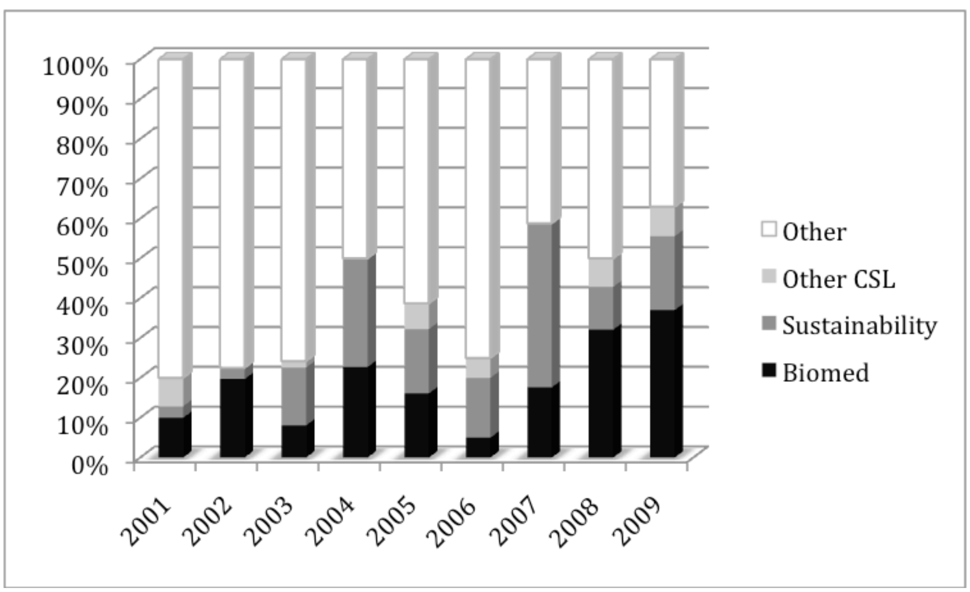


Figure 5. Categories of community-service learning (CSL) projects in MECH 45X over the past 9 years. Overall, the two MECH priority areas of biomedical/rehabilitation and sustainability have dominated the CSL project types throughout, and the CSL projects have increased from 20% in the early years to approximately 50% in the past three years.

CONCLUSION

By generating the environment to attract projects in CSL and priority areas, the department and the Faculty of Applied Science have formalized their commitments to providing education in areas students naturally find most relevant to their future. The Capstone Design Course allows our graduating students a premier opportunity to develop innovative solutions and thereby have the greatest value to project sponsors, which is especially important in these human-centred domains.

The formal inclusion of self-assessments in the form of reflection sessions, a central component of CSL, encourages more student awareness of the value of their work in relation to human needs. The development of a sustainable practice within the department to attract such projects in the capstone design course has been a key development over the past years, and will also lead to the natural expansion of CSL activities into 2nd and 3rd year curricula, with the overall goal of creating a more compelling and attractive offering to incoming engineering students from a broader spectrum of demographics and interests.

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H.F. Machiel Van der Loos received the Ingénieur Mécanicien degree from the Swiss Federal Institute of Technology in Lausanne (1979), and an Engineer's Degree (1984) and Ph.D. (1992) from Stanford University in Mechanical Engineering, all in the domain of robot interface design. He is currently Associate Professor in the Dept. of Mechanical Engineering at the University of British Columbia, Vancouver, and specializes in the teaching of design courses and in research related to human-robot interaction and roboethics, primarily in rehabilitation applications.

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