A Successful "INTRODUCTION TO ChE" FIRST-SEMESTER COURSE

Focusing on Connection, Communication, and Preparation

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As a new assistant professor at the University of Massachusetts Amherst (UMass), my first teaching assignment was "Introduction to Chemical Engineering." Being a new faculty member, I had my preference of courses to teach, and after some serious consideration I chose the first-semester engineering students. In my six years at UMass I have been fortunate to have taught this course four times now, and as a result I have learned a great deal about how to effectively teach and motivate beginning engineering students. The course is primarily designed for first-semester engineering students who have a strong interest in pursuing chemical engineering as a major, but it is also attended by transfer students and upper-class, novice engineering students (*i.e.*, transfers from chemistry or biochemistry).

Many chemical engineering departments offer freshmen-level introductions to engineering courses, but few focus solely on chemical engineering,[1] and even fewer focus on first-semester freshmen. The format and content of these offerings are varied and include such things as general engineering education,[2-3] faculty/advisor seminars,[4-5] and laboratory experimentation.[6-7] This paper describes the design and implementation of a first-semester freshmen chemical engineering course.

FIRST YEAR ENGINEERING AT UMASS

The UMass College of Engineering has instituted a two-course sequence in each respective department to teach beginning engineering students the fundamentals of engineering. Each two-course sequence has been designed to provide new students with an excellent foundation in a specific engineering discipline (*i.e.*, chemical engineering, civil and environmental engineering, mechanical and industrial engineering, and electrical and computer engineering). There is flexibility, however, so students can switch mid-sequence if they decide to pursue a different discipline at the completion of the first-semester course.

This two-course sequence, which has evolved over the years with significant input from both students and faculty, incorporates discipline-specific activities. The two-course sequence in chemical engineering consists of a first course that is further described in this paper and a second course that extensively covers material balances and phase equilibria. The combination of these two courses provides students with an extraordinary background in chemical engineering fundamentals in addition to giving them a broad perspective of what the field of chemical engineering offers. Some students who transfer to UMass or who decide to switch to chemical engineering from another discipline in the spring semester enroll in the second course without taking the first course. In the main, these students fare well since the fundamental material balance content is repeated in the second course. Students can enroll in the first course the following year to gain experience in design, economics, and communication.

COURSE OBJECTIVES AND DESCRIPTION

In addition to introducing the students to the basic prin-

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TABLE 1
Course Syllabus

Week	*Topics during "lecture" (2 x 1.25 hours) and "laboratory" (50 minutes) periods*
1	Course introduction; Computer set-up, printing, and establishment of accounts
2	Physical sciences library introduction; Introduction to the Internet and Microsoft Word*; Units, conversions, and engineering estimation
3	Introduction to Microsoft Excel**; Effective technical writing; Introduction to processes (unit operations, flowsheets, etc.)
4	Ammonia synthesis—process design improvements; Material balances on nonreactive processes
5	Material balances—in-class exercises; Process economics
6	Process economics (continued); Learning in teams—discussion of the group project; Peer review of paper
7	Process economics game; Leblanc process—an illustration of chemical engineering principles[11]; Tour of the unit operations laboratory*
8	UMass Chemical Engineering faculty research panel; Examination review; Midterm examination
9	Introduction to Microsoft PowerPoint; Presentation skills workshop
10	Student midterm presentations**; Industry career panel
11	Introduction to Mathcad**
12	Safety in the laboratory and plant—case studies
13	Engineering scale-up
14	Energy balances
15	Student final presentations**; Engineering ethics; Course summary

* *Indicates activities held during laboratory periods; laboratory periods include computer instruction, departmental tours, presentations, and communication skills workshops*
** *Indicates activities held during both lecture and laboratory periods*

TABLE 2
ABET-Type Outcomes

At the end of this course students should...

