REFLECTIONS ON THE USE OF CASE STUDIES IN THE TEACHING OF ENGINEERING DESIGN

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ABSTRACT
Engineering design skills are critical to drive economic growth while addressing such societal issues as sustainability and innovation. To help address this need in postgraduate students – both recent graduates and those with several years of industry experience – a Professional Masters of Engineering (MEng) Design Certificate program was recently introduced in Mechanical Engineering at the University of Waterloo. The program consists of a small core based on a design methods course and a two-course equivalent industry design project. The design methods course relies on a combination of lectures and a major project. Recently, the lectures have been increasingly supplemented with case studies, wherein students get to practice design. Reflections on the role of these case studies in the development of design skills are presented.

Keywords: Case studies, engineering design, industry projects, post-graduate design education

1 INTRODUCTION

Over the past few years, there has been increasing emphasis on the development of design skills of undergraduate engineering students in Canada. This has been driven largely by the evolution of the accreditation rules published by the Canadian Engineering Accreditation Board (CEAB), most notably their recent move to outcomes-based assessment criteria and procedures [1]. This aligns Canada more closely with many other jurisdictions, including the USA [2]. This increased emphasis in design engineering education has resulted in many initiatives, mostly aimed at the undergraduate engineering curriculum [3]. In some cases, graduate programs have been discussed, although the emphasis has been on education and design research. To complement a larger program focused on the development and implementation of case studies for use throughout the undergraduate curriculum [4], a Professional Masters Certificate program in Design Engineering has been developed. This program has a simple structure: of the 8 courses required for the degree, students are required to take a design methods course plus a two-course equivalent design project to receive the certificate. A fourth course is specified to complement the design project.

The design methods course was originally lecture and project based: readings and lectures on various aspects of design methods, and a whole class project to apply these methods and practice the skills. Cases were increasingly used in this course to develop engineering design skills as they became available through the undergraduate program. The two-course project was modelled after industrial projects in undergraduate programs.

A case study is a representation of a real engineering situation that has a realistic context and appropriate complexity. Cases can be a documentation of an engineering failure [5], but are more commonly simply a description of an engineering challenge. Case studies have been seen as a way to enrich student learning [6, 7]. Cases provide a solid basis for the discussion of the design process, and an opportunity for students to work through the stages in the solution of a real problem. As such they allow a more inductive learning mode [8]. This is particularly relevant for design education, as the concepts are abstract and application is situational.

2 MENG PROGRAM OVERVIEW

Despite the increased emphasis on engineering design in the Canadian undergraduate curriculum, most programs still tend to be very engineering science oriented, and an opportunity was identified to offer an engineering design program at the graduate level. In addition to meeting the needs of recent Canadian graduates, the MEng program was designed to accommodate the needs of engineers working full-time in Canadian industry who felt the need to upgrade their design skills, and for foreign-trained engineers who found it difficult to find their first Canadian industry experience. Over the first five years of the program, the majority of students have been foreign-trained, with a smaller number of part-time students who were currently employed full-time in Canadian industry, and a smaller number of recent Canadian graduates.

The first design methods course is open to any student in a Mechanical Engineering Master's level program. By far the most students are enrolled in the MEng (course-work) program, while a few have been enrolled in the MASc (thesis) program. Over the first 5 years, a total of 88 students have taken this course. A subset of these students, a total of 22 to date, has successfully applied to participate in the design project courses to complete the certificate. The majority of these students have worked on a design project for external clients, with a total of 11 separate companies participating to date.

3 DESIGN METHODS COURSE

The design methods course is intended to provide students with a solid understanding of design methods, and takes a general approach [9]. The design process is seen as a collection of activities which allow an engineer to go from a challenge to a solution, by combining specific domain knowledge with design process knowledge, Figure 1. Emphasis is placed on developing design process knowledge, so care must be taken to choose examples and projects for which students collectively have sufficient domain knowledge. The importance of constraints is also emphasized – both on the process (design for safety, time, and financial and human resources) and the final result (size, weight and cost).

