Teaching Engineering Design in a Four-Course Sequence

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***Abstract*—Engineering design is an art that takes skill, training, knowledge, and effort. It is one of the most difficult subjects to teach at engineering schools. A typical design course requires students to perform design tasks without explanation of the design methodology. With the ever-changing demands of the society and advances of technology, teaching engineering design effectively has become an urgent agenda in many engineering programs worldwide. The Department of Electrical and Computer Engineering at the University of Victoria had been offering a single engineering design project course for its programs since the 1980s. It was only till late 2000s that its curricula were revised and have been re-visited continuously since then. The latest programs have a sequence of four compulsory design project courses. This work presents an introduction and evolution of these design project courses. Issues and problems encountered, as well as solutions, are described. Successes, failures, and lessons learned are also discussed.**

Keywords—engineering design; engineering curriculum; design projects; program accreditation; generic skills

I. Introduction and Background

An engineer, regardless of the discipline, must be well versed in many subjects including mathematics, science, management, communications, and design [1]. This makes educating engineers a difficult task, especially teaching them engineering design in this ever-changing technological society.

The accreditation of engineering programs in Canada is the responsibility of the Canadian Engineering Accreditation Board (CEAB) [2]. Only graduates from accredited programs are qualified for professional designation and licensing in various provincial jurisdictions, for example, PEng in British Columbia. Among the criteria for accreditation [3] is design:

The engineering curriculum must culminate in a significant design experience conducted under the professional responsibility of a faculty licensed to practice engineering in Canada, preferably in the jurisdiction in which the institution is located. The significant design experience is based on the knowledge and skills acquired in earlier work and it preferably gives students an involvement in teamwork and project management.

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The Department of Electrical and Computer Engineering (ECE) at the University of Victoria (UVic) offers engineering degree programs in the electrical, computer, software (in collaboration with Computer Science Department), and biomedical (jointly with Mechanical Engineering Department) engineering disciplines. Students are required to complete eight academic terms of six courses each, interleaved with compulsory co-op education as shown in Fig. 1. A minimum of four co-op work terms is needed to satisfy the degree requirements.

Prior to 2010, all ECE students had to take only one design project course, during their final year of academic studies. Since then, the curriculum has been revised such that students are required to take a design course during each of their four academic years in the program.

Academic and Work/Other Term Schedule			
Year	September–December	January–April	May–August
1	Academic Term 1A	Academic Term 1B	Academic Term 1C or Work/Other Term
2	Academic Term 2A	Work/Other Term	Academic Term 2B
3	Work/Other Term	Academic Term 3A	Work/Other Term
4	Academic Term 3B	Work/Other Term	Academic Term 4A
5	Work/Other Term	Academic Term 4B	

Fig. 1 UVic Engineering Program Schedule

This paper describes the design courses, first, from a motivational and historical perspective. Then, specific issues, such as operation and management, associated with each course are discussed. Lessons learned over the years and solutions proposed to resolve common issues are presented, followed by a synopsis of future plans.

II. Evolution of Design Courses

Virtually all of the accredited engineering programs in Canada have a senior-level course offering significant design

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experience, or a capstone design project. The CEAB defines design as [4]:

Engineering design integrates mathematics, natural sciences, engineering sciences, and complementary studies in order to develop elements, systems, and processes to meet specific needs. It is a creative, iterative, and open-ended process, subject to constraints, which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may also relate to economic, health, safety, and environmental, societal or other interdisciplinary factors.

The ECE department has incorporated five design courses in its curricula. Four of them are offered by ECE and three were introduced over the past five years. The following subsections summarize each course, 499, 120, 399, and 299 in chronological order of their introduction.

A. 499 Design Project II (Design Project I prior to 2013)

Since the department's inception in 1983, ECE students are required to take a one-term compulsory capstone Design Project course 499 in their final year [5]. The objective of the course is to integrate knowledge and skills acquired in earlier course work in a design-focused project to meet multiple criteria. Teams of three to five students either choose a project from a list of projects or propose their own projects that must be approved by the Design Project Coordinator (a registered professional engineer). Each team is supervised by at least one faculty member who is a professional engineer.

