Engineering Design : Thoughts and Perspectives

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Abstract

According to the Canadian Engineering Accreditation Board, all engineering programs in Canada must include a minimum of 15% of activities allocated to design. One can assume that these activities vary in content and scope between different programs.

In this context, how can we define engineering design? Is there a recognized academic definition? Should our design goals be aligned with industrial needs and practice and if so, what should be the content of our design activities and how should they be structured? How is it possible to reach academic design goals given the limited resources available in our engineering schools?

These are some of questions that will be addressed in this paper with the intent of better understanding the very important aspect of design's engineering practice. Additional topics include: the change in design philosophy and approach resulting from a major program reform in the Mechanical Engineering Department at Université de Sherbrooke as well as the importance of industrial partnerships in design projects.

1. Introduction

Engineering design can be defined in many ways and the understanding of what it involves also varies within engineering programs. However, one constraint is common to all of us: our programs must include a design component roughly corresponding to a full term of activities to satisfy the requirements of the Canadian Engineering Accreditation Board (CEAB)(1). From an engineering practice perspective, engineering design skills are critically important for the young engineer starting his/her career. If properly trained in design, he/she will be able to effectively join a design team, understand the process being followed, use his

analytical, numerical and experimented skills to come up with and validate new concepts while being an effective team player.

How can we, in a university environment, train our students to become efficient designers in industry? The main purpose of this paper is to propose one answer to this question, being well aware that there is no single right answer and that various approaches and course contents can lead to competent designers. To do so, we will first compare CEAB and ABET design requirements to establish a platform from which design activities can be structured. We will then introduce the concept of concurrent engineering to determine whether there is a gap between the university community and industry on the understanding of what design should mean. Finally, we will briefly describe the design activities in the Mechanical Engineering program at the Université de Sherbrooke, how they are integrated and the synergy that has been built over the years between the department and industry through various design projects.

2. CEAB, ABET and design

The Canadian Engineering Accreditation Board professionally recognizes engineering programs in Canada through an accreditation process that takes place every six years. The board has different rules, some specifically aimed at design activities. Under these rules, an engineering program must incorporate a minimum of 225 units in design out of a total of 1800 units. Therefore, design must represent a minimum of 12.5% of all activities, which represents approximately one full term in a four year program.

In the 2003 CEAB Accreditation Criteria and Procedures Guidelines, engineering design and context are defined in the following two quotations:

- Engineering design integrates mathematics, basic sciences, engineering sciences and complementary

studies in developing elements, systems and processes to meet specific needs. It is a creative, iterative and often open-ended process subject to various constraints...

- The engineering curriculum must culminate in a significant design experience, which is based on the knowledge and skills acquired in earlier course work, and which preferably gives students an exposure to the concepts of team work and project management...

The equivalent of the CEAB in the United States is ABET, the Accreditation Board for Engineering and Technology. It is of interest to look at the ABET interpretation of what engineering design is since the organization has completely rethought its rules over the past decade and produced Engineering Criteria 2000(2). The ABET definition of design is very similar to the CAB definition. The main difference is related to program educational objectives. Each institution must now state objectives that describe the expected accomplishments of graduates during the first several years following graduation from the program. And since specific accomplishments are expected on design skills, this indirectly forces the institutions to take into consideration the way design is practiced in industry.

3. The concurrent engineering approach to design

It is widely acknowledged that concurrent engineering (CE) practices originated in Japan(3). The actual term Concurrent Engineering was coined in 1986 by the Institute for Defense Analysis (IDA) in the United States where engineers had been slowly experimenting with and applying CE practices since the early 1980's(4). During the same decade, a major report entitled "Made in America"(5) explained the decline in U.S. markets by linking this with the failure of many U.S. companies to produce state-of-the-art processes for designing, manufacturing, marketing and distributing their products. The European and Asian companies on the other hand were focussing on product and process development thereby greatly shortening the time-to-market while assuring good quality at a competitive price. US companies took notice. In the 1980's, major industrial sectors adopted CE practices in order to regain their edge in product development. These practices have become the benchmark for companies that want to succeed at introducing new products in their marketplace.

