AN INTRODUCTORY ChE COURSE FOR FIRST-YEAR STUDENTS

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Freshman students who have an interest in chemical engineering have several important needs that we feel should be addressed. First, many of them are still undecided about their major and need help making that decision. Second, these students need to receive instruction that provides a broad, integrated perspective to serve as a foundation for subsequent classes. Finally, first-year students need to experience support and encouragement from faculty and other students.

In spite of these needs, chemical engineering departments traditionally have done relatively little for these students, often relegating them to a generic computing class or to a generic freshman engineering class. For example, for many years at BYU, the only "chemical engineering" courses taken by first-year students were a course in FORTRAN programming and a 0.5 credit freshman seminar. But we have recently changed our curriculum to better meet the needs of these students; among those changes has been the development of a new introductory course—the subject of this paper.

GOALS FOR THE COURSE

We began development of a course for first-year students with several distinct goals in mind (summarized in Table 1), with the most important of those goals being

1. To provide knowledge about the chemical engineering field to help students select their major.

2. To provide an integrative foundation for future courses.

We wanted to provide sufficient information about the discipline to enable students to make an educated decision regarding their choice of a major. To meet this goal, we felt it was important for the students to experience chemical engineering reasoning, calculations, decisions, and applications. These experiences should include an introduction to some of the fundamental principles and equations (*e.g.*, Fick's Law, Fourier's Law, etc.). To increase learning and interest, we also wanted to help students understand the impact of chemical processing on their own lives and to understand the connection between chemical engineering and their "everyday" experiences. We felt that it was important for the students to evaluate and draw conclusions from numerical results as would be typically done by a chemical engineer. Further, we wanted to expose students to "design" problems that were open-ended and had multiple solutions.

Finally, we wanted the material to challenge the students in order to stimulate their interest and to provide them with a sense of the curriculum's rigor. This last goal was motivated in part by our prior experiences with survey courses that failed because they did not offer much intellectually to the students entering our department; students felt that such courses were neither challenging nor informative and were essentially a waste of their time.

We wanted this course to play a significant role as part of our undergraduate curriculum by providing a foundation and perspective for subsequent classes. It has been our observation that sophomores, juniors, and even seniors sometimes view each course in their program as an isolated entity, unrelated to the other subjects they have studied. Instead of building on past learning, they often seem to start over with each new subject. Hence, they frequently fail to see the discipline as a whole until very late in their program (if at all). Therefore, a key objective of our course was to provide

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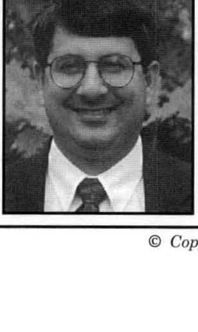

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an integrated overview, offering a broad perspective and serving as a framework upon which subsequent courses could be built. That objective included helping the student understand where subsequent chemical engineering courses fit within the larger perspective as well as how knowledge obtained from other disciplines (*e.g.,* chemistry, math, physics, economics, etc.) is essential. In a figurative sense, the introductory course would create a "skeleton" by broad shallow coverage of the discipline, and later courses would add the "meat" to that skeleton.

Additional goals were related to the social needs of the students. It is our opinion that first-year students should have close interaction with the faculty. While some interaction is facilitated by faculty-student socials, required meetings with advisors, etc., our course provides many more faculty-student contact hours than any other method. Of equal importance to faculty-student interactions are interactions between the students themselves. One of our goals for the introductory course was to help develop a "community of chemical engineers" through the use of learning teams and group activities.

CONCERNS

There were several concerns that influenced development of the course and led us to minimize the credit hours and faculty resources associated with it. It was clear that a new course could not simply be added to a curriculum that was already overflowing, especially at a time when we were being encouraged to decrease the number of credit hours in order to help students graduate more quickly. Thus, inserting this course meant reducing the credit hours of more advanced courses, and some faculty questioned the value of such a trade. Also, since a large number of beginning students do not continue in the discipline after their first year, there was concern that an introductory course would dedicate resources to teaching students who would not graduate in chemical engineering. Further, the course we envisioned would need to be developed from scratch since a suitable text was not available, thus adding to the required resources.

After some discussion, the department decided to support the course because of the potential advantages that it would offer our students, provided that the course was designed to minimize the resource requirements associated with it. Consequently, the course was designed as a two-credit-hour one-semester course without a laboratory (even though we recognized the value of a laboratory experience for our beginning students). Two credits were made available for the course as part of a general restructuring of the curriculum, and the necessary resources were allotted for development of the course.