The team members' work is evaluated based on their problem solving capability, project execution competence, oral and written communication skills, as illustrated in their progress and final reports, a public demonstration and competition of their project prototypes, and a web site designed to promote their project. Detailed information on the Design Project course can be found in [6] that also includes archives of past projects. The interesting and prominent features of this course worth mentioning are:

- Students from Biomedical, Computer, Electrical, and Software Engineering programs are taking the course together and an interdisciplinary project group is highly recommended. Furthermore, a group may even include students from other technical and non-technical departments.
- Students are encouraged to select topics proposed by external organizations or companies.
- Students are allowed to propose their own projects that must be approved by the course coordinator and group supervisor.

In an attempt to improve students' learning experience, many modifications have been made to the requirement, operation, and execution of the course in the past five years. These are elaborated in section III.

The formal course description for the Electrical 499 is [5]:

A significant technical design project in Electrical Engineering completed under the supervision of a faculty member. This design experience is based on the knowledge and skills acquired in earlier course work. Projects may originate from faculty members, students, or external sources. They may have a diverse nature and serve diverse needs. Multi-disciplinary projects are encouraged.

B. First Year Design and Communication Courses

Between 1996 and 2010, the ECE department offered a course to all first-year students related to design—199 Laboratory in Engineering Fundamentals with the following calendar description [7]:

The objective of this course is to introduce students to concepts in electrical, computer, and mechanical engineering through a practical project to be undertaken by teams of students. The project will involve mechanical construction, sensing of mechanical quantities by electrical means, as well as interfacing to and programming of a simple microcontroller. Students will be required to acquire suitable components, demonstrate their designs, and write a report documenting their efforts.

At UVic, the first year is common to all engineering disciplines: biomedical, civil, computer, electrical, mechanical, and software. The focus of 199 was on theoretical design with minimal laboratory and practical work. In addition, the majority of the materials were taken from the electrical and mechanical fields. It was not a popular course and students found that they do not learn much about engineering design. As the Faculty was expanding to accommodate biomedical, civil, and software, it was deemed necessary to create new design courses for the common first year.

The Faculty of Engineering at UVic has two first-year courses that teach design: ENGR 110 and 120. Instructors from the Faculty of Engineering and the Department of English teach these courses collaboratively. Before the introduction of these courses, it was found that students' motivation to learn communications skills was low. A large number of students believe that communications skills are somehow less important than technical skills. By combining these courses, communications skills are presented in the context of technical reports, project proposals, status reports, and other types of communications that engineers need to produce when they are conducting design during their careers.

1) ENGR 110 Design and Communication I

This first design course covers basic design skills including teamwork, conflict resolution, and project management. Several short design projects, such as building a paper platform capable of holding a person's weight, enable the students to acquire these skills. As a pre-requisite to ENGR 120, this course's calendar entry reads [8]:

Introductory principles of engineering design processes through practical projects to be undertaken by teams of students; integrated development and demonstration of writing, research, design and presentation skills through research and design projects. Writing, research and organizational skills appropriate for University level writing.

The technical part of this course is taught by the Department of Mechanical Engineering; hence, the projects are primarily mechanical oriented.

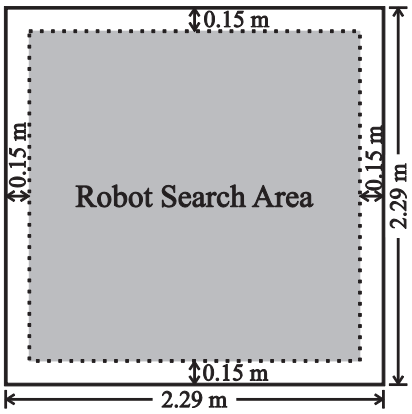
2) ENGR 120 Design and Communication II

This course was taught by Mechanical Engineering during its offerings from 2010 to 2012. It was agreed by all departments that it would be appropriate for ECE to offer this course with electrical and computer emphasis [9]:

Principles of engineering science and design applied to practical projects undertaken by student teams; Integrated development and demonstration of writing, research, design and presentation skills; Referencing methods for scientific and technical literature; Characteristics of effective technical and scientific style; Emphasis on clarity, precision, and consistency; Practical experience in writing short technical documents such as memoranda, letters, abstracts, reports, papers, manuals, brochures, and specifications.