It is therefore interesting to compare academic design activities with CE practices to evaluate how well

universities are to training young engineers to meet industrial design needs. This question was raised in an inspiring report published by the National Research Council (NRC) in 1991(6). This report establishes a clear link between engineering design, concurrent engineering and competitiveness. Moreover, a whole section of the report focuses on the need to improve engineering design education and provides a list of specific recommendations that are still valid today.

Taking the original IDA concurrent engineering definition and adding pertinent elements from the NRC report, we propose the following definition:

- Concurrent engineering is a systematic and multifunctional process that simultaneously integrates the various phases of product development and the management of its process through:
 - identification of client needs,
 - product specification,
 - conceptual design,
 - preliminary and detailed design,
 - fabrication

while considering the complete product life cycle including distribution, maintenance, recycling or disposal.

Central to the practice of concurrent engineering is the integration of the different phases of product development. It is this integration that explains reduced time-to-market. To achieve integration, design teams have to be multifunctional. The main functions normally represented are engineering (design), production or fabrication and marketing.

4. Product design in Mechanical Engineering at the Université de Sherbrooke

Over the past decade, we have been experimenting with the concurrent engineering approach in our internal design activities. In May of 1992, we launched a design pilot project at the undergraduate level (7) as we wanted to make our students more competitive and train them to become better designers of products using best suitable manufacturing processes. To accomplish this goal, the students worked in multidisciplinary teams on projects encompassing the whole product development cycle.

Central to this experiment was a major design project of 15 credits, the equivalent of five full courses. Through this project, students were introduced to the integrated and multidisciplinary approach of

concurrent engineering and became familiar with fundamental modern design tools and best engineering design practices.

The project was such a success that students insisted it be repeated - which we have done for all cohorts. In 1996, we introduced a completely revamped undergraduate program based on competencies (8) with design as the ultimate competency integration activity - the backbone of the entire program. A major design project forms an integral component of the new program with all students receiving the same training in design. The project has the following features:

- 15 credits, representing 675 hours of work, spread over 4 terms
- Activities and coursework covering all phases of product design from market analysis to building and testing of a functional prototype.
- A requirement for students to follow a formal product development process (PDP)
- Mandatory project teams of 5 to 15 students, often working in association with external industrial partners.

The scope of the design project maybe outlined as per the following breakdown (S5 means 5th term, and so on):

- S5: Project definition, team selection, feasibility and risk analysis, partnership agreement.
- S6: Market definition, clients needs, functional analysis, engineering specifications (QFD), generation and selection of concepts (Pugh), conceptual design review.
- S7: Preliminary design including all the necessary engineering analyses for the definition of optimal dimensioning, parts and assembly drawings, preliminary design review.
- S8: Detailed design, fabrication and assembly of the prototype, experimental validation, final design review, public exhibition (prototype, technical reports and poster).

Dozens of projects have been completed so far, the outcomes of which can be viewed at www.conception.gme.usherb.ca/. To respect the requirements of concurrent engineering, many projects are multidisciplinary with students from electrical and computer engineering working with students in mechanical engineering. This usually occurs when the chosen project has a major mechatronics component. Since 1993, we have also had an informal partnership with the École de design industriel of l'Université de Montréal which permits students in industrial design to participate in some of our projects and contribute their know-how in ergonomics, aesthetic, design of forms, etc. The added value of this multifunctional

approach can be seen with project EXOCET, shown in Figure 1, during which our students teamed up with industrial design students to develop the watercraft shown below in collaboration with Bombardier. Since 2003, we have also had a partnership with the Faculté d'administration of l'Université de Sherbrooke with marketing students forming part of the engineering team. At this moment, we have two projects under development applying this engineering-marketing approach, thus bringing us one step closer to a true concurrent engineering environment.

Figure 1. One-of-a-kind watercraft designed and fabricated by a multifunctional student design team

5. The importance of industrial partnerships

When we began major design projects in the early 1990's, all projects were selected from ideas submitted by students or professors. Certain students wanted to work on ideas that they had been thinking about for a long time, imagining that they might eventually develop a product that could lead to a start-up company. Other students just wanted to let their creativity loose and turn an idea into a real product with no commercial application in mind.