TABLE 1
Goals for an Introductory Course in ChE

1. To provide information about the chemical engineering field and thus enable students to knowledgeably select their major.
2. To provide an integrated overview of chemical engineering as a foundation for subsequent courses.
3. To teach significant chemical engineering principles, including
   - Fundamental concepts and quantitative relationships
   - Connections to the students' past experiences
   - Typical chemical engineering calculations and analyses
   - Open-ended, multi-solution design problems.
4. To promote interaction between first-year students and the chemical engineering faculty.
5. To help develop a "community of chemical engineers."

THE COURSE

The goals listed in Table 1 had a significant impact on the course's structure during its development. In particular, our desire to provide an integrated overview required that the individual course topics be connected together in a logical fashion. This integration was accomplished by structuring the course around an *engineering design problem* that could be solved by designing a simple chemical process. The entire semester and all the material presented in the course were dedicated to the design of that process.

The problem-oriented scenario begins the first day of class when the students are asked to imagine that they "are chemical engineers working for the ABC Chemical Company." The student engineer receives a memo from his/her supervisor reporting that the contractor who has been disposing of the hydrochloric acid by-product 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 toward leading the student to that solution. This design problem provides the framework for integration of material presented throughout the semester.

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

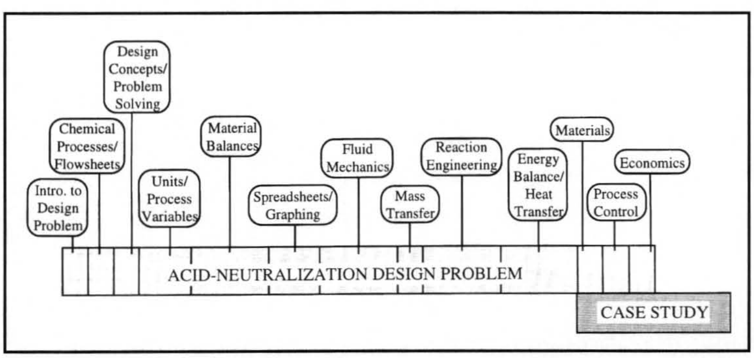


Figure 1. *Schematic of the topics covered, where the length of each bar represents the time spent on the topic.*

rate chapter. The table of contents of the textbook, shown in Table 2, reflects the detail and sequence of topics treated in the course.

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 HCl. Material balances are then taught in order to determine how much NaOH is needed. Spreadsheets are also introduced as an engineering tool. The students are then taught simple fluid mechanics to provide the basis for delivery of the NaOH and HCl from the storage facilities to the point of reaction. This approach continues as issues are considered regarding mixing the acid and base (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 skills in several of the subdisciplines that make up chemical engineering and have applied them toward the solution of an engineering design problem. These skills represent a useful subset of those that they will learn in subsequent chemical engineering courses. In order to illustrate the level at which the material is presented, Tables 3 and 4 provide examples of problems used in the course along with the appropriate solutions as presented in the textbook.

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 (Chapter 2). 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.

In contrast to the acid-neutralization design problem, the solution for which is developed for the students throughout the semester, the course also features a second design problem, or *case study,* to be solved independently by student teams. The case study, described in the last chapter of the book, involves the isomerization of meta-xylene to ortho-xylene and 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, to learn from each other, and to apply nearly all of the concepts and principles they have learned throughout the semester. Although new material is presented in class during the time that students are working on the case-study assignment, the last few topics (particularly engineering materials and process control) are treated qualitatively and briefly, with minimal homework assignments, to give the students time to focus on the case study. Students are periodically required to inform their "supervisor" in writing concerning the progress made to date on the case study, and a final design report is also required from each team. The xylene-isomerization case study is the only

TABLE 2
Table of Contents

<u>*Chapter*</u>

case study currently included in the textbook. Thus, it has been reused from year to year, in spite of the risk that students may copy reports from previous semesters. We have not found this to be a problem so far, probably because of the honor code at BYU, but we do recognize the value of developing additional case studies for future use.

In order to teach first-year students with varying backgrounds, the course was designed with few prerequisites. Specifically, we did not assume any previous exposure to calculus. We also assumed only a minimal knowledge of chemistry, such as provided by even a mediocre high-school chemistry class. Finally, while the course requires minimal computer word-processing experience, it does not require prior exposure to computer spreadsheets.

