Teaching Design to First-Year Chemical Engineering Students

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Abstract

Despite the evolution in the chemical engineering curricula, the first years of the curriculum are still primarily devoted to the basic sciences and the application of scientific principles to technological problems. The author describes how the Department of Chemical Engineering at McGill University accepted the challenge of introducing first-year students to design. An overview of the design component implemented in the Introduction to Chemical Engineering course is given. Key features include design objectives and methodology, design projects and assesment. The author identified a significant increase of students' enthusiasm about the course due to the application of their knowledge to "real" problems.

1. Introduction

Over the years, the capstone course has greatly evolved and in most universities involves projects based on "real" problems provided by companies. In the 1990s, various formats of first-year design courses also started to emerge in some universities. Building on its strong experience in the capstone design course, the Department of Chemical Engineering at McGill University decided to expose first-year students to open-ended design projects in order to provide them with some flavor of what engineers actually do, and at the same time enjoy a challenging experience where they could learn the basic elements of the design process.

Considering that first-year students with limited science and engineering background can derive reasonable engineering solutions, it was decided to implement a design project in one of the first year courses namely, Introduction to Chemical Engineering. This paper discusses the implementation of this new design component to the curriculum by presenting the methodology used, some case studies and feedback received from the students.

2. Course structure

Course objectives and content

The objective of the course Introduction to Chemical Engineering, in which the design component has been implemented, is to provide a general view of the nature of industrial chemical processing and to

develop skills in solving engineering problems using the law of conservation of mass and the first and second laws of thermodynamics.

The course content mainly covers engineering calculations, material balances, energy balances, phase equilibria and the 1st and 2nd Law of Thermodynamics (turbines, compressors, heat engines and refrigeration cycles). The introductory material and energy balances can easily be covered using simple design projects introducing basic design components. Figure 1 gives an overview of the concepts involved in the preliminary design project. The concepts in shaded boxes identify the ones covered in Introduction to Chemical Engineering. Important concepts such as the Law of conservation of mass and the First law of thermodynamics covered during the lectures are then applied to a "real" chemical process through the preliminary design project. The need for learning other concepts included later in the program is also demonstrated.

Figure 1. Concepts involved in the project

Design project goals

The preliminary design project is used to introduce concepts such as the steps involved in process design, the integration of sciences and engineering in solving problems and some common equipment used in chemical processes. Introducing design concepts early in a student's education is believed to motivate and excite them, and promote teamwork. By implementing this first-year design project, we aim at reaching the five goals of early exposure to design identified by Sauer [1]:

1. Expand student's knowledge of various areas of endeavour available to chemical engineers
2. Develop student's understanding of how basic science and mathematics interface with engineering
3. Increase student's awareness of the chemical engineering curriculum and core competencies
4. Develop, extend, and improve the written and oral communication and teaming skills of the students
5. Present the students with a realistic view of practicing chemical engineering

Methodology for teaching design

Although it is not the objective through that design component to teach the engineering design process, the students are introduced to basic stages of a design process. These stages are:

1. Idea generation
2. Conceptual design
3. Detailed design
4. Prototyping
5. Refinement and ramp-up

Considering the limited background of first-year students, we focus heavily on conceptual design and limit the discussion mainly to the first two stages of a design process. Engineering design is thus introduced as a thoughtful systematic process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function must achieve a specified set of constraints and objectives.

Based on the limitation previously mentioned, the preliminary design consists primarily of a proposed flow sheet, a selection of the types of equipment for the main unit operation and the identification of means of transportation of material from one unit to another. The latter also includes a detailed material and energy balance on each unit and on the overall process designed.

To facilitate the preparation of the final report and provide more feedback to the students during the design process, students are asked to provide staged deliverables. As described in Table 1, PART I is mainly a design proposal and PART II is the preliminary design report. PART I is an opportunity to redirect teams that have veered off-track.

