DESIGN PROJECTS IN THE MECHANICAL ENGINEERING CURRICULUM AT SHERBROOKE UNIVERSITY – PAST, PRESENT, AND FUTURE

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1.0 INTRODUCTION

Since 1992, students in our undergraduate mechanical engineering program have been carrying out major design projects. The process of integrating major design project activities was spread over three phases. The first phase, which took place between 1992 and 1994, consisted of a pilot program with forty students. The implementation of an engineering design option between 1995 and 1999 constituted the second phase. The last phase embraced the complete reform of the undergraduate curriculum based on the development of competencies and the horizontal/vertical integration of engineering sciences and engineering design.

One of the principal objectives of the major design projects is to allow the students **to live a major design experience** within the undergraduate curriculum. The students work on the same project during the last four terms of their program (more than two calendar years as a result of the work terms). They receive 12 credits for their design project work.

This paper presents our ten years of experience in using design projects as a tool for teaching engineering design. It also sets out our development plan for teaching engineering design over the next five years. NSERC (National Sciences and Engineering Research Council of Canada) Engineering Design Chair will support these future developments.

2.0 ENGINEERING DESIGN PROJECTS

2.1 1992 to 1994 - Pilot Program in Engineering Design

Following a literature review on the use of design projects as a tool for teaching engineering design in other universities and an assessment of the scale of the work required for introducing major design projects in our program, our department decided to start with a pilot program. The principal advantage of this approach was the state of mind of the project stakeholders (professors and students). This certainly facilitated the program from development to implementation. It should be noted that our program comprised several major teaching developments that were innovations both in our department as well as in the world of teaching engineering design. It would have been very difficult, perhaps impossible, to receive the necessary support and approval for all these teaching innovations in, as an example, the development of an engineering design option.

Moreover, this state of mind allowed us to create an excellent atmosphere of cooperation between the professors and the students. It would have been difficult to duplicate such a climate within the framework of a more formal approach.

The principal characteristics of our pilot program [1,2] were:

- 15 credits (3 credits in design methodology and 12 credits distributed over the three last terms of the undergraduate program for the design projects).
- 40 students (a typical cohort is just over 100 students).
- 3 design projects (a Formula SAE, a bicycle trailer, and a dismountable catamaran).
- Development of new laboratories (a design studio and a manufacturing workshop).
- Development of new evaluation tools (e.g. logbooks, grading templates for presentations, reports, project exhibition, etc.).

The major problem with our pilot program was inadequate student preparation (e.g. no training in project management) for carrying out a design project of this scale. On the other hand, the results obtained were so conclusive that our department decided, a few months before the end of the pilot program, to develop an engineering design option.

2.2 1995 to 1999 - Engineering Design Option

The two principal objectives associated with developing and implementing a mechanical engineering design option was to institutionalize our new vision of teaching engineering design and to have an opportunity to improve our teaching approaches, methods, and tools.

As mentioned above, the students in the pilot program were not sufficiently prepared for carrying out design projects of such scale. In order to correct this situation, we developed a new block of 6 credits in design methodology (e.g. needs analysis, functional analysis, design process, concept generation and selection, etc), creativity, project management, and teamwork.

The principal characteristics of our engineering design option were as follows:

- 18 credits (6 credits in design methodology, teamwork, creativity, and project management, and 12 credits distributed over the last three terms for the design project).
- Development of a case study used in the design methodology course.
- 20 to 25 students (a typical cohort is just over 100 students).
- 3 to 4 design projects per year

- Improvement of the design and manufacturing laboratories developed in the pilot program.
- Improvement of the evaluation tools (e.g. logbooks, grading templates for presentations, reports and exhibit, etc.).

In summary, the engineering design option was a good opportunity to develop solutions to the difficulties identified during the pilot program, to institutionalize our new vision of teaching engineering design, and to improve our laboratories and evaluation tools.

2.3 1996 to Today - New Undergraduate Engineering Program based on Competency Development

After completed our pilot program from 1992 to 1994 and conducting an exhaustive literature review about mechanical engineering education [3], our department decided to develop and implement a major reform of our undergraduate program [4]. The two principal cornerstones of our reform were:

- a program based on the development of competencies (technical and professional);
- a program combining engineering sciences and engineering design through integration projects carried out during the first five terms and a design project carried out during the three last terms.

The following sections present the various elements involved in teaching engineering design in our new undergraduate mechanical engineering program.

2.3.1 Undergraduate program structure

The following table presents the principal engineering design activities.