There are several other aspects of the day-to-day operation of the course that may be of interest to the reader. For example, the course includes frequent use of group activities, which serve to hold student interest, increase learning effectiveness, and help first-year students form friendships with one another. In-class quizzes are also used to motivate students to keep up with their learning (a particular problem for many first-year students who developed the habit of last-minute cramming in high school). Classroom demonstrations and examples from everyday life are used to illustrate the chemical engineering principles being discussed. Small pieces of equipment, such as pumps and heat exchangers, are partially disassembled and passed around during class for students to examine; photographs of larger equipment items are also used.

Outside the classroom, we assign reading questions to be answered for each new reading assignment before the mate-

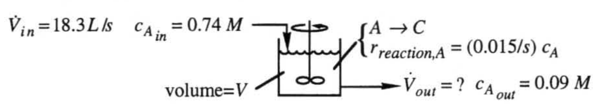
TABLE 3
Example Used in Course

Species A in liquid solution (concentration=0.74 M) enters a CSTR at 18.3 L/s, where it is consumed by the irreversible reaction

$$A \rightarrow C$$

where $r_{reaction,A} = k_r c_A$ ($k_r = 0.015/s$ and c_A is in units of gmol/L) What reactor volume is needed so that the concentration of species A leaving the reactor equals 0.09 M? The density can be assumed to be constant.

<u>**SOLUTION**</u> (Note that the steps correspond to the instructions in Tables 5.1 and 5.2.)
Drawing a diagram for this problem:



As outlined in Table 5.2, we want to construct a <u>mole balance on A.</u> For this case (for a single input and single output stream), the mole balance becomes

$$\dot{n}_{A,in} + r_{formation,A} = \dot{n}_{A,out} + r_{consumption,A}$$

Species A is being consumed, but no species A is being formed, so $r_{formation,A} = 0$. This, along with substituting more convenient forms for the molar flow rates, gives

$$c_{A_{in}} + \dot{V}_{in} = c_{A_{out}} \dot{V}_{out} + r_{consumption,A} \qquad (a)$$

The value of the outgoing volumetric flow rate is not specifically given, so we need a <u>total mass balance</u>, which for a single input and single output stream, is

$$\dot{m}_{in} = \dot{m}_{out}$$

which, in more convenient terms, is

$$\rho_{in} \dot{V}_{in} = \rho_{out} \dot{V}_{out}$$

Since the density is constant, this reduces to

$$\dot{V}_{in} = \dot{V}_{out} = \dot{V} \qquad (b)$$

We can now calculate $r_{consumption,A}$ using Eqs. (a) and (b). Equation (a) becomes

$$r_{consumption,A} = c_{A_{in}} \dot{V}_{in} - c_{A_{out}} \dot{V}_{out} = \left(c_{A_{in}} - c_{A_{out}}\right)\dot{V}$$

$$= \left(0.74\frac{gmol}{L} - 0.09\frac{gmol}{L}\right)\left(18.3\frac{L}{s}\right) = 11.9\frac{gmol}{s}$$

Up to now, everything we've done is a repeat of the material balances we learned in Chapter 5. The new step is to equate the $r_{consumption,A}$ term to the given rate expression times the reactor volume, where c_A (in the reactor) = $c_{A_{out}}$.

$$r_{consumption,A} = \left(k_r c_{A_{out}}\right)V$$

or

$$V = \frac{r_{consumption,A}}{k_r c_{A_{out}}} = \frac{11.9\,gmol/s}{\left(\frac{0.015}{s}\right)\left(0.09\frac{gmol}{L}\right)} = 8{,}800\,L$$

TABLE 4
Example Used in Course

A heavy oil stream must be heated to a higher temperature, so the decision is made to use a heat exchanger with saturated steam being condensed to saturated water as the heating source on the other side of the exchanger. The characteristics of the oil are

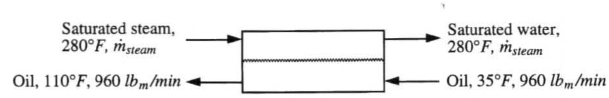
Oil mass flow rate:	960 lb_m/min
Oil mean heat capacity:	0.74 Btu/lb_m°F
Oil inlet temperature:	35°F
Desired oil outlet temperature:	110°F

The saturated steam has the following properties:

Steam temperature:	280°F
Heat of vaporization (@280°F):	925 Btu/lb_m

What steam flow rate is needed for this exchanger?