For the design portion of this course, students are provided with some basic robotics knowledge and given a two-month project to design an autonomous robot. At this first-year stage, students have limited technical knowledge. Therefore, basics of electrical circuits, computer programming, control theory, motors, project management, design process, and software engineering are taught. The robot project is highly structured, and thus, allows creativity in the design, while at the same time enforcing that the proper design methodology learnt in class to be put to practice.

Modeled after the Fukushima Daiici nuclear disaster in 2011, the project simulates the design of a robot to neutralize a radiation source after a major incident. Students working in teams of three build a prototype mobile robot that can autonomously do a simple search and deployment task within an arena as shown in Fig. 2.



Rules:
1. Search area of 2.29 m by 2.29m will be surrounded by walls of at least 5 cm height.
2. Centre of infrared source will be at least 15 cm from outside wall.
3. Robot will be placed at least 15 cm from all walls before each run.
4. Initial robot direction will be selected by laboratory Teaching Assistant.

Fig. 2 ENGR 120 Robot Arena

The robot specifications are:

a) Find a beacon (see Fig. 3) that emits an infrared light signal modulated with a 10 Hz square pulse signal within the arena.

b) Simulate radiation neutralization by removing an object placed on the beacon housing.

c) Cover the beacon housing with a creative technique or drop the object from the beacon outside of the arena.

The robots are built using VEX robotics kits and other structural and mechanical components. There are four milestones and each team are graded on their achievement at each milestone:

a) Evaluation of sketches of possible robot designs.

b) Evaluation of the mechanical system for moving autonomously, and picking up and dropping of the object.

c) Evaluation of the sensor system for judging the distance from the beacon for object pickup and from the edge of the arena for safe drop.

d) Evaluation of the full operation of the robot.

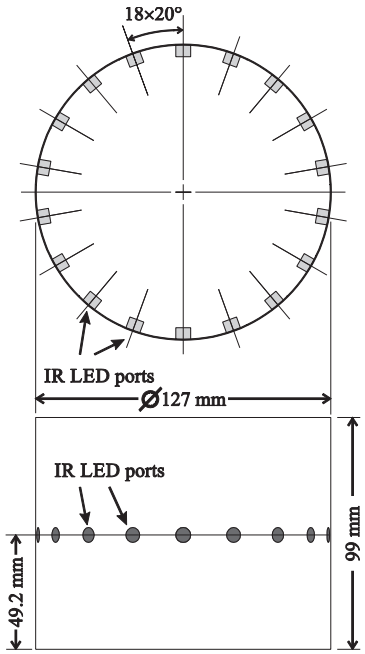


Fig. 3 ENGR 120 Target Beacon

ENGR 120 has been offered three times and it is found to improve the learning experience of the first-year students of the Faculty. Some issues remained to be resolved including the diverse cultural and educational backgrounds of the students, the shock of a big change in the learning process from high school to university, the ability to manage time and project, and the interaction within a team environment. It is a also challenge to find qualified lab TAs and Instructors.

C. 399 Design Project I

The 499 Design Project runs for 13 weeks. However, the public display with the teams' prototypes is often scheduled for the 11th or 12th week of classes. This is an extremely short period of time for the students to find members to form a team, select a project, conceptualize the design, source parts and supplies, and implement the prototype.

