Biosystems Engineering Design Trilogy: An Overview

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Abstract

In the fall of 1998, the Department of Biosystems Engineering at the University of Manitoba introduced a package of three courses to enhance the teaching of engineering design. The objective was to teach undergraduate engineers how to design by exposing them to the type of design environment they will encounter in industry. Fundamental to this environment is a real design problem provided by an industry collaborator. Consequently, our undergraduate students are now required to complete three, four-credit courses in consecutive years. In each course, the students work on an industry-based design problem in a team environment. For second-year students, the solution is conceptual. For third-year students, a detailed design must be produced. For fourth-year students, the detailed design must also include an economic analysis and an in-depth engineering analysis. Interaction between classes is achieved by requiring each student to contract his or her services to a design team from another year. Engineering communication skills (i.e., oral, written, and drawings) and practical fabrication skills are emphasized throughout all three courses. A high level of coordination between the three courses has been achieved, culminating in a joint presentation of the design projects at a formal technical meeting of the Canadian Society of Agricultural Engineering. This paper will discuss the details of this "Design Trilogy" including some of the modifications that have taken place over the past four years.

I. Introduction

Society expects that engineers should be able to design practical solutions to problems. Employers hire engineers with the expectation that they can design workable, affordable solutions to problems. It is the job of the university, therefore, to make sure that graduating engineers are capable of meeting these expectations.

A lack of appropriate design training in the engineering curriculum has been identified by several authors.[5,10,11] Design training may be inadequate if engineering students are not able to apply fundamental engineering principles to solve practical problems. This ability has been observed to be a weakness of engineering students.[4] Logically, this weakness may be due to an inadequate knowledge of fundamental engineering principles or an inadequate knowledge of the

design process. Of these two potential causes, it is likely that engineering students have an inadequate knowledge of the design process.

Various models of the design process have been presented in the literature.[1,3,6,8,9] Although the models are not all identical, the design process is typically considered to cover all of the steps from the initial stage of project planning through to manufacturing of the product (some models even include marketing as the final step in the design process). In a previous review of the Biosystems Engineering curriculum at The University of Manitoba, it was determined that students graduating from our program did not experience the entire design process. The purpose of this paper is to describe the trilogy of design courses that have been incorporated into the Biosystems Engineering curriculum to provide students with adequate knowledge of the design process.

II. Description of the Design Trilogy

Objectives

The objectives for the Design Trilogy are quite ambitious. The overall objective is to teach undergraduate Biosystems Engineering students the entire design process from formulation of the problem to fabrication of a prototype. Within this overall objective, the following specific objectives have been set: i) to strengthen team building skills; ii) to strengthen communication skills (all aspects); iii) to instill a sense of professionalism; and iv) to instill safety engineering principles. It is intended that students who complete the Design Trilogy will have a good understanding of the environment in which they will work after graduation.

Structure

Our intention was not to simply expose undergraduate students to a design environment. This could be achieved by encouraging participation in a co-operative education program. Rather, we intended to create an environment in which we could teach the design process within the context of real design problems. It was decided that three, thirteen-week semesters would be required to provide enough time for the students to fully absorb the experience. The fall term, four-credit courses are offered at the second, third, and fourth-year levels. During second year, students develop a conceptual design in response to a problem submitted by industry. During third year, students provide a detailed design (complete with engineering drawings and analysis) in response to a problem submitted by industry. Finally, in fourth year, students provide a final design (complete with an economic analysis and an in-depth engineering analysis) in response to a problem submitted by industry.

Using this model, more is expected from design teams according to their year of registration. With practice, the students should become more efficient at completing the preliminary stages of design. This is an example of mastery learning where students are able to repeat previously learned tasks so that they can learn from their shortcomings of the previous experience.[7] As a bonus, this model allows each undergraduate student to work on three different design projects within three different design teams during their engineering education.