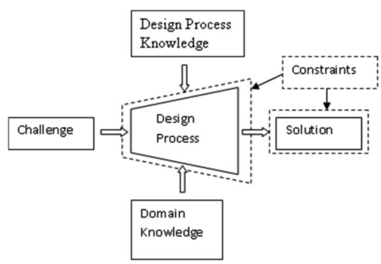

Figure 1. Design process overview

In order to provide a common language for the elements in the design process, a specific design process model has been adopted, Figure 2. This stage-gate process has a series of high-level stages wherein the design is successively refined, and intermediate gates where stakeholder feedback is obtained to control the overall direction and maximize the success of the project. The importance of proper documentation is emphasized, with design reports and formal presentations required at each gate. Documentation includes comprehensive engineering specifications, which evolve throughout the project as more information and feedback are obtained.

Experience has shown that all students, including those with significant industry experience, have a tendency to jump straight to a preferred solution [10]. Much of the effort in this course is therefore directed at forcing students to spend more time to more thoroughly understand the problem by introducing tools and techniques that promote abstraction [11]; including a clear need statement, a schematic block diagram, function structure diagrams, and culminating with clear and quantifiable specifications. Emphasis is also placed on distinguishing between customer requirements and engineering specifications, using the house of quality approach. This emphasis on problem understanding is meant to foster innovation in solutions, through a deeper understanding of what is required. This is complemented by a requirement that proposed solutions be conceptually different (based on a different physical principle) and that each proposed solution be equally feasible.

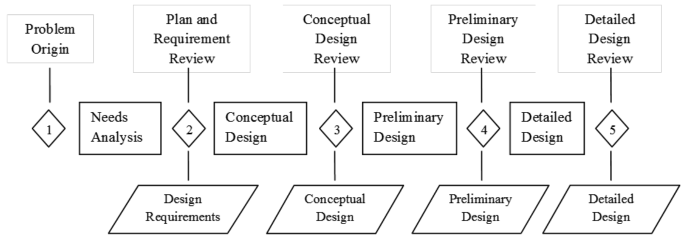

Figure 2. Stage-gate design process

In earlier versions of this course, a single case study was used to provide an overall introduction to the design approach and the appropriate nomenclature, and emphasis was placed on a class design project to reinforce design concepts and develop student skills. Class projects would typically be run over two-thirds of the course. Projects included a human-powered tricycle, a device to assist an artist who carved glass vases, and a house-integrated astrophotography observatory. In the most recent delivery, more cases were used to provide more experience with these design concepts, and to reinforce learning, before they were applied to a shortened class project, spanning about one-half of the course.

3.1 Use of Case Studies

A total of six case studies were used in this course: three were used to introduce and reinforce design concepts, two were used as quizzes to assess student understanding of the design method, and one was used as the design project. In addition, students were asked to complete a dissection project, wherein they were asked to dissect and develop design specifications for a simple mechanical object.

The first case study covered the design of a rainwater harvesting system for a village in India [12]. This case was developed in collaboration with Engineers Without Borders and includes data from which the household need can be defined, and data on available rainwater. This case was used in the first class to introduce the basic engineering approach and to emphasize the importance of simple engineering calculations to both define a problem and to verify the feasibility of potential solutions. Students worked in groups to develop a plan to solve this problem prior to the class discussion. This was used to draw out from students their own prior experience and initial understanding of the design process.

A second case study was used to amplify the various stages of the design process, from problem definition to the development of a physical prototype. This involved the design of a foot brace for long distance running, and was developed from a fourth year project completed by a student [13]. This case was used to reinforce the overall design process, emphasize the importance of thoroughly understanding and defining the problem, and the need to generate a wide range of potential solution concepts.

