A First-Year Course as a Foundation for Engineering Education

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Abstract: *First-year students interested in studying an engineering discipline need an introduction to that discipline that is both broad and meaningful. Most do not have sufficient information about the discipline to finalize their choice of major. Also, those who remain in the major lack an overall view of the discipline and fail to recognize connections between subsequent topics studied. These deficits can be overcome through the use of a first-year course in which the students do meaningful introductory work in a broad assortment of topics organized to provide an integrated view of the discipline.*

An introductory chemical engineering course is described as an example of the first-year course suggested above. The course is structured around an engineering design problem which can be solved by designing a simple chemical process. The students participate in solving the problem which involves a combination of topics and applications representative of chemical engineering, and the entire semester is dedicated to the design of that process. The design problem is environmentally oriented, thus helping the students relate to its societal importance, and the many societal benefits of the chemical industry are also discussed. As each new topic is studied, a new feature of the process design is developed and the process flow chart is expanded accordingly, thus providing an integrated view of the topics. As the students are introduced to and required to use fundamental principles and equations (e.g. Fick's Law, Fourier's Law, etc.) at an introductory level, they experience chemical engineering reasoning, calculations, decisions, and applications, including some open-ended problems. The level of material is designed to challenge the students in order to stimulate interest and provide them with a sense of the rigor of the chemical engineering curriculum. The course has received very positive evaluations from the students, even from students who subsequently select other majors after reflecting on their experience in this course. Also, course graduates are perceived to be better prepared for their more advanced chemical engineering courses. Further, course graduates have a more integrative view of the field and are better able to learn each advanced topic from the perspective of connections to other subjects and to the field as a whole. The benefits are judged to be well worth the relatively-limited resources expended for this 2-credit course.

Introduction

We propose a course which will provide to engineering curricula some of the same features as a well-designed lecture. Suppose that our goal for a particular class period was to teach the students about a complex subject consisting of many parts. We most likely would not begin by first describing each component in detail, one-by-one, until all the parts had been described. Instead, we would first provide an <u>overview</u> describing the topic as a whole and introducing the component parts in relation to the whole subject and to each other. This introduction would provide a <u>foundation</u> for our subsequent descriptions of the individual parts.

Yet, most engineering curricula begin by jumping right in to the study of specific topics, without an overview at the beginning to provide a foundation for those topics. First-year students unsure about their choice of major have only their brief exposure to the first topic (or two) to help them understand what the discipline is about before finalizing their decision about their major, and those first few courses often provide an inadequate, if not distorted, picture of the discipline. Further, students who choose to stay in the major continue to form their understanding slowly, semester-by-semester. Without a broad perspective as a scaffold, they often see each topic as a new subject, unrelated to knowledge previously acquired. In most cases, the students obtain their first glimpse of the discipline as a whole in a capstone course at the end of the curriculum, but many opportunities for connection and integration are lost in the years before that course is taken.

An introductory course at the beginning of an engineering discipline can provide the same kind of overview and foundation as provided at the beginning of a good lecture. In such a first-year course, the students do introductory work in a broad assortment of topics organized to provide an integrated view of the discipline. The work must be sufficiently rigorous to provide to the students a meaningful indication of the nature of the major and of the discipline, so that the students can evaluate their interest and aptitude for the field. The integration can be achieved by configuring the material around a project which encompasses all of the material of the course and which proceeds from a typical conception of a project to a meaningful conclusion. Furthermore, this approach is well suited to introducing open-ended problems, creative thinking, and team interaction, along with the technical principles of a discipline. Finally, this introductory experience can be provided to first-year students without expending significant resources, for example through a single one-semester, 2-credit hour course.

In this presentation, we describe a first-year introductory course in chemical engineering to illustrate the feasibility and value of the approach described above. The 1-semester, 2-credit hour course was first taught 5 years ago and has continued to evolve and improve, and the material for the course has now been published in textbook form [1]. While the description of the course specifically refers to chemical engineering, the same approach can be adapted to other engineering disciplines as well.