The task of identifying suitable design projects from industry tends to be time-consuming and difficult. Likely, our experiences are not different from other educational institutions. To date, we have been able to identify design projects so that each design team, from each course, has a unique problem to solve. As much as possible, assignment of the design teams by the course instructors is based on student topic preference as indicated in a one-page written proposal.

Coordination between courses

To make the Design Trilogy work to its full potential, all three courses have been scheduled in the same time slot. Lectures are presented in class specific rooms, but the laboratories are held in a common "design lab" (Note: our design lab is simply a classroom with round tables for efficient group interaction). This scheduling allows coordination between the three courses. We have formalized this coordination through four activities; three of which allow the senior students to mentor the junior students. First, the students from all three classes participate in a fun design activity on the first day of classes. This serves as an "ice breaker" to help students get to know one another. Such early interaction will encourage student participation in the courses.[2] Second, joint brainstorming sessions are held (at least one design team from second, third, and fourth year) with a design team from fourth year responsible for facilitating the session. In addition, two oral presentations are made during joint sessions. This gives the second year students, who generally are quite nervous about making oral presentations, an opportunity to see the strategies and techniques used by their more-experienced senior classmates in their presentations.

The fourth activity allows each student to contract his or her services to a design team from another year. Following the first oral presentation, students indicate, in a one-page written proposal, the group to which they would like to contract their services. After contractee placements have been finalized by the course instructors (as much as possible based on student preference), it is the responsibility of each design team to contact their contractees outside of class time (by telephone, e-mail) and assign small tasks of less than 4 h duration. A formal contract between the design team and the contractee, outlining the tasks to be completed and the completion date, is submitted to the course instructor. The completion date specified in the contract will depend upon the tasks to be completed (i.e., literature review would be due early in the semester, preparation of CAD drawings would be due late in the semester). It is the responsibility of each contractee to submit both a short report and an invoice to the design team. The contractees are instructed to not spend more than 4 h on the assigned tasks. At the end of the semester, the course instructor grades the design team on the terms of the contract (i.e., was the task of appropriate duration, were the deliverables clearly indicated, was the required completion date clearly indicated) and the design team grades the contractee on the services rendered (i.e., was the report of acceptable quality, was the report received by the required completion date).

Design assignments

To enhance student learning, a number of design assignments are used to both guide, and provide feedback to, the design teams during the semester. The first such assignment is a written analysis of the brainstorming session. Upon completion of the joint brainstorming session, each

design team has a list of potential solutions. As a group, they must then evaluate the ideas on the list and select the one which is considered to be the best. If no idea is considered to be acceptable, another idea must be proposed. This analysis, in point form, is put in writing and submitted to the course instructor. This assignment forces the students to explain why they have chosen a specific idea to pursue.

The next design assignment is an oral presentation of the preliminary design based on the analysis of the brainstorming session. This informal presentation is made to all of the students enrolled in the design trilogy. It is modeled after a weekly project meeting that encourages an informal discussion and exchange of ideas. The students are encouraged to solicit advice from the audience during their presentation. Typically, this occurs approximately one month after the design teams have been formed.

Approximately one month prior to the date of the final oral presentations, each design team must submit a brief written report complete with one or more drawings to be reviewed by the Department's shop technician. This assignment serves several purposes. First, it gives the students an opportunity to communicate with a technician to get the perspective of someone who would be responsible for fabricating the prototype. Second, the critical feedback from the technician comes early enough that it can be incorporated into the final design. Finally, it ensures that each design team is making acceptable progress.

In many ways, the climax to the design project is the final oral presentation. To provide the students with a formal setting in which to present their design projects, the event has been organized as an official (regional) technical meeting of the Canadian Society of Agricultural Engineering. Members of the society are invited to attend. Usually, a couple of invited presentations by society members are added to the roster of design presentations to ensure that the event is not perceived as being strictly academic in nature.

