A Workshop Course for Open-ended Engineering Design Problems

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ABSTRACT

This paper presents the main findings of recent experience in teaching open-ended design workshops for 3rd year undergraduate students at the Department of Mechanical and Mechatronics Engineering of the University of Waterloo. The paper offers several observations gathered from teaching this course two consecutive years with different classroom lecture format and project(s) scope/expectations. Based on a comparative study between the two offerings, we identify several strategies that contributed to a more enhanced learning experience during the modified course offering.
Keywords: open-ended design, evaluation criteria, design workshop

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 at the Department of Mechanical and Mechatronics (MME) of 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 major part of the course grade depends on the performance of the prototype in a competitive test. Other Mechanical Engineering faculty members, particularly those teaching 3rd year courses, are available to provide advice and supervision to ME 380 students.

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]. Furthermore, several studies by the MME Design Chair have indicated that teaching design through examples and case studies [6] can result in an enhanced learning experience for the 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 the present study is to investigate the effectiveness of the proposed changes. In Winter 2006, ME 380, was offered in its traditional or base format. In Winter 2007 changes were made to four major course components: **(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. Student feedback and instructor observations play key roles in assessing the effectiveness of each teaching approach.

II. COMPARSION CRITERIA

The modified course format differed from the base 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 two course formats. 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 base 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.

In the modified format a typical class would begin with a brief presentation by the instructor on the purpose of the exercise followed by the presentation of the exercise. For example, the following exercise was presented to illustrate generation of design alternatives:

> *You have three containers: an eight litre container, a five litre container, and a three litre container. The eight litre container is filled with water, while both the five and three litre containers are empty. Using only these three containers, is it possible to separate the eight litres into two four-litre parts? If so, what is the strategy for achieving this in the least number of steps? Describe how you go about solving this problem.*

Depending upon the exercise the students work on the exercise individually or in the project teams. Each exercise was 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 1% to the overall course grade.

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 three to 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 base course format the workload is kept to a reasonable level by setting a tightly defined design challenge. An example design challenge is the design and optimization of a heat sink to dissipate 35 W at 60 C^o. The design is constrained by limited choice of materials, formed shapes, and machining options. The completed designs are evaluated relatively upon size and weight criteria.

In the modified course format, the design challenge also used well defined evaluation criteria. However minimal constraints were provided. For the Winter 2007 offering, the challenge was to design a nut sorting mechanism capable of sorting 12 nuts of different materials and sizes into storage containers at predefined locations on a packaging platform. Each student team was provided with a standard parts kit including a wide variety of sensors, actuators, and PIC microcontrollers. Designs were evaluated on accuracy of sorting, speed of sorting, footprint of the mechanism, and effective use of sensors to implement a mechatronics-based solution.

Midterm Feedback

As the formal instruction ends and student emphasis switches to the design challenge interim feedback is provided to the students. In the base course format a closed book midterm examination is used to assess and provide feedback to the students on their understanding of topics and concepts covered in the formal instruction.

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 and to provide experience with the components in the standard parts kit.

Type of Student Feedback

In the base course format all the feedback to the students for applied design understanding and learning is given as group feedback. This feedback is provided on the preliminary design report, the design performance, and the final design report, all of which are group submissions.

The in-class exercises used in the modified format provided 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

The base format was offered in the Winter 2006 semester and the modified format was offered in the Winter 2007 semester. Both formats were given by the same instructor.

At the end of each 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, the usefulness of the assignments and quizzes, 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.

For the offering of the base format 46 out of 74 students participated in the evaluation and for the offering of the modified format 59 students out of 90 participated.

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

Characteristics of Course	A weighting extreme	E weighting extreme	N	Score
1. Rate the difficulty of the concepts covered by the course.	Very easy	Very difficult	**44**	**78**
			48	**72**
2. Rate the workload required to complete this course.	Very little	Very heavy	**44**	**69**
			50	**66**
3. To what extent did the assignments contribute to your better understanding of the concepts?	Helped very much	Totally useless	**32**	**49**
			36	**65**
4. How well did the tests reflect the course material?	Very closely	Not at all	**45**	**54**
			32	**63**
5. What is your overall appraisal of this course?	Excellent	Poor	**44**	**76**
			50	**80**
6. How many classes did you attend?	All classes	No classes	**44**	**96**
			50	**96**

Table II: Summary of number of student responses, N, and weighted scores for the questions. For each question the upper response and score is for the base course format and the lower response and score is for the modified course format. Questions 1 and 2 were scored with the neutral weighting and all other questions were scored with the ordinal weighting.

Scores for the student responses on the six questions analysed in the present work are shown in Table II. For each question, the upper score applies to the base course format and the lower score applies to the modified course format. Figures 1 to 4 show the distribution of student responses for questions 1, 3, 4, and 5, respectively.

Table II shows that the students scored the difficulty of the course concepts slightly lower for the modified course format than for the base format. Figure 1 shows that students taking the modified format course found the concepts easier with 18% of the respondents from the modified format course selecting “Very easy” compared to 12% of the respondents from the base format course making the same selection. These differences are noteworthy given that the modified design challenge was more open-ended and therefore probably perceived to be more difficult by students.

The modified method of formal instruction, 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 learning 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. Since the students perceived that course difficulty was lower in the modified format than in the base format it is reasonable to conclude that the learning exercises, and feedback mechanisms in the modified format are promoting student learning of design concepts.