The ECE curriculum committee decided that a third-year design course should be introduced to all computer, electrical, and software engineering students. Replacing a seminar course where students were to present a technical topic as well as to critique others' presentation, 399 Project Design 1 was offered the first time in the fall of 2013 [10] with the following formal course description in the university calendar:

A team-based technical project completed under the supervision of a faculty member, with a focus on Engineering design requirements and specification processes. Expected learning experience and outcome are based on the knowledge and skills acquired by the student in earlier and concurrent course work, and Professional Engineers' awareness and consideration with respect to the environment, ethics, equity, public and worker safety and health. Projects may have a diverse nature serving societal needs. Multi-disciplinary projects are encouraged.

As a pre-requisite to 499, 399 is similar in operation and execution. Guest speakers from industry are invited to give informal talks on various aspects of engineering. Students are also required to give presentations about their projects and complete a feasibility report. Specifically, each 399 team has to give an elevator pitch on their proposed project at the beginning of the term, followed by an oral presentation of in-depth investigation of their project towards the end of the term. A final and four progress reports allow the students to practice written communication skills.

The motivation for having this course was to have students form teams, select project, and carry out a preliminary design from an approved list of 499 projects. It was envisioned that a proper design and prototype would be easier to materialize given a longer time period to execute the project. In addition, the teams can continue to develop their 399 projects during their co-op work term before taking 499 in their next academic term. Though, the students were allowed to change the project or team when they took 499.

After two offerings, it was obvious that 399 did not work according to our plan. Only 10% of the teams continued to develop their projects in 499. There was much negative feedback with the primary complaint being that the specifics of electrical and computer engineering design process was not really taught formally in class. The students also indicated that they would like to learn more about project management methods.

It was decided that some changes are necessary. For the fall 2015 offering, students are still required to investigate the feasibility of a project but the emphasis is on design methodology. Also, faculty members and industrial engineers are invited to give presentation on design in various application areas including hardware, software, signal processing, and telecommunication. More lecture time is devoted to project management.

At the time of this writing, the students seem to be more receptive to the new content, judging from the attendance in the first eight weeks of classes.

D. 299 Introduction to Electrical and Computer Engineering Design

This second-year 299 course emphasizes different aspects of design and implementation. Students in electrical and computer engineering are taught formal engineering design methodologies, and various project implementation skills such as Computer Aided Design (CAD) software, microcontroller embedded code development, printed circuit board design, components soldering, and circuit testing. The students are required to design and implement a prototype device. They have a choice of choosing one of the two given projects.

1) Alarm Clock

The students implement a music-playing alarm clock using a microcontroller board that has many functions including digital-to-analog conversion, analog-to-digital conversion, and pulse width modulation.

The alarm clock should display the time on a 7-segment display. It should have buttons for alarm on/off, snooze, switching from 12 to 24 hour modes, changing the time, changing the alarm time, and adjusting the playback volume. When the alarm is triggered, MP3 files are played from a USB. The audio should be run through an active low pass filter and a power amplifier circuit. Panel mount buttons and a potentiometer are used as controls for the various functions.

2) Maze Robot

A robot is designed to run through a maze without internal loops (minimum distance between corners is 14 inches and the finish block is 3 inches by 8 inches) made from black electrical tape on a white melamine surface. There is a button that starts the robot after a small delay, and it stops automatically when the finish line is found.

The robot uses a set of infrared emitters (light emitting diodes) and receivers (phototransistors) set at a fixed distance away from the surface. An infrared signal is transmitted and reflected off the ground and the resulting signals are measured to determine where the taped line is. Software determines whether it needs to simply follow the line, or if an intersection has been reached. The DC motors on the robot are controlled by an H-bridge circuit designed by the students, which allows a microcontroller to control speed and direction.

299 is offered for the first time in the fall of 2015. As a pre-requisite to 399, it has the following formal description [11]:

Computer Aided Design (CAD) tools used in electrical and computer engineering design: drafting, printed-circuit board layout, scientific and system simulation. Instrumentation devices used in control and measurement. Case studies illustrating electrical and computer engineering design process. Time and project management. Technical communications and presentations.