- Understand what chemical engineering is and what careers are possible with a degree in chemical engineering
- Be able to use Microsoft Office (Word, Excel, and PowerPoint) to write technical papers, create spreadsheets to perform calculations, and design effective presentations
- Develop proficient oral presentation skills through group project presentations
- Understand the role of chemical engineers in process design
- Understand the importance of process economics in process design
- Be able to perform material balances on nonreactive systems
- Acquire an appreciation for the role of ethics and laboratory safety in the field of chemical engineering
- Be prepared to use the principles and tools learned in this class to solve problems not covered in detail as part of this course and to continue learning related material as needed in the future

ciples of chemical engineering (*e.g.*, mass balances, process design, engineering economics, scale-up, etc.), the objectives for the course are essentially threefold: first, to educate students about the variety of possible careers one can pursue with a degree in chemical engineering so that they can confidently decide if this degree is, in fact, what they ultimately desire; second, to create an environment where students can develop effective oral and written communication skills through individual writing assignments, group work, and classroom presentations; and third, to foster a learning atmosphere where students can openly discuss relevant issues (*e.g.*, engineering ethics) and become "connected," *i.e.,* familiar, with one another and with the faculty in the department. Table 1 is an abbreviated course syllabus, which outlines the activities planned for the semester. Throughout this paper, the implementation of specific activities for attaining these classroom goals is discussed. A list of ABET-type outcomes is additionally presented in Table 2.

CHEMICAL ENGINEERING AS A CAREER CHOICE

It is my opinion that most students in the introductory course chose chemical engineering as a potential major based on the simple fact that they enjoyed chemistry and mathematics in high school, but when queried as to what types of jobs they would pursue with this degree, most were unable to answer. Therefore, throughout the semester, activities are planned to introduce them to the types of careers that are available with a chemical engineering degree (they are usually very surprised to discover the choices!).

A portion of the first day is spent showing a video titled "Careers for Chemical Engineers," which is available through AIChE. This medium is an excellent introduction to the numerous arenas in which chemical engineers can focus their careers upon graduation. Additionally, the video is an effective way of illustrating the types of skills that students should develop during their academic careers, including computational, communication-related, and problem solving (all of which are important, regardless of what they ultimately choose as a career!). An "industry career panel" is planned, with chemical engineering representatives (typically UMass alumni) from different industries (*e.g.*, chemical, microelectronics, pulp and paper, biotechnology, etc.). This panel format has proven to be an extremely successful tool for addressing the career-education objective and for motivating the students to seek additional information. I also discuss the types of research that I personally do and incorporate some of my own results into problem sets, thereby allowing the students to see how chemical engineering fundamentals can be applied to solving nontraditional problems (*e.g.*, biotechnological problems). The students are encouraged to become involved in the local AIChE student chapter as freshmen, which also affords them access not only to the invited speakers (*e.g.*, career office personnel, industry representatives, etc.) but also to the upper-class chemical engineering students, whose own objectives are more well-formed.

A Web site has been developed for the first year (<http://www.ecs.umass.edu/che/che110/index.html>) that includes not only details on the two first-year courses offered by the department, but also has information on chemical engineering as a career choice, career skills, scholarships and internships, and safety and ethics. Students are strongly encouraged to partake in summer industrial internships or research opportunities as early as the summer following their first year. Opportunities regarding research experiences for undergraduate programs are summarized on the Web site and brought to the students' attention throughout their first year.

Additionally, many of our students are in the Honors Program (Commonwealth College) and are required to complete a senior honors research thesis. Students are therefore encouraged to learn about departmental research as freshmen, so they can begin research in either their sophomore or junior year (when Honors Research Fellowships are available). Many of our students have been amazingly productive, with published articles resulting from their research work.[8-10] When beginning students learn of the achievements of upper-class students and alumni, they become excited about the opportunities available to them.