This approach to project selection is viable in long term only if projects are paper-based and don't lead to prototyping. Historically, the majority of engineering programs have been following this course. But when a design project evolves from concept validation to prototyping, financial implications are a major factor. Laboratory space is needed for manufacturing activities and assembly. Technical support has to be provided to student design teams. And finally, monetary funds are required to pay for material and

outside sub-contractors. In some cases, amounts required can easily reach tens of thousands of dollars.

This cost constraint explains why our design projects have evolved from being proposed by students to the present situation where projects are almost entirely conducted in conjunction with and financially supported by industry. Originally, students were able to finance their projects through monetary or in-kind sponsorships. Over time, this became more difficult to arrange as companies became increasingly disenchanted with repeated requests for contributions without any direct return.

How were we able to convince companies to submit projects and then eventually to finance them? It has been an evolving process which can best be summarized as a triad synergy illustrated in Figure 2. In the early 1990's, professors from our department met many engineering managers in companies to discuss concurrent engineering design approaches and establish possible partnerships. After a few years of collaboration, during which we gave many presentations on concurrent engineering, it was decided to launch an independent entity, the Institute of Product Development, that would pursue and strengthen that collaboration. The Institute, formally launched in 1995, is a non profit corporation based in Montréal with 6 permanent employees. The main mission of the Institute is to promote best product development practices within Canadian companies in order to make these companies more competitive.

Figure 2. Our industrial partnership triad

The Institute has 55 active corporate members, ranging from small to big corporations, involved in the manufacture of general consumer to high-tech products. Our active participation in the Institute has produced many positive benefits. We constantly monitor and follow design trends, processes and tools used in the industrial environment. We are involved in training programs for participating industries. Also, the Institute acts as a window that we use to promote our design projects and to inform our industrial partners of

the advantages of hiring our engineering graduates because of their design knowledge and training.

The fact that our involvement in creating and participating in the Institute has resulted in links with industry, explains why our design projects are now almost entirely proposed and supported by industry. The advantages of this industrial collaboration are many:

- Students no longer have to spend time and energy searching for funding.
- The stress on our labs and technicians has been alleviated since prototyping is usually paid for by participating companies.
- As students work on design development of real products, they become aware of industrial constraints.
- Companies acquire ready access to competent design engineers who:
 - have mastered design processes;
 - possess analytical, numerical and experimental skills;
 - have experience working on functioning teams.

It has been necessary to devote time and energy to make this collaboration work and there is always an element of risk that during the two-year project, the company will pull out for various reasons. The management of projects is also more complex when there are multiple partners involved. One way of assuring a smooth operation is for all parties to understand and agree to the objectives of the project, its scope, respective responsibilities and deliverables. The most complex issue is related to intellectual property (IP). Over time, we have developed a partnership agreement document that helps students negotiate IP issues with their industrial partners. Even though companies sometimes will refuse any sharing of IP related to the project, the majority of them are willing to discuss IP and to put an agreement on paper.

6. Conclusion

Engineering design is a challenging and rewarding activity. From the student perspective, it is challenging in that it is open-ended, possible solutions are numerous and constraints have to be dealt with. Design is also the ultimate activity for integrating various skills, whether technical or complementary. Students cannot reach a sound level of design competency if they are unable to efficiently use their analytical, numerical and experimental skills. They also have to be good team players and use their creative and problem solving skills.

Looking back at our design experience over the past decade, we can unequivocally say that students enjoy designing products and find it rewarding. They obtain a sense of accomplishment when they finally reach the prototyping phase and close the loop by validating their engineering specifications. We can see the pride in their faces during poster sessions and design reviews when they present and explain their accomplishments.

Needless to say, design is also a challenging activity for professors. The mindset has to switch from teaching to coaching, from the certainty of mathematical and physical principles to the uncertainty of a desired yet unpredictable outcome and the various ways of reaching it. Design is also an activity that leads to interaction between people especially if the design team is multidisciplinary.

Is design a rewarding activity for professors? As it is the case for students, we believe it is rewarding on an intellectual level as it puts all our cognitive and behavioural skills to work. On the other hand, we have often heard that design is not a career rewarding activity as it is not properly recognized when tenure and promotions are considered. Let us hope that this will be less and less true and that design initiatives such as the NSERC Design Chairs and the Canadian Design Engineering Network (CDEN) will put engineering design at the forefront of our preoccupations and begin to recognize it appropriately.

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