Table 1. Report content

PART I – Design proposal (≈ 2 pages)
○ Clear and concise description of the process proposed
○ Flowchart representing the unit, the streams, the known and unknown variables
PART II – Preliminary design report (≈ 15 pages)
○ Clear and concise description of the designed process
○ Brief description of the selected equipment for the main unit operations (how it works, drawbacks, etc)
○ Flowchart representing the units, the streams, and all independent values needed to have a completely specified system
○ Presentation of the material and energy balances on the overall system and on each individual unit

3. Case studies

A major challenge faced in the implementation of a design project in the first-year of the curriculum is the selection of processes appropriate for that level. The concepts involved must be familiar to the students from their personal experiences and the material previously covered in the course. The projects proposed to the students differ markedly to the capstone design courses in their tendency to focus more heavily on conceptual design methods and less on detailed design because first-year students can do reasonable conceptual design without the detailed technical knowledge they acquire later in the curriculum. The following paragraphs give a brief overview of simplified case studies in which students worked in groups of four members.

Production of concentrated Apple Juice

Mandate: Design a process to produce 30L of concentrated apple juice.

Raw material: To prepare the juice you dispose of McIntosh apples having a concentration of 80% water, 10% solids, the remaining being aroma substances.

Product specifications: The concentration of the final product must be 55% water, the remaining being aroma substances. Before being bottled, the juice must be pasteurized at 75°C.

Hypothesis:

- Aroma substances are considered as one species
- Only 70% of the water and aroma substances can be extracted from the apple
- Raw material is stored at room temperature
- Heat capacities given are constant over the temperature range

Production of paint pigment

Mandate: Design a process to treat 100lb/h of wet paint pigment following given product specifications.

Raw material: The wet pigment is at 80°C and contains 50%wt water. The size distribution analysis indicates that 10% dry wt of particles have a diameter greater than 300 nm.

Product specifications: The dry pigment produced must be at a temperature of 20°C, contain 1%wt water and no particles having a diameter greater than 300 nm.

Hypothesis:

- The boiling point of the pigment is 2,500°C
- Heat capacities given are constant over the temperature range

Production of beer

Mandate: Design a process to produce 10L of an apple tasting beer.

Raw material: Premixed ingredients: Barley Malt, Hops and yeast (considered as 80% glucose and 20% other constituents), water from a natural spring stored at 25°C and apple concentrated juice stored at 8°C are used to produce the beer.

Product specifications: The final product contains 1% of apple juice.

Hypothesis:

- The fermentation starts after the addition of 8 liters of water per kilogram of premixed ingredients
- During the fermentation process, 60% of the glucose is transformed to ethanol and 227 kcal/mole glucose transformed is released
- The temperature must be kept constant at 18°C
- Apple juice is considered as one species
- Heat capacities given are constant over the temperature range

The preliminary design of these processes require that the students answer questions such as: “How much product do we produce per hour?”; “How much cooling water do we need to keep the temperature constant?”; “How much raw material do we need?”; “How can we process the material?”.

To answer the first three questions, the students have to apply the laws of conservation of mass and energy they learned during the lectures. To answer the last question and select equipment and means of transportation, students have to find information in the literature. They first have to discover ways to obtain information, visit the library, read books and find information over the Internet. They also have to brainstorm and think critically in order to select what seems to be the best alternative based on their limited knowledge and the information obtained. Most importantly, probably for the first time in their student career, they have to learn how to deal with uncertainties.

4. Assessment

Evaluation of the preliminary design

The traditional evaluation setting is well known: the instructor set the requirements, acceptable solutions, deliverables and due dates and feedback is given to students when the project has been submitted. Considering the open-ended aspect of the project and the limited experience of students in working on such problem, it had been decided to use staged deliverables, as described previously and to provide feedback to each team after the first part is submitted. PART I was thus used only to provide feedback and put the students back on track.

PART II was evaluated and a mark was attributed to the team. This numerical mark carried a 6% weight towards the final grade. As expected, the evaluation of the preliminary design report required more effort than the evaluation of traditional assignments and exams; the main reason being that in design, there may be many possible answers, without a clearly superior one.

Student's point of view

As many design teachers pointed out, students can be frustrated and emotional during the design process. This observation is even more significant for first year students having limited sciences and engineering background. An emotional and frustrating experience through a course usually results in a negative impact on instructors and course evaluations [2].

In order to analyse the evaluation results, taking into account that possible bias of the students, the author decided to do a comparative analysis of the results obtained (Fall 2005) with those obtained the previous year taught without the design approach (Fall 2004). Some interesting results, presented in Figure 2 and Table 2 are briefly discussed here.