S4[1]	S5	S6	S7	S8
Teamwork and Leadership – ING615 (1 credit)	Design Methodology – IMC156 (3 credits)	Design Project I – IMC900 (3 credits)	Design Project II – IMC906 (3 credits)	Design Project III – IMC907 (6 credits)
Creativity and Critique – ING630 (1 credit)	Project Management – ING670 (1 credit)	Creativity and Critique – ING635 (2 credits)		

Table 1 - Engineering design activities in our undergraduate program

2.3.2 Laboratories for the design projects

Obviously, engineering design requires laboratories in which projects can be carried out (from design to manufacturing and testing)[2]. The following tables present our laboratories.

[1] S4 : Fourth term

[2] Typically, between 20 to 40% of the design projects are done with an industrial partner. In most cases, the prototypes for this type of project are manufactured and assembled at the industry workshops.

	Design Studios	
Description	140-m^2 hall divided into 8 work cells. Includes a reference library, printer, and plotter. Each cell has a workstation with design software, tables, filing cabinets, etc. and the CAD/CAE room	
Photos		

Table 2 – Facilities for carrying out design projects - development phase

	Fabrication Workshop[3]
Description	100-m^2 workshop with 4 conventional lathes, 4 conventional milling machines, 1 numerically controlled lathe, 1 numerically controlled milling machine, 1 industrial boring machine, etc.
Photos	

Table 3 – Facilities for carrying out design projects - manufacturing phase (Part I)

[3] Students are trained to use all the equipment and are responsible for producing the parts and components used in their prototypes. Furthermore, they can send work orders to the University's specialized mechanical shop.

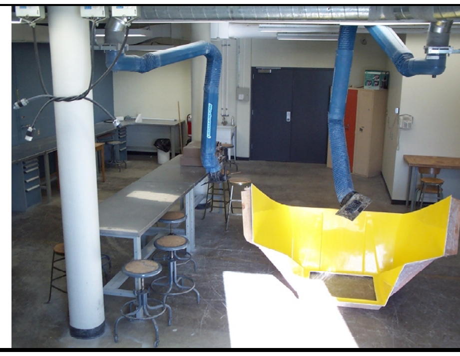
	Assembly Workshop	
Description	Two assembly workshops with a total of 220 m^2 of floor space, including workbenches and toolboxes, and a 100-m^2 finishing room for polymer and composite components.	
Photos		

Table 3 – Facilities for carrying out design projects - manufacturing phase (Part II)

2.3.3 Design project definition and industrial partnership

Teams are formed and design projects selected in the fifth term (S5), which is one term before the beginning of the design project. From the very start of the term, projects suggested by companies are presented to the students.

As the result of repeated discussions between students over eight weeks and a student presentation given at around mid-term, each team submits a proposal including a project description, team composition, a technological pre-feasibility study, and a preliminary budget with the potential sources of funding [5]. Professors review the proposals and provide final comments to the students before the end of the fifth term.

2.3.4 Design project exhibition

It was apparent to us from the outset that manufacturing a complete functional prototype would be a key element of this new vision of teaching engineering design. However, the design and manufacturing of a product, system, or machine will always involve a number of uncertainties, which justified the fact that the objective would not always be achieved if the students were not ready to intensify their efforts to deal with certain exceptional situations.

After reflection, we felt that the best means for ensuring that the students would achieve the goal was to have them exhibit their projects. It should be kept in mind that students are like all designers: they are proud of their projects and have a very strong sense of team belonging. An exhibit is a simple way to strike this sensitive cord.

Moreover, the exhibit also offers an opportunity to present four posters about the project. These posters show the main results (e.g. needs, functions, concepts, calculations and simulations, etc.)

obtained as a result of the projects. Lastly, the exhibit can also be a catalyst in stimulating the development of new partnerships with companies and to show to the community the student's accomplishments.

2.3.5 Examples of design projects during the past two years

The following table presents a list of projects presented at the last two exhibits.

Year	Projects
1996-2000	Hybrid sea and river kayak, automatic pill-counting machine, walking robot, high-speed bicycle, rocket, aircraft door mechanism, aerospace vehicle, trimaran, bicycle for persons with impaired mobility, submarine, stretcher, solar heat receiver, bike support, autocross vehicle, high-speed pedal boat, special tool rack for remote-sensing equipment, and two confidential projects (18 projects - 113 students)
1997-2001	Water-ice-snow-sand sailing, rubber-band installation machine for broccoli, cargo aircraft for the SAE Aero Design Competition, chiropractic table, surfboard with a propulsion system, door-opening system for a fast-food garbage container, bus seat, microwave heating system for water, ski maintenance machine, key management system, granite tool, leg brace, ride for the Santa Claus Village amusement park, system for removing snow from the roadside rail, and one confidential project (15 projects - 106 students)

Table 4 - List of design projects presented during two last exhibits

The great diversity in projects should be readily evident. This can be explained by the fact that the definition of design projects rests mainly on the personal interests of the students and the opportunities offered by the companies from a variety of economic sectors.