Goals for the Course

A discipline-specific course for first-year students to meet the objectives described above could have a number of specific goals, including the following:

1. Acquaint the student with the particular engineering discipline, both from information and participation.
2. Provide an integrated overview of the engineering discipline as a foundation for subsequent courses.
3. Teach significant engineering principles, including:
   - •fundamental concepts and quantitative relationships
   - •connections to the students' past experiences
   - •typical discipline-specific calculations and analyses
   - •open-ended, multi-solution design problems
4. Promote interaction between first-year students and the department faculty.
5. Promote interaction among first-year students to develop a "community" of students in the major.
6. Avoid adding significantly to the degree requirements and to faculty loading.

Acquaint the Students with the Discipline

A major recommendation of this presentation is that we give students a broad introduction to the discipline at the beginning of their studies. The introduction should include not only technical issues but also societal aspects (such as the impact of the discipline on their lives and the connection between the discipline and their "everyday" experiences). One purpose of this introduction is to help students evaluate their interest and aptitude for the discipline and to finalize their decision about whether to choose that field for their major study; a wise match between the student and his/her major increases the effectiveness of the student's subsequent education. A second purpose for teaching first-year students about the discipline is to generate interest and motivation among students, which increases learning. A third advantage is that it equips students to begin recognizing applications of the discipline in their experiences in other classes and also outside of campus, which provides invaluable enrichment to their education. Finally, learning about the discipline contributes to the foundation discussed later in this paper.

To accomplish the objectives just described, the introduction of first-year students to the engineering discipline must be more than superficial. This includes helping the students understand the topics and activities with which the discipline deals, including the reasoning, calculations, decisions, and applications of the discipline. Not only should the students hear about those issues, but it is important that they have personal experiences as they perform those operations themselves. These experiences should include an introduction to some of the fundamental principles and equations of the field. For example, in the introductory chemical engineering course which we developed, the students learn about and practice using the laws of conservation (mass and energy), Fick's Law of molecular diffusion, Fourier's Law of heat convection, reaction rate equations, etc. The students should be given the opportunity to evaluate and draw conclusions from numerical results as would be typically done by an engineer. They should also be exposed to "design" problems which are open-ended and have multiple solutions. For example, students in our introductory chemical engineering course generate and evaluate various solutions to an environmental problem posed in general terms. In all of the above, the material should challenge the students in order to stimulate their interest and provide them with a sense of the rigor of the specific engineering curriculum.

Provide an Integrated Foundation

This introductory course should play a significant positive role as part of the undergraduate curriculum by providing a foundation and perspective for subsequent classes. Before the development of our introductory chemical engineering course, it was our observation that sophomores, juniors, and even seniors seemed to view each course in their program as an isolated entity, unrelated to the other subjects they have studied. Instead of building on the perspective forged by past learning, the students often seemed to be starting over with each new subject. Hence, students frequently failed to catch a glimpse of the discipline as a whole until very late in the program, if at all. Therefore, a key objective of our introductory course was to provide an integrated overview that would offer a broad perspective and serve as a framework upon which subsequent courses could build. That objective included helping the student understand where subsequent courses fit within the larger perspective and also how knowledge obtained from other disciplines (e.g. chemistry, math, physics, economics, etc.) is essential. In a figurative sense, the introductory course was to build the "skeleton" by broad shallow coverage of the discipline, and later courses would add the "meat" to that skeleton

To provide the foundation for later courses, the introductory course should expose the students to the same topics they will see in the later courses. The exposure will, of necessity, be at a low level appropriate for first-year students and should require few prerequisites. Further, the individual course topics should be connected together in a logical fashion. This connection can be accomplished by structuring the course around an *engineering design problem*. In the case of our introductory chemical engineering course, the design problem was one which could be solved by designing a simple chemical process. Whatever the discipline, integration of the topics can be achieved if the entire semester and all the material presented in the course are dedicated to that one design problem. In this way, the students can see how the topics fit within the greater whole of the discipline. They can also be helped to recognize how the various seemingly-separate topics are based on common principles. To illustrate the use of the semester-long design problem, we will describe the strategy used in our introductory chemical engineering course.

Example: The Design Problem in the Introductory Chemical Engineering Course

The problem-oriented scenario begins the first day of the class where the students are asked to imagine that "you are a chemical engineer working for the ABC Chemical Company." The student engineer receives a memo from his/her supervisor reporting that the contractor which has been disposing of the hydrochloric acid byproduct from "our" manufacturing process is going out of business. The memo goes on to ask the student to take responsibility for solving this problem, and the remainder of the course is directed at leading the student to that solution. The problem is environmentally oriented, thus helping the students relate to its importance. It also involves very simple chemistry to which essentially all of our students have been exposed. Most importantly, this design problem provides the framework for integration of the material presented throughout the semester.