As shown in Figure 2, the change of level of enthusiasm of students over the course has been evaluated for each year. The graph clearly indicates that using the conventional lecture approach (Fall 2004), the level of enthusiasm decreased significantly over the course period even though it stayed constant at the departmental level. With the implementation of the design component (Fall 2005), the level of enthusiasm significantly increased throughout the course; from 3.5 to 3.8 while the overall departmental level decreased slightly.

Figure 2. Level of enthusiasm of students

With the implementation of the design component, the role of the instructor changed from lecturer to mentor and coach as described by Burton and White [3]. This teaching approach is more demanding than the lecture courses for the instructor. However, that change had a very positive impact on the quality of the relationship between the instructor and the students. As shown in Table 2, the evaluation at the Faculty level remained constant over the two semesters, while the quality of the relationship significantly increased for the course Introduction to Chemical Engineering taught by the same instructor in both semesters. This change might have a positive impact on retention of students.

Table 2. Quality of the relationship

Item	CHEE200 (Avg Chem Eng)
Relationship between the instructor and the class	
Fall 2005 + design component	4.5 (4.1/5)
Fall 2004	4.2 (4.1/5)

An evaluation specific to the design project was also done in order to get feedback on the implementation of a design component in the first-year of the program. Although some negative comments were formulated, such as the first four mentioned below, most of the comments were very encouraging:

“One of the drawbacks of the project was that it added pressure and deadlines to comply with.”

“The design project should weigh more considering the amount of time we spent on it and how much we learned.”

“Four person groups seemed to me like a bit of overkill - two or three person groups might have been better suited.”

“Considering that the project was a little vague, at times I found I was confused as to what was required of us.”

“Most of us in our first year of chemical engineering have very little idea of what chemical engineering is actually all about. This was a great chance for us to learn a bit about the sorts of equipment we might use in the future, their pros and cons, and their various implementations, as well as a chance to see how well our minds were suited to developing a process (particularly important early on in the chem eng program, to ensure we're in the right type of engineering, or even the right faculty at McGill!).”

“Being able to work through a larger, somewhat realistic problem really helped me in making sure I completely understood all the fundamentals of the course.”

“The design component allowed us to see and examine the practical applications of what we were learning.”

“Giving us a little taste of where we are headed from the beginning, is very useful to us in making the decision of whether or not we want to stay in chemeng-early on.”

“It was a little more work but definitely worth it when you saw the whole thing come together. It gave us an opportunity to apply some of the knowledge we obtained in class to a real life situation. The project also gave us some idea of what a chemical engineer does in one part of the work field.”

“It encouraged team working and helped me get to know more people from my class.”

“It was a good revision of all our energy and mass balances and gave us an idea of how what we learned would be used in our careers. It also provided me an opportunity to learn how to write a good report.”

“At first, it seemed to be quite a large task given that we had never done something of this genre before. As the project came along, it did not seem to be so difficult as we were able to connect the work done in class with tasks of this project.”

“Personally, this project actually made the course much more interesting as it allowed me to get a real sense of

chemical engineers work. I think it's a good thing to have for students in their first year in order to give them an idea of what is lying ahead."

"I liked that we were given a chance to see some potential creative applications of Chem Eng at such an early stage."

5. Discussion

Based on that first experience in teaching design to first-year students, the methodology used to introduce the design component needs some adjustments. The most important aspect which needs to be revisited is the supervision of the students. Even though a large amount of time had been invested by the instructor to supervise and give feedback to the 25 groups of students, a more systematic approach to provide students with regular supervision and feedback must be defined (one instructor might not be enough!). This would give a greater payback in terms of learning and overall satisfaction with the design component of the course.

To hold students interest and motivation, the actual portfolio of interesting and feasible case studies must be extended in order to change the projects from one year to another. This aspect is quite challenging considering the limited engineering background of the students. It would also be interesting to have an integrated approach throughout the curriculum [4]. That would require the adoption and use of the same cases studies at different levels of detail throughout the curriculum. As in several academic institutions, efforts should also be made to integrate a social dimension in the selected design projects [5].

Although the design component still has to be optimized, it seems that the students benefited from the experience. The implementation of the design component in the first-year course Introduction to Chemical Engineering provided a better overview to students of what chemical engineering is. Students have been introduced to a design process, improved their teamwork and communication skills and enjoyed the challenging and rewarding experience of completing a preliminary design of a chemical process. They now have a better idea of what is lying ahead.

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7. References

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