Use of Cases in Teaching Engineering Design Workshop for Undergraduate Students

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ABSTRACT

This paper summarizes the findings of a recent experience in teaching open-ended design workshops for 3rd year undergraduate students in the Department of Mechanical and Mechatronics Engineering at the University of Waterloo. The paper reports the results of the use of design cases to teach students basic engineering design topics in order to prepare them for an end-of-term open-ended competition as well as their final year capstone project. Based on feedback gathered from students regarding the proposed method of instruction in this course, we identify several key points that can be investigated in the future to improve the learning outcomes when teaching similar open-ended engineering design courses.

Keywords: open-ended design, evaluation criteria, design workshop, case studies

I. INTRODUCTION

Engineering design is the set of decision-making processes and activities used to determine the form of an object which meets the functionality required by the end user [1]. In order to determine the best solution from among a set of feasible alternatives, the engineer(s) must first be able to recognize and develop each of these alternatives. To perform this task in an effective manner, engineers apply a procedure known as engineering design [2]. Many text books are available for teaching engineering design to undergraduate students [3]-[4]. Engineering design education is an integral part of the undergraduate curriculum in the Department of Mechanical and Mechatronics (MME) at the University of Waterloo. During the course of their undergraduate education, students are introduced to courses in introductory design, open-ended design workshops, and individual 4th year design projects. Of particular interest in this study is the open-ended design workshop course, ME 380, offered to MME students in the second semester of the 3rd year of the program. In this course, students study the design process, including needs analysis, problem definition; design criteria and critical parameter identification, generation of alternative solutions; conceptual design, detailed design, optimization; and implementation. Much of the student

effort in the course is devoted to a significant design project in which student groups work independently and competitively to meet a common design challenge while applying the design process. The design project typically includes construction of a prototype, and a significant part of the course grade depends on the performance of the prototype in a competitive test.

In recent years, the Department of Mechanical and Mechatronics Engineering has been investigating means to refresh the design modules of the undergraduate curriculum and introduce continuity in the design stream courses from one academic term to the next [5]. Several studies have indicated that teaching design through examples [6] and Engineering design cases [8-12] can result in an enhanced learning experience for students. In this environment of renewed interest in engineering design education, it was proposed that changes be made to several components of ME 380.

The purpose of this paper is to investigate the effectiveness of the use of a design case generated by the Waterloo Cases in Design Engineering (WCDE) group at the University of Waterloo (www.design.uwaterloo.ca) in teaching ME380.

The study described in this paper which utilizes the WCDE design case was conducted during the most recent offering of ME 380 in winter 2010. In this offering (referred to herein as *modified format*) engineering design topics are introduced to students through a set of modules that detail the WCDE design case from the need analysis to the final design implementation. The case used in this study involves redesign of a cabinet assembly fixture. A typical class would begin with a brief presentation by the instructor on the design topic and its implementation as a part of the WCDE engineering case. The presentation is usually followed by an exercise or quiz which asks students to analyze one or more aspects of the case as they relate to a specific engineering design topic discussed during the lecture, i.e., preliminary design or selection of alternatives. This strategy represents a major deviation from methodologies used in previous offerings of the same course (referred to herein as *original format*) where engineering design topics are covered in formal lectures presented by the course instructor, often with the aid of an engineering design textbook [1].

To analyze the impact of the use of modified format for teaching ME380, this paper targeted the following four major components of the course: (i) the methods of instruction of key engineering design concepts, (ii) the nature of the design challenge, (iii) the method of midterm feedback, and (iv) the types of student feedback on design skills acquired. Student feedback and instructor observations play key roles in assessing the effectiveness of the proposed teaching approach.

II. COMPARISON CRITERIA

The modified course format differed from the original format in four significant course components. In design terminology, these four major differences provide four comparison criteria that can be used to assess the effectiveness of the modification proposed herein in teaching ME380. In this section these differences or comparison criteria are presented in detail.

Method of Formal Instruction

A key component of ME 380 is formal instruction in the phases of engineering design methodology and central concepts of engineering design. These topics include problem formulation, generation of design alternatives, project planning, time management, and design evaluation. In the original course format these topics are covered in formal lectures presented by the course instructor. In the modified format these topics were illustrated through a set of in-class student exercises. A typical class would begin with a brief presentation by the instructor on the design topic and its implementation as a part of the WCDE engineering case. The presentation is usually followed by an exercise which asks the students to analyze one or more aspects of the case as they relate to a specific engineering design topic such as preliminary design or selection of alternatives.

The case covered in this course involves the redesign of a clamping fixture (Figure 1) used in assembly of kitchen cabinets [7]. The clamping fixture in Fig. 1 was developed and used by the E.P.B. Cabinetry owner who asked his son, a student in the Mechanical Engineering program at the University of Waterloo, to design, build and test a device that would address the opportunities for improvement that he envisioned to his existing clamping fixture.