The general topics presented in the course are shown in Figure 1. This two-credit course is designed to be taught in fourteen weeks, which is the length of a semester at BYU. The approximate amount of time dedicated to each topic is also indicated on Figure 1 by the length of the segment to which the topic title is attached. Written material developed for each of these topics has recently been combined into a textbook[1], with each topic forming a separate chapter.

The topics are introduced on a "just-in-time" basis as the solution to the design problem is developed throughout the semester. For example, after discussing strategies for generating and evaluating possible solutions, the decision is made to design a chemical process in which sodium hydroxide is used to neutralize the hydrochloric acid. Material balances are then taught in order to determine how much sodium hydroxide is needed. Computer spreadsheets are also introduced as an engineering tool. The students are then taught simple fluid mechanics to provide the basis for delivery of the sodium hydroxide and hydrochloric acid from the storage facilities to the point of reaction. This approach continues as issues are considered regarding mixing the acid and hydroxide (mass transfer is taught), the volume of reactor needed (reaction engineering is introduced), and cooling the final product to an acceptable temperature for disposal (energy balances and heat transfer are studied). The final step is an evaluation of the profitability of the proposed process (economics are introduced). By the end of the semester, students have developed preliminary skills in a number of the sub-disciplines which make up chemical engineering and have applied them toward the solution of an engineering design problem. These skills represent a useful subset of those which they will learn in later chemical engineering courses.

Process flow diagrams are used throughout the course to help the students visualize how the different aspects of the course and design problem are connected. Students are introduced to these diagrams and required to use them very early in the semester. Then, as each new topic is introduced and used to design an additional component of the "process," the process flow diagram and stream table are updated to reflect the new addition and its relationship to the previous components of the process.

Other Features of an Introductory Course

To reinforce the principles taught using the design problem throughout the semester, the students can be assigned at the end of the semester to solve a similar case study in student teams. In our introductory chemical engineering course, this case study requires the use of material and energy balances, the sizing of a pump, reactor, and some heat exchangers, the preparation of a process flow diagram, and the completion of an elementary economic analysis. It is introduced near the end of the semester and provides the students with an opportunity to work together, learn from each other, and apply nearly all of the concepts and principles that they have learned throughout the semester. Team dynamics and organizational skills are also taught in conjunction with the project. Students are periodically required to inform their "supervisor" in writing concerning the progress made, and a final design report is required from each team.

The use of a case study near the end of the semester also fits well with the need to present a few topics in a cursory manner. With some of the engineering subjects to be introduced to the first-year students, the introduction will, of necessity, be brief and qualitative. In our introductory chemical engineering course, such topics include process control, engineering materials, and economics. That material can be presented in class (with minimal homework assigned) during the weeks that the students are working on the case study assignment, thus giving them time to focus on the case study.

The first-year course should be designed so that the concepts taught are reinforced in subsequent courses. The nomenclature, terminology, and approach used in this course should match, as much as possible, those used in later courses. Thus, the students taking those later courses will recognize the material as it is repeated and then extended. Even more, the first-year course should provide an overview showing how the various topic areas all contribute to the whole. Thus, students will approach the later study of each individual topic with the ability to recognize those relationships anew. That recognition will not only aid in the further understanding of the topic but will also help to combat the tendency toward compartmentalization.

An introductory course is also a valuable social aid for first-year students, who need close interaction with the department faculty and with each other. While some student-faculty interaction is facilitated by department socials, required meetings with advisors, etc., we have found that our introductory course provides many more faculty-student contact hours than any other method. Importantly, an introductory course can also help to promote interactions among students and to develop a "community" of students in the same major. The use of learning teams and group activities within the course enhances that "community" even further.

There are significant reasons to minimize the credit hours and faculty resources associated with a first-year introductory class. A new course usually cannot simply be added to a curriculum; curricula tend to be overflowing already, and we were being encouraged to decrease the number of credit hours in order to help students graduate more quickly. Thus, inserting an introductory course may mean reducing the credit hours of more advanced courses, and some faculty will question the value of such a trade. In addition, many beginning students in engineering do not continue after their first year, and an introductory course would dedicate resources to teaching students who will not graduate in the discipline. Further, in most fields, the course which would meet the goals described here would need to be developed, since a suitable text will not be available, thus adding to the required resources. To meet those goals, our introductory chemical engineering course was designed as a two-credit hour one-semester course without a laboratory.