PREPARATION

The UMass chemical engineering curriculum has moved the traditional mass-and-energy balances class (typically a fall-semester, sophomore-level course) to the second-semester freshman year. Therefore, even though the "Introduction to Chemical Engineering" class is not a requirement for graduation, there exists a need to begin exposing students to "real" chemical engineering calculations early in their education. Additionally, students should be introduced to the type of work a typical chemical engineering class entails (calculations, calculations, calculations!). Thus, although the class focus is (in part) on connection and communication, suitable time is also dedicated to learning some basic chemical engineering fundamentals. The concept of process design and optimization, which separates chemical engineering from the other engineering disciplines, is very well explained in a book written by Duncan and Reimer (*Chemical Engineering Design and Analysis, An Introduction*, Cambridge). In this reading, examples are used to illustrate the building and improvement of processes based on physical or chemical changes. The LeBlanc Soda Process is used as an example to depict all aspects of design from improvements in technology to attention to safety and the environment.[11] Students are also taught engineering economics (an economics game was developed where groups of students compete to design the most cost-effective process), nonreactive material balances, and scale-up issues. Freshman engineering design experiences give students exposure to the creative nature of engineering; there has been a recent resurgence in freshman-level design activities.[12]

Students learn to effectively write nonreactive material balances on simple systems (see Table 3 for some specific examples of both homework and exam problems). Calculus is not needed for students to understand the concept of a material balance, and the inclusion of this material in the first-

TABLE 3
Examples of Material Balance Problems

Appeared on a Midterm Exam

A liquid mixture containing 30 mol% benzene (B), 25 mol% toluene (T), and 45 mol% xylene (X) is fed at a rate of 1275 kmol/h to a distillation unit consisting of two columns. The bottoms product from the first column is to contain 99 mol% X and no B, and 98% of the X in the feed is to be recovered in this stream. The overhead product from the first column is fed to a second column. The overhead product from the second column contains 99 mol% B and no X. The B recovered in this stream represents 96% of the B in the feed to the second column.

(A) Draw and label a flowsheet for this process.

*(B) Calculate the molar flow rates (kmol/h) and component mole fractions for the product streams of the second distillation column.**

Appeared on a Homework Assignment

Ethanol can be synthesized by yeast from grain and water in a reactor. Assuming an idealistic process, the yeast converts 2 kg of grain into 1 kg of ethanol and 1 kg of water. A perfectly efficient yeast reactor (efficiency = 1.00) would convert all of the grain entering the reactor. A reactor with an efficiency = 0.50 would convert half the grain entering the reactor, and so on. The feed is 100 kg/min, 20 wt% grain, and 80 wt% water.

(A) Calculate the total flowrate of the reactor effluent for an efficiency of 0.50. Also calculate the flowrates of all components in both the reactor feed and reactor effluent streams.

*(B) Calculate the reactor effluent composition using a range of reactor efficiencies starting at 0.00 and increasing in step by 0.05 up to 1.00. Also, create a chart that will display the effluent grain flowrate as a function of reactor efficiency. Explain the significance of your results.***

Appeared on a Homework Assignment

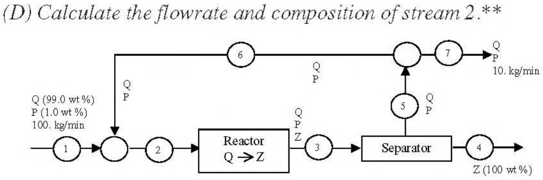
The chemical Q reacts to form Z. Unreacted Q is separated from Z and recycled to the reactor. The feed contains an impurity, P, which is inert and is purged from the system via stream 7. The splitter purges 5.0% of stream 5. Note that a mass balance on Q must account for the Q that reacts to form Z. Likewise a mass balance on Z must account for the Z formed from Q.

(A) Which stream has the highest flowrate of Q?

(B) Calculate the flowrate of product stream 4, in kg/min.

(C) Calculate the composition of purge stream 7.

*(D) Calculate the flowrate and composition of stream 2.***



* *Adapted from Felder, R., and R. Rousseau,* Elementary Principles of Chemical Processes, *3rd ed., John Wiley & Sons, New York, NY (1999)*

** *Adapted from Duncan, T., and J. Reimer,* Chemical Engineering Design and Analysis: An Introduction, *Cambridge University Press, New York, NY (1998)* semester course gives students a realistic view of the types of approaches chemical engineers use to solve problems. I have found that students thoroughly enjoy this section of the course (although most feel quite challenged) and they gain confidence in their ability to pursue chemical engineering as a major. Students are also well prepared for the second-semester "Fundamentals of Chemical Engineering" course that is dedicated to mass balances and phase equilibria.