During the case presentation segment of the class, the students are introduced to the requirements that must be satisfied to realize the improvements envisioned by the company owner. For instance, a “new” clamping fixture design should: (i) require less time to clamp each individual cabinet than the existing fixture, (ii) enable cabinets to be clamped in the vertical direction, (iii) supply an adequate clamping force at the dowel joints of each cabinet (this includes standard cabinets with two pressure locations as well as microwave cabinets which have a central horizontal divider, requiring three

pressure locations, and (iv) be stiff enough such that, under load, the deflection is not excessive. Other constraints and criteria that define the requirements of the new design are also presented during this part of the lecture. Furthermore, when a specific engineering design topic is being studied such as conceptual designs, students may be presented with the morphological box such as that in Fig. 2, which lists several possible options to design the various parts of the system based on the requirements and constraints introduced.

Figure 1: Clamping Fixture – courtesy of [7]

In the second part of the lecture, students are given a quiz or an exercise such as one that requires answering the following questions: (1) Using the above morphological box, create three conceptual designs that **MUST** satisfy all the design constraints discussed during the introduction part of the lecture, and (2) Using the various design criteria discussed during the lecture and a proper weighting values (that describe the importance of criteria relative to each other), evaluate the three conceptual designs you created in step 1 (against each other) and provide recommendations on which design should be selected for fabrication.

Depending upon the exercise, the students attempt the quizzes individually or in the project teams. Each exercise is designed to be completed in 15 to 20 minutes after which the student solutions were collected. Each class ends with a guided discussion and summary based on the students experience in the exercise. Student solutions to the exercises were graded and contributed 2-3% to the overall course grade.

Structure						
Vertical Motion	Rack	Threads	Ratchet	Mechanical Linkage	Pneumatic	Hydraulic
Vertical Lock	Ratchet	Screw	Linkage locks itself			
Horizontal Motion	Sliding Pad	Tower Moves	Rack	Threads	Pneumatic	Hydraulic
Horizontal Lock	Pressure	Screw	Linkage locks itself			
Clamping	Screw	Pneumatic	Hydraulic			

Fig.2: Design Case morphological box [7]

Nature of the Design Challenge

The major opportunity for student learning in ME 380 is provided through the design challenge which is undertaken by student teams, typically of four students. One significant consideration in the design of the challenge is to ensure that the workload required to adequately meet the challenge remains reasonable. It is often difficult to *a priori* estimate the expected workload because of variations in the students' understanding and application of project planning and time management, in the students' standards of success, and in the variation in specific skills such as machining and programming.

In the modified course format the design challenge introduced to the students addresses a "fictitious" need by the Waterloo Regional Fire Department to realize the goals of its 'Put-out-the-Candle' campaign. This campaign raises awareness for the risks of having unattended candles in the household. To meet the goals of this campaign, ME380 groups are required to design an autonomous mobile robot capable of navigating households and extinguishing lit candles. In specific terms, groups are required to design and implement a simplified, scaled down prototype of such a robot, which can then be used as a starting point for the design of a complete full-size prototype. The robot will be required to: (1) detect and extinguish tea candles, and (2) avoid static and dynamic obstacles within a predefined environment. The performance of each robot is evaluated on an obstacle course containing tea candles placed at unknown locations, static obstacles and one dynamic obstacle.

It is worth noting, that previous offerings of ME380 that used the original format involved a different end-of-term competition with a tightly defined design challenge. An example challenge under this format involves the design and optimization of a heat sink to dissipate 35 W at 60 C⁰. The design is constrained by limited choice of materials, formed shapes, and machining options. Designs are evaluated relatively upon size and weight criteria.

Midterm Feedback

As the formal instruction ends and student emphasis switches to the design challenge interim feedback is provided to the students. In the modified course format a mini-challenge was assigned and required to be completed in a one week period. The mini-challenge was designed to exercise students understanding of the design process learned through the introduction of the WCDE case in the classroom.

Type of Student Feedback

The in-class exercises associated with the WCDE case used in the modified format provide the opportunity to have students receive feedback for applied design understanding as shown in both individual and group submissions. In-class exercises were defined as individual or group at the time of presentation and this information was not known by the students before class.

III. BASIS OF EVALUATION

At the end of the course offering, students' feedback was solicited in a standard faculty questionnaire. The

analysis of the student response to the questionnaire provides the primary basis of evaluation for the present study. Observations on the design solutions presented for the design challenge are also used.

The evaluation questionnaire included questions about the difficulty of the concepts covered by the course, the work load, effectiveness of the tests, overall appraisal, and interest in the course through percentage attendance. For each question a five point rating scale is used. In most questions the ratings have an ordinal rank (i.e. from low to high). In a few questions the ratings are ranked about the neutral midpoint response. Table I shows the weightings used to score the student responses for both rating scales.