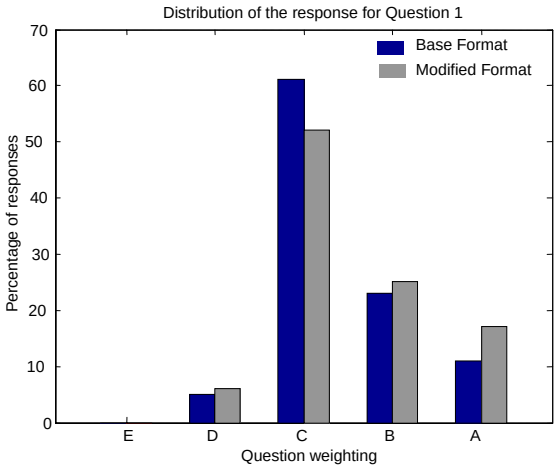

Figure 1: Distribution of the responses to Question 1

From Table II the student scores for the course workload were almost the same for the base and modified course formats. Hence, it is concluded that the format changes had little if any impact on the amount of time students dedicated to completion of the requirements for their other courses.

As mentioned above, the course assignments, the learning exercises and midterm design problem, were designed to provide students with direct experience and learning in the design concepts required for successful completion of the design challenge. The student scores for the usefulness of course assignments shown in Table II are noticeable higher (65 compared to 49) for the modified course format. The distributions of the student responses shown in Figure 2 indicate that the fraction of students rating assignments as “Very Helpful” almost doubled from the base format to the modified format.

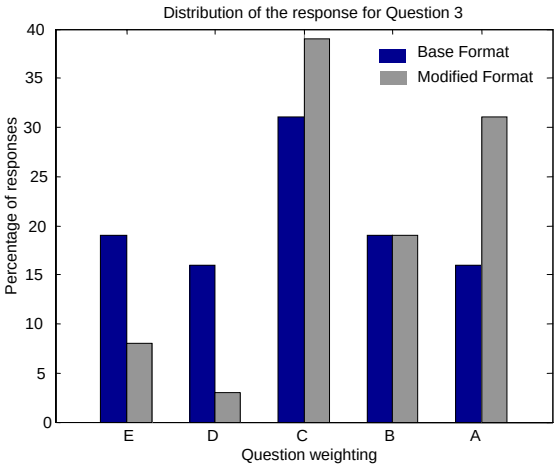

Figure 2: distribution of the response to question 3

The student rating of the degree to which tests reflected the course materials, shown in Table II and Figure 3, indicate trends similar to those evident in their responses to the assignment usefulness.

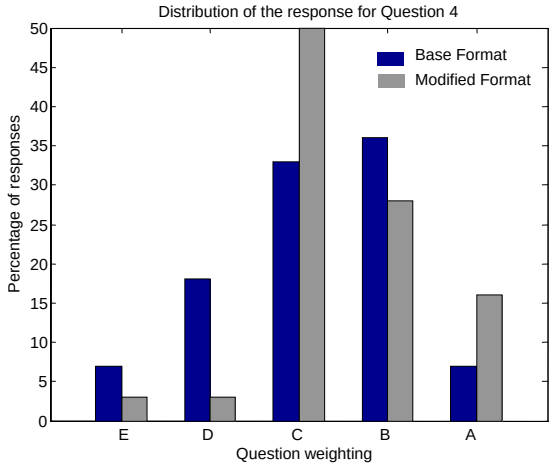

Figure 3: distribution of the response to question 4

The student perception of the overall effectiveness of the course as indicated in Question 5 and shown in Table II and Figure 4 was similar for both course formats and was relatively high. There are slight differences in the distributions of the student responses between the base format group and modified format group as shown in Figure 4. In particular, the student group from the modified format course gave a higher fraction of responses for the "Excellent" rating and a lower fraction of responses for the "Poorer" ratings.

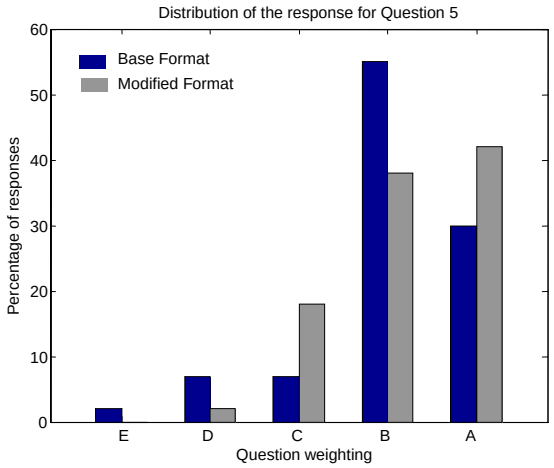

Figure 4: distribution of the response to question 5

Finally, for question 6 the weighted response indicates that the student who completed the questionnaire attended 96% of the classes for both offering, respectively. The percentage of the students that completed the questionnaire in the first offering is 62% compared to 55% in the second offering. 43% of the students who completed the questionnaire for the second course attended all workshop sessions compared to 30% in the first offering. Based on additional feedback from students, we realized that the 13% increase in this category is partially 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 design challenge. In the modified offering 23 original design prototypes completed the design competition successfully and had little, in any, resemblance to each other. This is clear proof that the students in the modified format course truly learned design methodology.

IV. CONCLUSION

In this paper, we presented a comparative study between two course formats for an undergraduate engineering design workshop. We identified several teaching strategies that contributed to the success of the modified course format. In future studies, we plan to examine the impact of longer duration design exercises and whether or not it enhances the student engagement into the workshop activities and if it maximizes the learning experience and engineering design material delivery. In specific terms, we plan 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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