<u>**SOLUTION**</u>



For this problem, the oil is the cold stream and the steam/water is the hot stream. For the oil side, Eq. 10.24b gives

$$\dot{Q}_{duty} = \left[\dot{m}\bar{C}_p\left(T_{out} - T_{in}\right)\right]_{oil}$$

$$= \left(960\frac{lb_m}{min}\right)\left(0.74\frac{Btu}{lb_m\,°F}\right)(110 - 35°F) = 53{,}280\frac{Btu}{min}$$

For the steam/water side, as indicated in Table 10.2, for condensation

$$\Delta\hat{H}_{phase\ change} = -\Delta\hat{H}_{vaporization}$$

so Eq. (10.24c) gives

$$\dot{m}_{steam} = \frac{-\dot{Q}_{duty}}{-\Delta\hat{H}_{vap}} = \frac{-53{,}280\,Btu/min}{-925\,Btu/lb_m} = 57.6\frac{lb_m}{min}$$

rial is discussed in class, and we assign homework problems for the material after it has been discussed in class. Other course features include the case study, which has already been described, two mid-term examinations, and a final exam. Grading is performed according to predefined criteria in order to encourage cooperation between students.

As mentioned previously, this introductory experience is completed in a two-credit-hour one-semester course. Thus, the resources expended are relatively minimal, while our experience indicates that the benefit derived is significant.

RESULTS

We have now taught the course for four years, and student response has been very positive. At the end of every semester, all courses in our department are subjected to a student evaluation questionnaire, which includes numerical scores to specific questions and the opportunity for students to make unrestricted comments. The numerical scores for the introductory course have consistently corresponded to an overall rating of "excellent" and are among the highest in the department. We also send a questionnaire to all students who change their major from chemical engineering to another discipline. The comments from both of these types of questionnaires, along with feedback during informal conversations, indicate that students feel they have a much better understanding of and appreciation for chemical engineering after having taken the course. Some comments from those surveys are:

- *"The course gave me a good idea of what to expect in my major."*
- *"The course is much more applicable to a business or real-life situation than any course I have taken."*
- *"The course was EXTREMELY helpful in my decision to stay with ChemE as my major."*
- *"The course has given me a good idea of what Chemical Engineering is about."*
- *"I really enjoy this course. If it were up to my chemistry class, I would drop out of ChemE. But this course shows the light at the end of the tunnel."*
- *"Good prep (sic) for my major, applies concepts and possible real life situations, but not too far over our heads."*
- *"ChE 170 [was a] good class—I just knew after that one that I didn't belong."*
- *"I enjoyed ChE 170, but I wouldn't like to do it for a career."*

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.

The course appears to have slightly increased the overall retention of students in the chemical engineering program, but that is difficult to verify at this time. The difficulty arises because approximately 80% of the first-year students in our program leave the university after the first semester or after the first year to serve a two-year mission for the Church of Jesus Christ of Latter-Day Saints. Some of those students take our introductory course before leaving, while others take it after returning. Those students who took the first-year course in the last three years and then began serving their missions have not yet returned for a full year of school, so we are not able to determine if they will continue in the program.

Where there are complete data, we have examined retention as defined by the percentage of first-year students who eventually, but not simultaneously, took the subsequent course in our program (our sophomore course in material and energy balances). During the five years before implementation of our course, freshmen took FORTRAN programming as the first-year course, and 40% eventually took the sophomore class. During the last four years, the new course has been offered in both the first semester (enrollments ranging from 86 to 105) and the second semester (enrollments ranging from 47 to 76). For students who took the introductory course during the first of those years, the retention was higher, at 46%. We will continue to compile retention data as they become available. We feel, however, that changes in overall retention are less important than, and may not be a good indicator for, the increased ability of first-year students to intelligently decide if chemical engineering is a good field for them (one of our main goals).

In addition to providing an overview of chemical engineering, students felt that the introductory course helped prepare them for future courses, particularly the course on material and energy balances normally taken by sophomores. This opinion was consistent with that of the course instructor for the sophomore course, who observed that the students who had taken the introductory course were better prepared than previous students. The instructor also noted that the students had a significantly broader knowledge of the discipline. For example, when he mentioned to the students in the class that phase equilibrium would be important in separation processes such as distillation, they recognized the processes to which he was referring and appreciated the significance of his statement.