Good portions of the class and homework assignments are dedicated to developing students' computational skills, in particular the use of Microsoft Office (Word, Excel, and PowerPoint) and Mathcad. This is particularly important because there is always a certain percentage of students who have reached this level of their education with very limited computer skills. Since these computer applications will be used in all future chemical engineering classes, it is critical that the students know how to maximize their use. To achieve this end, there is a mandated requirement that all homework assignments must be completed on the computer (thus assuring that the students are getting the practice they need).

Since there is no formal requirement at UMass that students take a course in engineering safety or engineering ethics, two class periods are spent discussing safety in the laboratory and plant and engineering ethics. A case-study approach is used to stimulate thought and discussion about the importance of these subjects in the chemical engineering profession. Although only a short time is spent in the classroom on these subjects, the students are encouraged to incorporate ethics and safety into their homework problems as well as into their group project assignments.

CONNECTION

The majority of students enrolled in the "Introduction to Chemical Engineering" class are first-semester freshmen. Most of them have recently arrived on campus and are new to the college experience itself. UMass has approximately 25,000 students, and most of the first-year classes are conducted in large lecture halls, giving the students limited contact time with the faculty and upper-class students. Studies have demonstrated the importance of students feeling "connected" with the university in terms of student success, happiness, and retention. Previous studies have demonstrated that advising and mentoring during the freshmen year were successful in decreasing attrition rates for engineering students.[13]

Because this introductory course is relatively small (40-50 students) in relation to the other first-year courses, the opportunity exists to foster "connections." Although this takes a bit of time on the instructor's part, it is well worth the effort in terms of yield in student retention and class performance. Getting to know each student on a first-name basis is critical and being easily accessible to students is a must. Other means of fostering this "connection" are

(1) *A class lecture that is dedicated to a "faculty research panel" where several faculty in the chemical engineering department take part in a panel presentation and discussion about their research activities. Students get to know the other faculty in the department, develop enthusiasm about the ongoing research programs, and begin to see the diversity in the chemical engineering discipline.*

(2) *An outside-class activity (which most students attend) that is arranged where the sophomore and freshmen classes are brought together in a casual environment to discuss issues relating to the UMass Department of Chemical Engineering and curriculum.*

(3) *A unit operations laboratory tour, given by the senior class. The tour takes place in the same time slot as the senior laboratory so that all the seniors are present and the equipment is operational. This not only allows beginning students to see what types of experiences are ahead of them, but also gives them the time to ask questions of the seniors.*

(4) *An "industry career panel," comprised of alumni, that not only gives the students the opportunity to see firsthand what types of jobs are available with their chemical engineering degree, but also allows them the chance to "connect" with former students and recent graduates.*

(5) *All students are encouraged to get involved with the student chapter of AIChE. The upper-class students are enthusiastic about including beginning students in their activities and the students feel as though they have a home in the department.*

COMMUNICATION

Group Projects for Collaborative Learning

Throughout the semester, students learn about process design, flowsheet construction, material and energy balances, engineering economics, laboratory safety, and ethics (see Table 1). With this background to support them, the students are assigned to groups of three and are given a particular chemical or pharmaceutical to research throughout the semester (*e.g.*, ethanol, penicillin, MTBE, sulfuric acid, ethylene, etc.). They are responsible for investigating the history of the process(es) involved, for describing the current process methods including the construction of flowsheets (synthesizing all information in the literature), for creating a simple market report, for performing an economic analysis, and for identifying potential problems in the process associated with hazardous materials, waste, inefficiency, and safety. The groups must give two presentations during the semester and then write a final report, which serves to hone both oral and written communication skills. For the second presentation students are asked to redesign the process based on their analysis of efficiency and minimization of waste. All students must partake in both presentations.