Finally, the figure on the following page shows a mosaic of pictures of some design projects exhibited in December 2000. Prototype quality shows through in the figure.

Figure 1 - Design projects exhibited in December 2000

3.0 DEVELOPMENT PLAN OF ENGINEERING DESIGN FROM 2001 TO 2006

In 1999, the National Sciences and Engineering Research Council of Canada (NSERC) launched a new program (Chair in Design Engineering - CDE) with the principal objective of stimulating innovation in engineering design (teaching and research).

We submitted a proposal to NSERC and obtained a positive response in October 2000. The Chair began its activities in June 2001. The following sections present the development plan of the Chair from 2001 to 2006 pertaining to the teaching of engineering design.

3.1 Develop, Teach, and Apply Product Development Processes that Take into Account the Nature of the Project or Product

The product development process (PDP) taught in the design methodology course (IMC156) and used in design projects (IMC900, IMC906, and IMC907) is well suited for developing consumer products. Unfortunately, the PDP does not really lend itself to other design situations such as the development of machines, technological products, or mechatronic systems. The design methodology (IMC156) course given in the fifth term (S5) should therefore be modified to introduce different PDPs (or a more general and flexible PDP) that take into account the various contexts under which products, processes, and systems are developed. Furthermore, the new undergraduate program in engineering does not include electives in design engineering. Consequently, it has been proposed that an elective should be developed in design methodology and the various product development tools (e.g. DFA, DFM, information management – PDM, reliability analysis – FMEA, etc.). The course would be based on acknowledged references in the various areas of design engineering. Lastly, **this course will also be open to master's students**.

3.2 Increase the Number of Professional and Physical Resources Needed to Produce Prototypes

Carrying out major design projects requires both facilities and professional resources. Up to now (1992 to 1999), not all students in the cohort were involved in the design projects. **Under the new undergraduate program, however, all must carry out a design project**. In 1999, when the Faculty of Engineering building was enlarged, the Department of Mechanical Engineering increased its facilities for design projects (development and implementation). Currently, the main shortcoming lies with a lack of professional resources needed to help students design and produce prototypes. Two new staff members will be added to respond to this need: a mechatronics technician and a CAD/CAE application engineer. The mechatronics technician is justified by the fact that many student design projects involve increasing levels of automation or mechatronics. Furthermore, new physical resources (e.g. machine tools and tools) will be acquired to fabricate prototypes.

3.3 Review the Breakdown and Weighting of Activities Carried Out during the Design Project Phase (S6 to S8)

Student activities related to design projects (IMC900, IMC906, and IMC907) are carried out within a strict, well-defined context. Unfortunately, past experience leads us to believe that students are not sufficiently advanced in their design projects by the end of IMC900. Moreover, at the end of IMC907, students must present a fully functional prototype that has been tested and validated. In reality, most students present fully functional prototypes that have not been tested and experimentally validated. In response, all student activities in IMC900, IMC906, and IMC907 should be reviewed in order to ensure that the final design concepts have been mastered by the end of IMC900 and that the final, functional prototypes have been validated by the end of IMC907.

3.4 Integrate a Software Application for Computer-Aided Mechanical Engineering (CAE) into the Curriculum

Over the last 15 years, computer-aided design (CAD) and computer-aided manufacturing (CAM) have significantly modified both the design and manufacturing phases for products, processes, and systems. In contrast, until very recently, CAE has been a tool for specialists; use of these modeling tools requires specialized training and costly infrastructure (computers and software). The advent of powerful personal computers, the development of applications for the Windows NT type operating systems, and the development of increasingly user-friendly, robust applications have led many small businesses to integrate these tools into their product development processes. This also applies to universities. The demand for design engineers able to master these tools will grow in the near future. Furthermore, due to design-project complexity, it is often impossible to finalize the dimensioning of the various elements or systems solely with analytical methods. The only alternative is to introduce simulation tools into all courses in the curriculum, including design projects.

Moreover, in order to minimize the learning effort required by simulation tools, we will strive to identify a CAE application (e.g., IDEAS, COSMOS, etc.) with the capability of solving a range of problems. The Department of Mechanical Engineering has already made its choice for courses in the first few terms by systematically introducing MATLAB software.