Although a quantitative evaluation is difficult, other anecdotal information provides positive feedback about the course. For example, two students who had recently completed the introductory course requested help from one of the authors to explore an issue in process control for use in a paper for a technical writing class. Specifically, they wanted to explore differences between feedback and feedforward control strategies. The students were in the first semester of their third year, a full year before they were scheduled to take our senior-level process control class. Prior to the time we began teaching the introductory course, students at the same point in their education had little, if any, concept of process control. Yet, these students had learned enough in the introductory course to define a question and pursue the topic further on their own. Incidentally, they were supplied with a process simulation program (PICLES[2]) and were able to use the program to address the issues of interest.

It has also been our perception that the course has served to help build relationships between students. They appear to be working in groups and helping each other much more than they did previously. This interaction is facilitated by the group work required as part of the class. Also, grading is structured so that students do not perceive that they are hurting their own grade by helping their classmates. Interaction between the faculty member teaching the course and the students has also been very positive. In many cases this has resulted in continued interaction and discussions, exchange of e-mail, sharing of wedding announcements, etc., long after the final exam is taken.

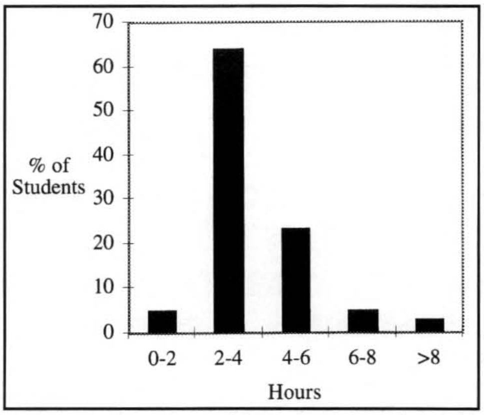


Figure 2. *Number of hours per week spent outside of class on this course.*

In order to provide the desired integrated overview, it was necessary to cover a broad variety of chemical engineering concepts. We were concerned that in doing this we might overwhelm the students with too much material. Like most schools, our target for work outside of class (reading and homework problems) is two hours outside class per one hour inside. For a two-credit class (two hours per week in class), this translates to four hours per week outside of class. A recent polling of all our students concerning the time they spend in class work outside of class indicated that the workload for the introductory course was *on target* at an average of approximately 3-4 hours a week. We conclude from this that the students have not been overwhelmed by the material presented in class.

Finally, the written material for the course has evolved considerably over the past four years, but has now stabilized to a large extent. As mentioned previously, we have recently published a textbook[1] for the course that is available for others who may be interested.

We end this section by noting that the course described in this paper has an appeal that extends to other situations where beginning students need to know about chemical engineering. For example, some colleges have a common freshman engineering course, and the chemical engineering departments do not see the students until the sophomore year. In those cases, the course described here could be given to first-semester sophomores prior to the traditional course on material and energy balances. It could also be used in two-year colleges from which students may transfer into our programs.

CONCLUSION

A new introductory course has been developed for first-year students interested in chemical engineering. This two-credit-hour one-semester course is designed to provide a broad overview of the chemical engineering discipline and a foundation for other courses in the curriculum. Other objectives for the course include the introduction of fundamental principles related to chemical engineering, connection of material to the students' experiences and future coursework, introduction of design concepts, and development of student/faculty and student/student relationships. Student feedback, although qualitative, indicates that the course has been largely successful in accomplishing these objectives.

The laying of a broad introductory foundation at the beginning of a long academic program was of particular interest and importance. Consequently, the course was designed to establish the framework for the rest of the curriculum. Our intention was to facilitate learning by providing an overview and establishing connections so that in-depth material from upper-division courses could readily be integrated into an existing framework, rather than waiting until a senior capstone course to attempt to tie things together. The approach also facilitates learning through repetition by providing a first-year exposure prior to the more-in-depth upper-division exposure.

We are providing this information so that other schools may consider this approach for adoption into their programs. Universities with no freshman engineering course may consider adding a course like the one described here. Schools with an existing general freshman engineering course might consider replacing it with this course for students who are seriously considering chemical engineering as a major. Where this is not possible, this course might be offered to sophomores in chemical engineering. In addition, two-year colleges might use this course to prepare their students for transferring to four-year chemical engineering programs.

We are anxious to receive impressions and suggestions from others who have seen our course or book, or who have experience with similar attempts to prepare first-year students for this discipline.

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2. Cooper, D.J., *PICLES (Process Identification and Control Loop Explorer System),* Version 4.1, Department of Chemical Engineering, University of Connecticut (1995) ❒