Student feedbacks will be reviewed carefully to make the necessary modification and adjustment to improve this course.

III. Issues Encountered in Design Courses

Several issues surfaced while teaching the mentioned design courses in our engineering curricula. Most of these issues can be classified into general categories of project management and workload.

A. Student and Project Management

The majority of the projects in 399 and 499 are proposed by the students themselves, instead of the ones given in the pre-approved list as provided by the faculty members or the industry. The advantage in a self-proposed project is that the students are more enthusiastic and dedicated in carrying out the project. On the other hand, it is a missed opportunity to connect with faculty members to explore graduate studies and a research career. Furthermore, developing meaningful links with industry, other organizations, and potential employers, are beneficial to a student's future but are currently missing from the course. We are seeking ways to improve this situation, for example, giving students opportunities to identify real-life problems during their co-op work terms and use them as their design projects. Another direction that we are investigating is participation in international group projects. Students working on common projects could communicate, collaborate, and compete over the Internet.

In order to monitor a team's progress, a web-based progress report tool was implemented and made available to several design project teams in 2012. Team members were required to enter their individual activities every two weeks. These reported activities were to be validated by other team members, as shown in Fig. 4. This form of peer monitoring reflects the actual contribution of each team member. The supervisor of a team is also required to validate the entries at major milestones. This tool is valuable for a supervisor to assign a grade to each team member depending on the member's contribution to the project. It also serves as a useful document for supporting the CEAB accreditation process.

To assist students in project management, teams in 299, 399 and 499 are required to hand in a Gantt chart of their revised milestones every two weeks. This serves as a very useful tool for learning by doing in project management.

After two sessions of 499, it was found that there was strong resistance from the students in using the web-based activities monitoring tool. After several meetings with the students, it was found, somewhat unexplainably, that the students were not happy with entering information individually using an electronic tool. For 2014 and 2015, teams were required to enter their individual members' activities with a hard copy paper form. It seems that when they sit down together and fill the form, it is more amicable and cooperative. The responses have been very positive since the introduction of the paper format.

B. Instructor and Teaching Management

At UVic, each course and the instructor are being evaluated at the end of the term through a learning experience survey. The design project courses 399 and 499 are not evaluated by due to the large number of individual supervisors involved. However, such feedback is very important to monitor the quality of delivery and learning outcomes. We are currently working on a web-based anonymous evaluation scheme that can be integrated smoothly into existing university practice and procedures, and yet capture the uniqueness of these courses.

For projects in 399 and 499, students are working in a more independent way than earlier design courses. Though each group is still under the supervision of a faculty member. For first- and second-year level courses, teaching assistants are required to facilitate and assist the experiments and projects. However, it is difficult to find highly qualified graduate students to serve as project teaching assistants, due to the multi-disciplinary nature of the projects and the large number of students (about 160 in the second to fourth year ECE programs and 500 in the first year common program). To maintain excellence in project learning and continuity, it is necessary to provide training to the teaching assistants in a standardized format.

Faculty members play important roles in each of these design courses. For the junior courses, slight modifications to the projects every year are desirable so as to stimulate students' creativity, instead of borrowing ideas and implementations from previous years.

C. Resource and Funding Management

With the shrinking resources available at universities worldwide, it is advisable to have a multi-year plan for design courses. Maintenance, repair, and replacement of equipment are vital to the success of running these courses.

Human resources, that is, technical staff members are the ones who ensure the design courses are running smoothly. Training of dedicated staff to each design course is of paramount importance. In addition, sensitivity training may be in order due to the diverse cultural and social background of our students.

Finally, all of the above issues are related to the financial strength of the university, faculty, and department. Many universities all over the world are facing financial crisis and UVic is of no exception. Well thought out budget plans and innovative schemes to acquire additional funding are must haves these days in the academic world.

IV. Future Plan

From the above presentations and discussions, one can readily identify the various issues and problems existing within the current sequence of engineering design courses. We are monitoring and reacting on a continual basis to the operations and demands of students, faculties, and staff.