Rating	A	B	C	D	E
Ordinal Weighting	100	75	50	25	0
Neutral Weighting	25	50	100	50	25

Table 1: Weighting factors in percentages used for ordinal and neutral rating scales.

IV. RESULTS

For the offering studied in this paper, 54 out of 81 students (66.67%) participated in the evaluation. Scores for the student responses on the five questions analysed in the present work are shown in Table II. Figures 3 to 6 show the distribution of student responses for questions 1, 2, 3, and 4, respectively.

Characteristics of Course	A weighting extreme (100)	E weighting extreme (0)	N	Average Score
1. Rate the difficulty of concepts covered by the course.	Very easy	Very difficult	52	64
2. Rate the workload required to complete this course.	Very little	Very heavy	54	31
3. How well did the case quizzes reflect the course material?	Very closely	Not at all	47	55
4. What is your overall appraisal of this course?	Excellent	Poor	54	60
5. How many classes did you attend?	All classes	No classes	54	92

Table II: Summary of number of student responses, N, and weighted scores for the questions. Questions 1 and 2 were scored with the neutral weighting and all other questions were scored with the ordinal weighting.

Table II shows that the average students' score for the difficulty of the course concepts to be 64%. Figure 3 shows the corresponding distribution with 36% of the students rating the difficulty of the concepts to be in the middle of the evaluation spectrum, i.e., C rating. 15% of the students gave a B rating and 26% gave a D rating. The 11% difference between the B and D ratings is noteworthy given that the modified design challenge was more open-ended and therefore probably perceived to be more difficult by students. The method of formal

instruction that utilizes the WCDE engineering case, midterm feedback, and type of student feedback were all designed to focus student learning on the issues to be faced in the design challenge. For example, the in-class exercises exposed the students to open-ended problem solving, competition, and group and individual solutions. The midterm exercise provided a direct replication of the design challenge exercise. With this format, the average student response indicates that the difficulty of the concepts covered by the course falls between the C and D ratings. This is an acceptable result given that fact that ME380 is meant to prepare students for their 4th capstone design project.

Figure 3: Distribution of the responses to Question 1

From Table II, the average score for the course workload is 31%. As shown in Figure 4, 82% of the students indicated that the course workload was very heavy. It was observed that the changes made in the modified format, particularly those associated with the design challenge, resulted in a considerable increase to the amount of time students dedicated to the completion of the competition prototypes. Therefore, future offerings should address this issue and focus on revising the midterm and competition requirements to achieve a reasonable overall course workload.

As mentioned above, the course in-class exercises, and midterm problem, were designed to provide students with direct experience and learning in the design concepts required for successful completion of the design challenge. As shown in Table II, the student average score of how well the course quizzes reflected (or related to) the engineering design topics involved in the project is 55%. The distributions of the students' responses to this question are shown in Figure 5. 77% of the students' responses are in the A to C categories with 35% of the responses being C rating. This indicates that the majority of students rated in-class method of instruction as "Very closely" to "closely" relevant to the engineering skills required to successfully complete the given design challenge.

Figure 4: distribution of the response to question 2

The student perception of the overall effectiveness of the course are indicated in Question 4 and shown in Table II and Figure 6. 40% of students are in the “Excellent” to “Very Good” A/B rating and 35% are in the “Good” or C rating. It is also observed that a low fraction of responses is in the “Poorer” ratings. Future offerings will focus on identifying means to improve the methodology with which the engineering case is presented in class in order to further improve the overall average response to this question.

Figure 5: distribution of the response to question 3

Finally, for question 5 the weighted response indicates that the student who completed the questionnaire attended 92% of the lectures. Based on additional feedback from students, we realized that the high attendance is attributed to the type of student assessment and feedback used for in-class learning exercises. In particular, both individual and group exercises were assigned and graded. This encouraged greater percentages of students to attend all classes because some exercises used individual assessment unlike group exercises for which similar marks are given to the

collective group regardless of the number of members participating in the learning exercise.

A final measure of the effectiveness of the modified format for teaching design principles could be seen in the variety of solutions provided for the end-of-term design challenge. Twenty one original design prototypes completed the design competition successfully (100%) and had little, if any, resemblance to each other. This is clear proof that students in the modified format course truly learned design methodology and were able to successfully implement it to build a prototype capable of completing the challenge given.

Figure 6: distribution of the response to question 4

IV. DISCUSSION

In this paper, we examined the effectiveness of the use of case studies in teaching undergraduate students basic engineering design topics. Based on students’ response to Q3-Q5, we observed the potential effectiveness of the use of cases in teaching engineering design. The upcoming ME380 offering will need content revisions to reduce the overall course workload associated with the design and building of a prototype for the end of term competition. We also plan to outline a better plan to correlate the in-class learning offered by the WCDE engineering case to the course learning objectives associated with the prototype design. In future studies, we propose to run a comparison between stand-alone design initiatives vs. design exercises that extend to future courses in the Mechatronics curriculum.

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