A week after the oral presentations, the final written reports are due. The specific criteria differ for each of the courses, but the reports must include a description of the solution in both written and pictorial form. Each team member is required to submit a job log that indicates the time spent working on the design project.

The final design assignment is the team contribution assessment which is completed individually. Each student is required to assess the contribution by each team member (including themselves) to the design project. A written explanation is required. Using these peer evaluations, a peer evaluation rating is calculated for each student. The team project grade assigned by the instructor is adjusted according to the peer evaluation rating to determine the individual grade. Students who have put in extra effort will see their grade increase while poor performers will see their grade decrease. This mechanism is necessary to ensure that each team member is held accountable to his or her team and so that students will not get a "free ride." Furthermore, we feel that it is important that students have an opportunity to assess their peers because they will likely be required to make such assessments on the job.

Lecture material

Each of these courses has certain lecture material that is unique to that course. Some of the topics are common, but are presented from different perspectives in each of the three courses. For example, project planning is introduced as a concept in second year, studied in functional detail in third year, and then incorporated into the design project delivery in fourth year. The lecture material, which is described in the paragraphs below, is evaluated using traditional techniques.

Fundamentally, the second-year course is introductory in nature. The students are introduced to the profession of Biosystems (formerly Agricultural) Engineering. The students are also introduced to the philosophy of project planning, safety engineering, the profession of engineering, and the business of engineering. A major focus of the course, however, is the development of communication skills and team building skills. Students are instructed how to create effective visual aids and are given numerous opportunities to make brief oral presentations in class. The students are given some "hands-on" experience by completing a reverse engineering laboratory assignment. One group of students disassembles a "gadget" and prepares an assembly drawing of all the parts. Another group of students must then reassemble the gadget using the assembly drawing. This assignment reinforces the importance of non-verbal communication.

The third-year course offers opportunities for the students to practice their communication skills, but the main emphasis is on the topics of project planning, safety engineering, and human factors engineering. The lecture material discusses the nature of hazards associated with agricultural machinery and how to consider these hazards in the design process. The students obtain some "hands-on" experience through an assignment that requires them to design and construct a piece of safety shielding. Through laboratory assignments (i.e., collection and use of anthropometric data), the students gain a practical understanding of human factors engineering.

The fourth-year course emphasizes the financial side of engineering and engineering design. Lecture material covers information relating to owning and operating an engineering consulting company and estimating costs associated with design. The students are required to invoice their time spent on the design project. Other topics include quality control, the use of computer software for project management, and professional responsibilities related to design (i.e., ethics, liability). The importance of quality control and tolerances is demonstrated through a number of "hands-on" laboratory exercises in which the students must fabricate and assemble various physical items.

III. Reflections on the Design Trilogy

Student numbers

Since our first offering of the Design Trilogy in 1998, two groups of students ($\approx$ 15 students per group) have completed all three courses. Another 60 students have completed a portion of the

Design Trilogy (≈15 completed the second and third courses, ≈ 15 completed the first and second courses, ≈ 15 completed only the third course, and ≈ 15 completed only the first course).

Objectives

Based on our experience to date, we are confident that the specific objectives outlined above are being achieved. Although there have been some personality conflicts within design teams, the difficulties were not insurmountable. Ideally we would like to see no conflicts, but that goes against human nature. In terms of communication skills, the improvement in oral communication skills is most evident. With time and practice, the nervousness of second-year students is transformed into the composure of fourth-year students. The AutoCAD skills learned in first-year engineering (prior to the Design Trilogy) are also evident.

At this stage, it is difficult to know whether we have successfully instilled the principles of safety engineering. A survey of former students might be necessary to make this determination. Finally, the students seem to be learning a sense of professionalism. The peer evaluations are usually consistent which indicates that the students are making fair assessments of the work done by themselves and their team members.