All four courses in engineering design are set up before the programs in biomedical and civil engineering began. It is necessary, especially for the first-year courses, to introduce and

integrate biomedical and civil components into the projects. In addition, it is highly desirable that upper-level design courses to have teams made up of students from different disciplines to simulate a real-life working environment.

Currently, we are reviewing additional first and second year projects to be added to the junior level courses in order to maintain students' interest and engagement.

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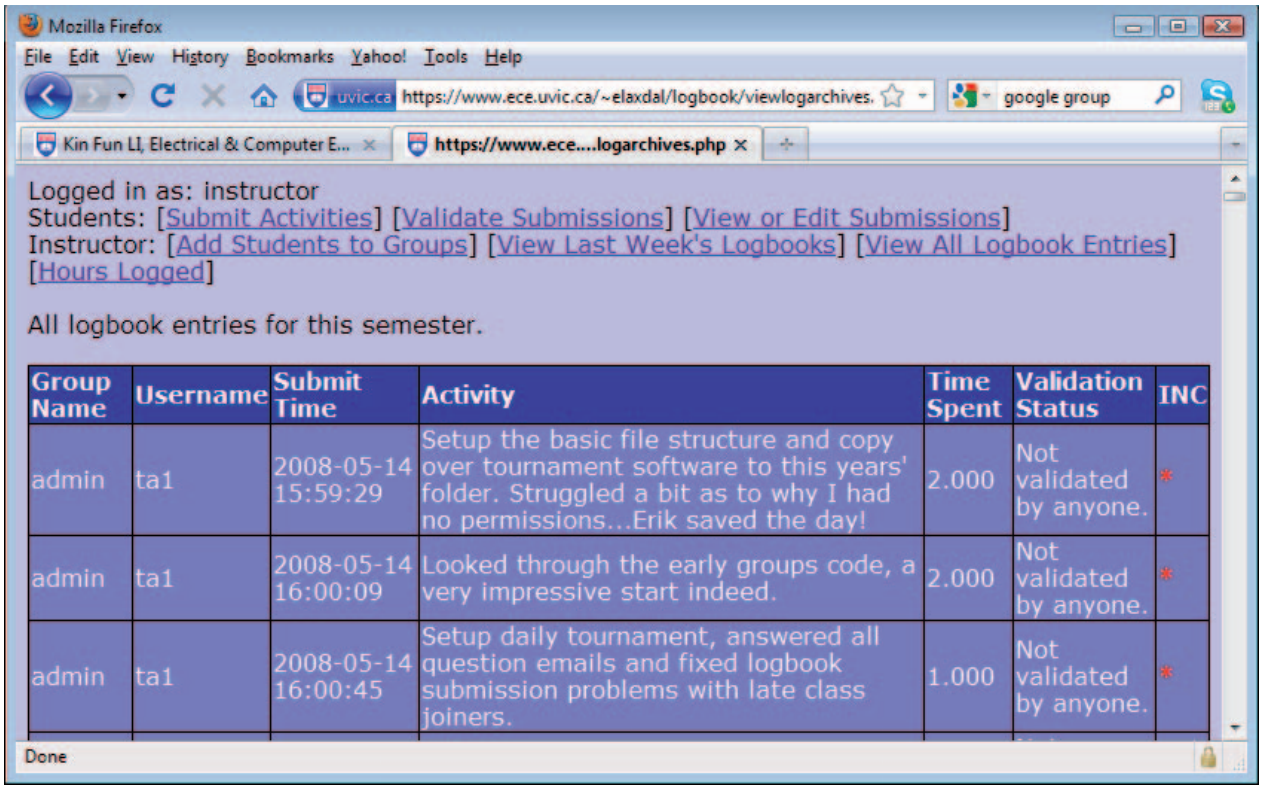

Fig. 4 A Screen Shot of the Web-based Tool for Team Member Activities Entry and Validation