A presentation skills "workshop" has been added to the syllabus to provide students with appropriate background on how to give an effective presentation. This "workshop" is cofacilitated with experienced university personnel. As part of the group project, students are required to complete a group-member evaluation form where they evaluate themselves and all group members (on a scale of 1 to 5).[14] The evaluation criteria include reliability, research, analysis, oral presentation, report writing, and leadership. The use of an evaluation system holds the students accountable and helps bring about conflict resolution, which creates a more realistic team environment. Also, using an evaluation form at the midterm point in the project allows the instructor to foresee problems with certain groups that can possibly be solved before the semester is finished. Currently, peer evaluation is used by the instructor solely to gauge group performance, but there are plans to include student review of feedback and team conferences to discuss group dynamics in future course offerings. Students embrace this project and are amazingly successful in generating a reasonable flowsheet and identifying process inefficiencies. This project is extremely effective at teaching students the concept of process design, which most chemical engineering students do not begin to understand until much later in the curriculum.

Emphasis on Written Communication

Although the group project and presentations are successful at enhancing students' communication skills, the individual-paper assignment helps them develop technical-writing skills. The students are responsible for writing a research paper on the past, current, or future impact of chemical engineering on society and are required to reference a minimum of five sources, only one of which can be from the Internet. I learned early on that students rely too much on Internet material, which may or may not have been peer-reviewed or regulated. At the beginning of the semester, one of the head librarians from the Physical Sciences Library visits the class and gives a complete introduction to library sources, including a list of relevant chemical engineering publications (*e.g.*, books, reference materials, journals, newspapers, etc.).

When this assignment was first implemented, the quality of the papers received was questionable in terms of organization, research, writing skills—and the simple ability to follow directions! This problem was somewhat solved through the institution of a technical-writing workshop, increased instruction on researching technical subjects, and the addition of a peer-editing session a week before the deadline. The technical writing workshop is facilitated by the course instructor and involves reviewing a publication on technical writing[15] and critiquing previous years' writing submissions.

For the in-class peer-review session, students are anonymously assigned two papers to review and are instructed on how to effectively critique and provide feedback. They edit the papers and provide comments directly on the manuscript. Authors then receive the written feedback and incorporate changes into a revised submission. The result is that most students dramatically improve their technical-writing skills; this was assessed through qualitative analysis from several years of teaching this course.

TABLE 4
"Pitfalls" Handout for Technical Writing

- Follow directions!!! Many students do not follow the formatting directions (paper length, reference and citation format, margins, title page, etc.) or the content instructions, and therefore lose significant points on the final paper grade.
- Include citations in the text of your paper. Citations provide the reader with the sources of information you have used to support your ideas and conclusions. Without citations, your paper will lack credibility.
- Perform a simple spell check on your paper to catch spelling and grammatical errors.
- Read over your paper before you hand it in. Many problems with punctuation, run-on sentences, and incomplete sentences can be avoided if you read the text out loud to yourself. Some misused words will not appear on a spell checker. For instance, the error in the sentence "Chemical engineering if fun," will not be detected using a spell checker.
- Pay attention to sentence structure and grammatical format. Some common mistakes are listed below:
  - There should be two spaces after a period (as well as after a question mark and exclamation point) before beginning a new sentence.
  - Only proper names and nouns should be capitalized. For example, many capitalize words like Chemical Engineer, which should be in lowercase. However, the University of Massachusetts Department of Chemical Engineering should be capitalized.
  - Citations in the text should be placed before punctuation (e.g., period, comma, etc.).
  - Acronyms should be written out in full the first time they appear in the text.
  - Author lists should not be shortened to et al. in reference lists, only in the citations.
  - Try not to use the words it, this, that, etc., as nouns. More descriptive words will make your sentences clearer.
  - Avoid using the first person when writing scientific or engineering papers.
  - Do not write extraneous commentary in the text.
  - Be careful when placing commas—the meaning of a sentence can be changed.
- Write about subjects that you understand. Don't bite off more than you can chew!
- Avoid excessive and improper use of quotations in scientific and engineering papers. Quotes taken directly from sources should add significant meaning to the paper or else you should paraphrase and cite the information. For instance, facts and statistics should not be quoted.