Results and Conclusions

We have now taught our introductory chemical engineering course for five years, and the results have been very positive. Student-generated evaluations for this course are among the highest of all courses in the department. Student comments from questionnaires and during informal conversations indicate that students feel they have a much better understanding of and appreciation for chemical engineering after having taken the course. In some cases, that knowledge has resulted in students changing majors to something other than chemical engineering; that decision is judged to be positive if made with adequate knowledge and experience. Overall, the course appears to have increased slightly the retention of students in the chemical engineering program, but our results are inconclusive, as described elsewhere [2]. Importantly, students and faculty have expressed their opinions that the introductory course helps to prepare students for future courses, particularly the course on material and energy balances taken by our second-year students. We also believe that the course has served to help build relationships among our students and between our students and faculty. Finally, in spite of the broad variety of topics covered in the course, survey data indicate that the hours spent by the students on this course are in good agreement with university guidelines for a 2-credit hour course [2].

This approach of a discipline-specific introductory course can be applied in various situations. Universities with no freshman engineering course may consider adding courses like the one described here. Schools with an existing general (not discipline-specific) freshman engineering course might consider replacing it with discipline-specific courses for students who already have significant interest in a particular engineering field or might consider incorporating blocks of this kind of discipline-specific material for several disciplines into the existing general course. Where this is not possible, the discipline-specific courses might be offered to second-year students in the various engineering departments. In addition, two-year colleges might use these kinds of introductory engineering courses to prepare their students for transferring to four-year engineering programs.

References

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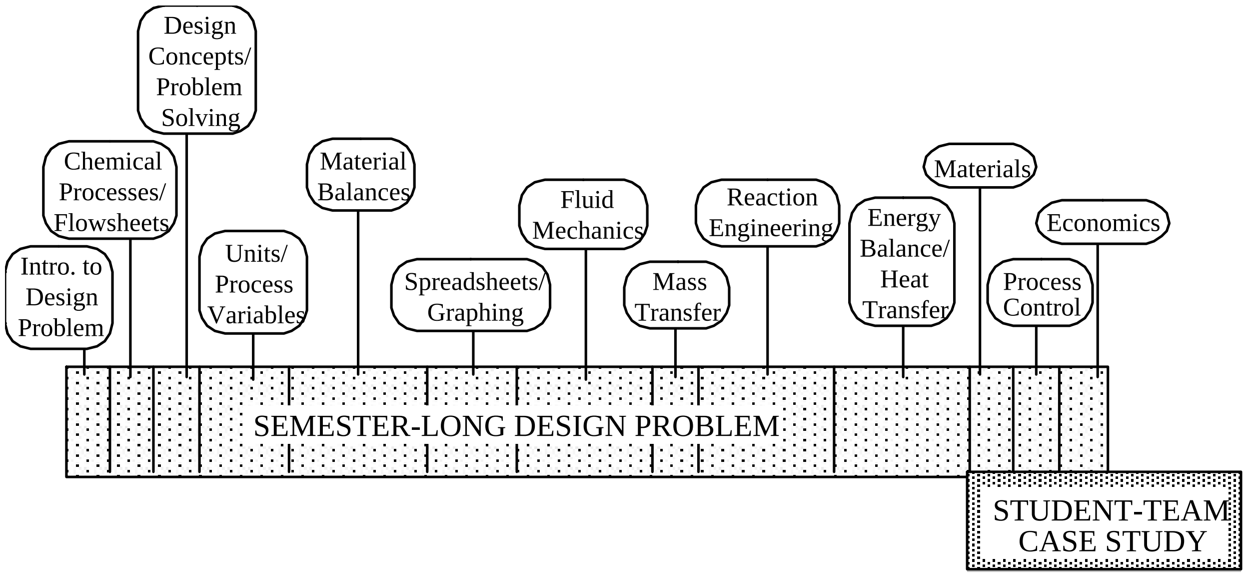

Figure 1. Schematic of the topics covered in the chemical engineering first-year course, where the relative length of time spent on each topic is represented by the length of the bar.