2006-1075: A FRESHMAN COURSE IN CHEMICAL ENGINEERING: MERGING FIRST-YEAR EXPERIENCES WITH DISCIPLINE-SPECIFIC NEEDS

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A Freshman Course in Chemical Engineering: Merging First-Year Experiences with Discipline-Specific Needs

Abstract

In many engineering curriculums, the first opportunity for students to become acquainted with their discipline is in the sophomore or junior years. While such an approach allows for general freshman and/or sophomore engineering classes, it creates other problems as well as misses several opportunities. At our university, we have designed a 1-credit class for first semester freshman enrolled in chemical engineering. This course, which was designed with much student input, includes a variety of areas such as: (1) time management, (2) departmental indoctrination, (3) meeting the faculty, (4) how do all the courses fit into the curriculum, (5) hands-on experimentation, (6) what chemical engineers do in practice and (7) student research opportunities Such a course looks to cultivate the intrinsic interest that students have in this area while addressing issues which are important in sustaining these students to graduation. In this paper, we discuss the lessons learned from this course as well as provide assessment information for use in future offerings.

Student assessment of this course indicated that, on average, the course was effective at reaching the stated goals (score of 4.2 out of 5.0). Each class session itself was assessed by the students. The top performers were the three "hands-on" experiments that were performed. In a students' comments section of the assessment, it was emphasized that more "hands-on" work should be included when this course is offered next semester. While it is too early to determine if this course was effective from a retention standpoint, anecdotal information suggests a substantial reduction in the number of students transferring out of chemical engineering this year (so far) relative to last year.

Introduction and Motivation

Students enter into chemical engineering (and STEM disciplines, in general) for a wide-variety of reasons: they like science, are good at math, want to make good money, have a parent who works in a STEM field, etc. Invariably, a percentage of these students do not sustain to graduate in the discipline they declared upon entering college. While in some circumstances the reasons for this can be considered reasonable (re: really wanted to be an English or a business major), in other situations the explanations provided for dropping from a particular curriculum are, at best, ill-informed (re: must work in an office all day). The later issue is a major problem since it is often a difficult task to "educate" a student on all that STEM (or, in this case, chemical engineering) has to offer *after* they have made the decision to switch majors.

In the Fall of 2004, the Chemical Engineering Department at Tennessee Technological University had eight of 30 chemical engineering freshman students drop out of chemical engineering. While this percentage may or may not be alarming, subsequent "exit" interviews with one of us revealed that several of the students were leaving for reasons that can only be described as "ill-informed". Comments ranged from "*I want to do biochemical engineering and think that a B.S. in biology would be better*" to "*I don't want to build robots*". Clearly, there was a misinformation problem with these students and, therefore, *misconceptions* among students developed. And, as engineering educators, we know that if a few students have an idea (correct or otherwise) about a certain issue, it is likely that many in that cohort are "non-verbal" carriers of this information. This incorrect piece of information could be the deciding issue for a student whose knowledge or choice of the discipline is not well-grounded. Since chemical engineering students at Tennessee Tech do not take a chemical engineering course until their sophomore year, there was no formal way to address these issues and remove misconceptions. Note that an "Underclassman Information Session" developed for Spring of 2005 (with pizza included) attracted only 3 students and, thus, more effective measures were required. Our approach was to take the broader generalizations outlined for students leaving STEM Majors by Seymour and Hewitt [1], and address those while, at the same time, gathering information on our students and assessing the impact of this intervention. The purpose of this article is to discuss this approach at Tennessee Tech.

All Engineering students at Tennessee Tech take a one-credit Introduction to Engineering course. This multi-disciplinary course is held in a large lecture hall with a class size normally exceeding 100 students. The course focuses on introducing students to the profession through topic lectures, videos and a capstone project (normally something mechanical in nature). After analysis of the topics and via discussions with chemical engineering students who have taken this class, it was clear that certain important pieces of information, including things specific to chemical engineering students, were never being discussed or even conveyed. Hence, the next logical step was to generate a separate class, Introduction to Chemical Engineering, which was to be required of *all* entering chemical engineering freshman. Note that this course, labeled ChE 1010, is currently not a substitute to the Introduction to Engineering course, but rather a second, complementary course.