3.5 Integrate Notions of Environmental Design (DFE: Design for Environment) and the Safe Design of Machines, Processes, Systems, and Products (DFS: Design for Safety) into the Curriculum

The environment and personal safety are two design criteria of growing importance in the development of products, processes, and systems. We believe that the real impact that engineers can have on environmental and safety issues lies specifically with product, process, and system design. As a consequence, we propose to develop a new elective relating to design safety (DFS) and environmental design (DFE). This course will also be open to master's students.

3.6 Develop an Improved Framework for a Pre-feasibility Study and Integrate It into Courses in the 5th term

Our experience over the last eight years leads us to believe that the term in which design projects are selected and student teams formed is a critical element that weighs heavily **in project success** and in the smooth running of the remaining activities in the design project. For example, students tend to select projects that interest them greatly but which are beyond their level of knowledge and the Department's available resources. Currently, project selection and team formation take place during the fifth term (S5); the design project officially begins in the sixth term (S6). Although students can select their own projects, the professor has the right of veto to ensure project feasibility within the context of IMC900, IMC906, and IMC907. On the other hand, we have observed that this feasibility assessment requires **stricter and more formal application**. We therefore propose to develop an improved framework to make it possible to carry out a formal project pre-feasibility study and to integrate this activity into IMC156. This new activity will be evaluated in IMC156 and should significantly enhance the team-creation and project-selection process. Another scenario that will be examined is to initiate the planning for the design project and the pre-feasibility study in the fourth term (S4).

3.6 Develop Tools Enabling Rigorous Evaluation of Individual Contributions to Teamwork and Teamwork Itself during Design Projects

The evaluation of the design projects calls for innovative methods to evaluate the work carried out by the team and by each individual team member. Moreover, ongoing evaluation is important, since it enables professors to stay in constant touch with students in order to assess the quality and quantity of work accomplished. Until now, the evaluation of teams in a term has been based on weekly reports (activities, tasks accomplished, planned activities, and difficulties), a design review,[4] and a report covering all the work during the term. Individual work is evaluated semimonthly based on the student's logbook. Students use their logbooks to record all work underway (e.g. calculations, drawings, records of meetings, etc.). Nevertheless, much work remains to be done on evaluation criteria and means. We therefore propose to review our methods and criteria used to evaluate design projects with the help of specialists in the field of evaluating skills and teaching objectives from the Université de Sherbrooke's Bureau de soutien à l'enseignement (Teaching Support Center) or the Association for the Development of Evaluation Methodologies in Education (ADMEE).

3.7 Develop Formal Partnerships with Marketing and Industrial Design Departments in Universities and Colleges

From 1992 to the present, many design projects have been carried out in cooperation with the students at the École de design industriel[5] de l'Université de Montréal. Moreover, a number of students in the Faculté d'administration[6] the Université de Sherbrooke took part in carrying out market studies and needs analysis. Unfortunately, this collaboration was never formalized. As a result, it has been proposed to develop formal partnerships with schools, faculties, departments, and colleges in the fields of marketing and industrial design. These partnerships will enable us to create work contexts (e.g. engineer, industrial designer, marketing specialist, etc.) similar to those found in industrial practice and allow our students to discover the **real meaning** of multidisciplinary teamwork.

3.8 Develop Partnerships with Industry in Carrying Out Design Projects

From 1992 to the present, some design projects have been carried out with the involvement of industry. This collaboration has made it possible to define realistic projects of an industrial nature, while giving manufacturers the opportunity to discover new ways of working (e.g. design methodology and product development tools) and meet potential new recruits. **This type of collaboration has proven very beneficial for both the students and companies involved**. Consequently, we propose to develop tools to promote the projects carried out by our students and **protocols of agreement, which deal with the issues of confidentiality and intellectual property**. Failure to develop these protocols of agreement on confidentiality and intellectual property will prevent us from achieving our objective by the end of the Chair's term: seven design projects carried out annually with the collaboration of industry.

4.0 CONCLUSION

After these ten years of experience, we are convinced that a key element in teaching engineering design at undergraduate level is the realization of a major design project including the development, manufacturing, and experimental validation of a product, a system, or a machine.

[4] In the 8th term (S8), the prototype will be displayed with posters at the end of the term, in addition to the design review.
[5] Industrial design
[6] Business School

The challenge is major; the effort, resources, infrastructure, and teaching innovations necessary to attain this goal should not be underestimated. On the other hand, the results obtained have been and remain an inexhaustible source of energy for us.

5.0 REFERENCES

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