Structure

Initially, it had been our desire that the students would be able to fabricate a prototype of their design in the fourth-year class. The experience of fabricating a prototype based on the design on paper would have provided valuable feedback to the students. Unfortunately, we do not have the financial, technical, or temporal resources to make this a reality. To give the students some experience in this area, the fourth-year students complete a series of "hands-on" laboratories where they fabricate components based on engineering drawings. During the last laboratory period, they must try to assemble all of the components to form a simple object (i.e., a lamp). Although the students do not get to fabricate a prototype related to their design project, these laboratory activities do ensure that all of the fourth-year students get a limited, and identical, amount of fabrication experience. Essentially, these activities attempt to provide insight into the skills required in the fabrication process.

As described above, our model for the Design Trilogy requires increased output from the students in each subsequent phase. We have experienced some difficulty getting the third-year class to understand what is expected of them. It seems that their natural tendency is to simply duplicate the purely conceptual solution that they completed as second-year students. By the time they are fourth-year students, they realize that both engineering and economic analyses are required. It is our challenge to get the third-year students to make this transition.

Finding a supply of design projects every year continues to be a time-consuming task. At present, this task falls on the course instructors. The Faculty of Engineering at The University of Manitoba is currently investigating the possibility of hiring a person to find design projects for the entire faculty. If this becomes a reality, it is likely that we will relinquish this task.

Coordination between courses

The coordination between courses has been improving each year that the Design Trilogy has been offered. It seems that we, as course instructors, have also been climbing the learning curve with respect to coordinating our courses. This past year, a significant break-through occurred when the procedure for contracting services was introduced to the Design Trilogy. It was observed, however, that many of the students were contracted to perform tasks such as proofreading the final draft or preparing an electronic presentation. Because these tasks had to be completed late in the semester, some problems arose when contractees decided to devote time to their own design team rather than fulfilling their contractual obligations. To overcome this problem, we will specify a date by which all contractual obligations must be fulfilled which is one week prior to the oral presentations. Design teams will be required to assign appropriate tasks based on this restriction. As we continue to climb the learning curve, we will continue to look for new means of coordination.

Design assignments

In general, the design assignments are serving their intended purposes. They provide feedback to the students throughout the semester and they help to ensure that continual progress is being made. As instructors, we have concern about both the final oral presentation and the final written report. We have found that it is difficult to provide effective feedback from the oral presentations. As course instructors, it is difficult to assess both the technical merits of the presentation and the communication strategies employed. Initially, we gave everyone full marks for the oral presentation at the start. We then deducted marks only for the obvious poor presentations. Last year, we had intended to videotape the presentations for later review with the students, but many of the students expressed serious concern. To alleviate this extra stress, we did not videotape the presentations. Consequently, we are still searching for an effective means of evaluating the oral presentations and providing useful feedback to the students. In general, it seems that the extensive practice making presentations is improving student confidence, but individual feedback would make a positive experience even better.

The issue of feedback is also a concern with the current structure for the written reports. Currently, the students submit their final written report during the last week of classes. Written feedback is provided to the students, but not before the semester has ended. It is likely that some students do not even read the comments. Even if they do read the comments, they are not going to spend time to make the changes because the course has been completed. Unfortunately, much of the feedback that we provide is likely to be forgotten before it can be applied. A potential solution to this problem is to require a draft to be submitted at least three weeks prior to the end of the semester. This would allow feedback from the course instructors to be incorporated in the final draft, but would decrease the time available to the design teams to work on their designs. A decision on this issue has not yet been made.

Lecture material

In general, there is a sense that we have the “right” lecture material included in each of the three courses. Of course, there are still improvements that can be made to individual lectures.

IV. Concluding remarks

Development of the Design Trilogy has been a frustrating, but rewarding experience. Many ideas have been tried. Some have worked; others have not worked. Fortunately, we feel that we are making progress toward the vision that we had when we started. In that sense, we are satisfied. In the future, we intend to use resources available through the University Teaching Service and the Engineering Design Program to collect data that will allow us to assess the impact on student learning that has occurred due to the Design Trilogy. That will be another interesting story.

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