TABLE 5
Examples of Student Research Paper Titles

- Development of Orthopedic Limbs
- Contribution of Chemical Engineering to Research on Alzheimer's Disease
- The Process of Manufacturing Urethane Wheels for Roller Sports
- The Removal of Chlorine from Water
- Producing Scents: The Production of Perfume and Cologne from Past to Present
- The Breakdown and Disposal of Nerve Gas
- Design of Artificial Kidneys
- Wastewater Treatment
- The Process for Decaffeinating Coffee
- The Synthesis of Tennis Balls
- Development of Mammalian Cell Processes for Supply of Pharmaceuticals

It must be remembered that most beginning engineering students have never written a technical research paper—the majority of their writing experiences have thus far been nontechnical, *i.e.*, high-school English and history. A "pitfalls" handout was developed that highlights problems observed with past classes. Some examples include avoiding excessive and improper use of quotations and including citations in the text to provide the reader with the sources of information used to support ideas and conclusions (see Table 4). Students are also provided with a list of previous students' paper titles (see Table 5 for some creative examples). Students are advised to choose a subject that interests them and to avoid complex material for which they have no or limited background. Although many faculty are starting to mandate oral presentations from students, most faculty still do not address the need to develop effective written communication skills. Further development of this course will include incorporation of additional writing assignments.

ASSESSMENT

At the end of the course, students are asked to evaluate their learning in several categories that reflect the course objectives. Responses to student surveys conducted during the past three years (with two separate instructors) are shown in Figure 1. Responses were consistently high, even with a turnover of instructors. Virtually all students agreed that the course was successful at illustrating the field of chemical engineering and the potential careers possible with a degree in chemical engineering. Additionally students felt they gained critical knowledge in chemical engineering fundamentals as well as proficiency in communication. The overall course evaluations were very high (> 4.0), when students were asked to compare this course to others offered at UMass. Qualitative feedback has also been extremely positive, particularly from minority and female students. Collectively, these data indicate that the course was successful in meeting the educational objectives. Before the redesign of this first-semester course, it was consistently rated one of the worst in the department; today, it is one of the most highly rated. Additionally I have appreciated the opportunity to get to know the beginning students early in their academic careers and to assist in connecting students with other departmental faculty.

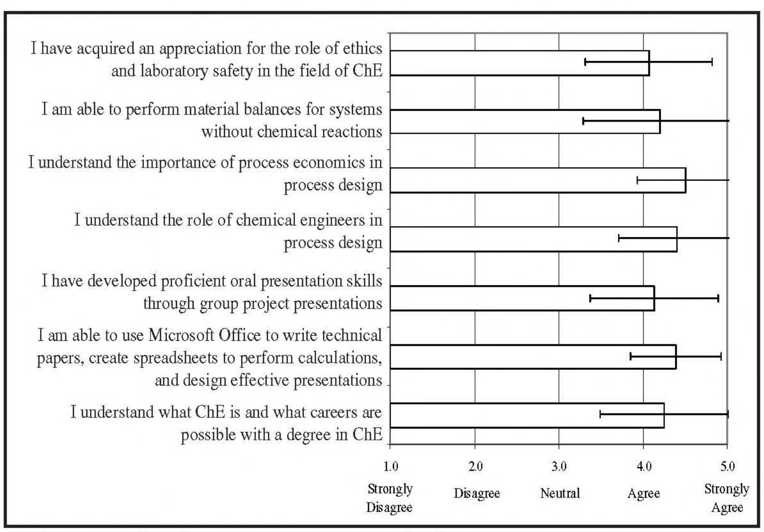


Figure 1. *Student responses to end-of-course assessment survey.*

SUMMARY

Do not underestimate the ability of beginning engineering students to learn! This course, although the workload is significant, is always highly evaluated and described as "useful" in student development. The overall time commitment can be managed through the use of teaching assistants, but faculty instructors must make the effort to get to know the students to foster their connection with the department. The right combination of preparation, connection, and communication through the described activities is instrumental in developing and preparing successful and enthusiastic chemical engineering majors.

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