The third case study was used to reinforce problem definition aspects of the design process. This involved the design of an assistive device for carving glass vases for a local artist [14]. The shape and size of the vases are quite variable, and the challenge is to design a fixture which will support the weight of the piece without significantly impacting visibility or freedom of movement. This case was used as the major class design project in two previous versions of the course. It was used in this course as an illustration of a particularly challenging problem, and the need to effectively communicate with a client, someone who is not an engineer.

The general implementation method for these cases was for students to read the case individually and answer short questions to demonstrate some level of comprehension. Then they were given the opportunity to discuss the situation in class in small groups, followed by a class discussion [15].

Two cases were used as quizzes to assess the students' ability to define a problem and develop at least one feasible solution. In both cases, students were shown a short video and then given a hardcopy of the case. The first case, EPB Custom Cabinets [16], was given early in the term to assess their existing understanding of the design process. The results from this case were also used as one component of the assessment for design aptitude for admission into the design project courses required for the completion of the design certificate. The second case, Golf Club Cleaner [17], was administered toward the end of the term, but followed a similar format. An intermediate quiz had a conventional format and assessed students understanding of the design process and nomenclature.

To supplement this case work, students were assigned a dissection project at the end of the first half of the course. They were given a simple mechanical component, an automotive door latch, truck latch, or cordless electric screwdriver, and asked to dissect it, identify the overall system block diagram, and develop preliminary design specifications for a key sub-component. This was used to reinforce their understanding of the problem definition phase of the design process.

The final case study was the design of an automatic shifter mechanism for a sequential shift motorcycle transmission used for a Formula SAE racecar. The case outlined the general problem and gave specific requirements for shift effort, speed, and guidance on use scenarios. This included basic information on an existing system. The team leader and the drivetrain manager for the Formula SAE team acted as clients for this class project, by answering questions and participating in design reviews.

3.2 Observations

Nine students took this course in the fall of 2012. They completed weekly surveys of workload and short feedback – on what went well and what could use improvement – to allow for continuous improvement of the course delivery. In addition, a survey specific to the use of case studies was completed later in the term, after the start of the design project (FASE Shifter) but before the last quiz (Golf Club Cleaner). In general, students were very receptive to the use of real-life case studies. This is consistent with previous experience, although few of our previous course used cases so comprehensively. Students were particularly pleased with the opportunity to work in groups to dissect a mechanical component, not having had similar previous opportunities in their undergraduate career.

Figure 3 presents the range of answers to the following question for each of the five cases: "This case was an effective application of design methods". Eight of nine students completed the survey. Most students either agreed or strongly agreed with this statement for each case. One student disagreed with the statement, but this was a different student for each case. Students were also asked to elaborate on each response. Most students felt that the EWB case was at the right level – very straight-forward, and served as an effective introduction to the design process. The negative response preferred a more open-ended case. The foot-brace case was seen as an excellent real-world problem which helped introduce the function structure. The glass carving case was more challenging and no acceptable solution had yet been identified. However, some appreciated this challenge. The Custom Cabinet case was used only as a quiz and no class discussion took place. The FSAE Shifter design was used as the major design project and the students had just started the case when the survey was completed. They appreciated the real-world application and the interaction with the student team members. The negative response came from someone with less interest and experience in the automotive area.

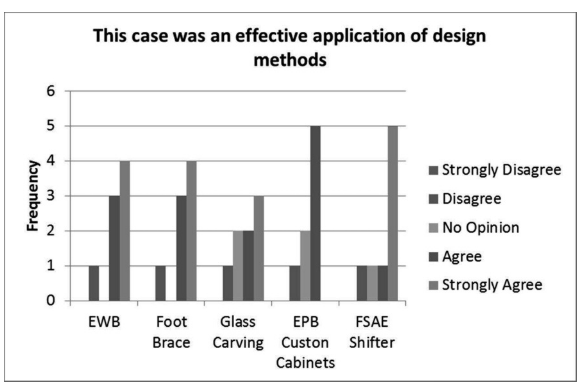

Figure 3. Student response to each of five cases

Figure 4 summarizes student responses to the value of small group and class discussions. They valued the class discussions more than the small group discussions. They appreciated the guidance provided during the class discussions. It is likely that the small group discussions would be improved if more time was provided, either in class or outside of class. The logistics of getting students together outside

of class was an issue. Some students were working full time and had a significant commute to campus, so arranging convenient meeting times was difficult.
Figure 5 summarizes the responses to questions relating cases to the course material. Most thought the cases were engaging, provided a better appreciation, and gave students a better understanding of the course material. The cases were interesting and quite diverse, each of which helped with student engagement and applying design methods in different contexts presented by each case study. The cases seemed to highlight a particular aspect of the course, from the importance of function structure to the need to consider all possible customers for a design. The use of cases made the student appreciate this more fully than a lecture example. Some mentioned the importance of doing more group work as opposed to the individual preparation. Several students appreciated the use of different cases to reinforce the same subject matter to help them improve understanding, especially for abstract concepts such as function structure. Although the use of cases is still a simulation of a real situation, some specifically mentioned the value of actually doing design for these cases to develop understanding.

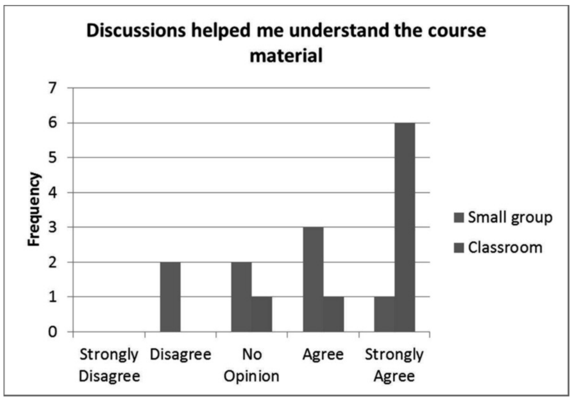

Figure 4. Student response to discussions

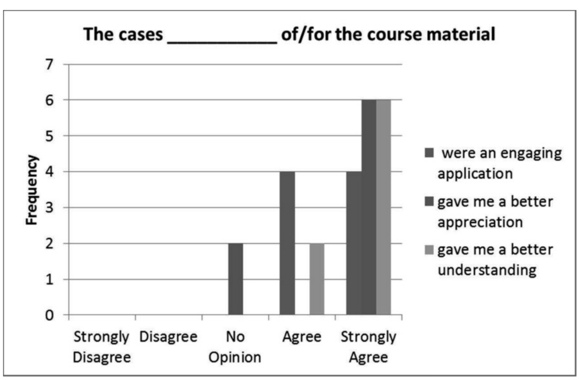

Figure 5. Student response to case relation to course material

4 DESIGN PROJECT COURSES

The design project courses are led by the second author, who has over 20 years of design project and management experience. Interested students formally apply, are interviewed, and must be accepted by both the faculty coordinator and the industry representatives prior to commencement of the project. Appropriate non-disclosure agreements and a design project agreement dealing with intellectual property are put into place. The first term is devoted to problem definition and culminates in a chosen conceptual design. The second term focuses on design development and verification.

5 DISCUSSION

The intensive use of case studies in the design methods course offered a significant improvement in student engagement and learning. They offered real-life applications of abstract concepts such as function structures and techniques for concept generation, which the students found engaging. This has been an equally informative learning experience for the course instructors, as this part of the needs analysis process is not trivial; fostering this learning is challenging. Students were particularly receptive to the class discussions, but more work is required to facilitate and improve small group discussions. This is a key part of the case method and was hampered by both difficulties in students getting together outside of class time, and insufficient time allotted during class time. It is expected that these small group discussions will improve the quality of the full class discussions – students were to apply the course concepts here, but were not sufficiently comfortable to get the most benefit.

A small subset of students in the recent design methods course continued to the design project course. They were found to be much better prepared for this course, especially in terms of their understanding of the stage-gate process and course expectations. This is likely a consequence of better preparation using cases and a more careful alignment of the terminology between courses.

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