Now that the idea for ChE 1010, Introduction to Chemical Engineering, had been developed, the course content would need to be decided. Since students were going to be the users of this class, we decided to inform all of our undergraduates (via email) that this course was in the planning stage and we would like their suggestions on what to include. The main thing emphasized was the issue "*What did you wish you knew about chemical cngineering, the discipline, the department, the university, etc. when you started that you now know…and, also, is there anything you still do not know but would like to know*?" Also, a focus group of about 15 sophomore students was chosen to provide more direct feedback on this issue. Once we had this information, it was discussed at a general faculty meeting with the use of literature on this subject [2,3] (most notably from NJIT) [4] as a reference. At the end of several iterations, a syllabus was designed.

Pre-Assessment

In order to get a profile of a typical student who chooses chemical engineering, we gave those students who attended the first session of ChE 1010 a pre-assessment. Thirty-two students completed this survey and the questions with answer frequency are provided in Table 1. Note that, because of space limitations, we have used an "others" heading which group all of those answers that were mentioned only once by a student. Additionally, for some questions, responses are greater than 32 as students provided more than one answer for a particular question.

Table 1: Pre-Assessment Survey Results (N = 32)

Why did you choose ChE as a major?	
Interest/Good in chemistry	20
Interested/Good at math	12
Good money	8
Most job possibilities	7
Interested in engineering	7
Love science	5
Interested in chemical engineering	4
Most challenging	3
Teacher recommendation	2
Want to go to Med School / Med Field	2
Other	5
Why did you come to Tennessee Tech?	
Good reputation	23
Close to home	9
Right price	8
Liked the campus	7
Offered chemical engineering	2
Friends go here	2
Good faculty/student ratio	2
Other	7
Do you know anyone who is a ChE? Who?	
No	16
Family member	6
Family friend	6
Other	4
What does a ChE do?	
Designs chemical processes (efficiently)	18
Product design (molecular level)	5
Determines chemical reactions	3
Applies chemistry to real world	3
Everything	2
Scale-up	2
Don't know	2
Other	3
What are you hoping to learn in this course?	
Better understanding of the field	12
What ChE's do for a living / opportunities	11
Whether I made the right choice in Major	5
What is it like to be a ChE	3
What to expect during school	3
How to get a ChE job	2
How to be a good ChE	2
Other	5

What jobs can you get with a B.S. in ChE?	
Pharmaceuticals / Medical	12
Petroleum	10
Chemical	10
Plastics	7
Don't Know	5
Environmental	4
Business	4
Anything	4
Paper mills	3
Teach	3
Law	2
Operations/Development	2
Design	2
Other	14
Why do ChEs have to take Math?	
To perform functions of a ChE	13
Need to solve different (process) problems	10
Need strong math background / foundation	7
Way to weed out students	1
Don't know	1
Is there a class that worries you?	
Senior	
Kinetics	1
Junior	
Physical Chemistry	3
Transfer Science	1
Thermodynamics 1	1
Physics 2	1
Sophomore	
Calculus 2	3
Thermodynamics 1	1
Physics	1
Freshman	
No	9
Math	7
English (Writing)	5
General Chemistry	3
History	1
Intro to Engineering	1
American Government	1
All	1

Not surprisingly, more than half of the students indicated an interest in chemistry as a reason why they chose chemical engineering as a major. This would validate intuition and the general perception among faculty as to why students enter chemical engineering. Additionally, this issue of "liking chemistry" as a very important selection factor has been observed in a larger study recently as well. [5] With regards to knowledge of the field, half of the students reported not knowing a single chemical engineer. However, more than half correctly identified chemical processes with chemical engineering when responding to a question about what chemical engineers do on the job. When considering fields where chemical engineers are employed, it is clear that even though only 3 people identified medical/biological/pharmaceutical as a reason they chose chemical engineering, many are cognizant of the fact that these fields employ an increasing number of chemical engineers.

Mathematics courses throughout the country are sometimes seen as a gate-keeping sort of class for students in engineering. In order to assess this area, we asked the students about their perception of why they are taking math classes. The top three answers point to three levels of understanding relevant to chemical engineering. Seven students plainly stated, without commenting further, that a chemical engineer needs a strong background in math. Thirteen students took this a step further by commenting that this strong background in math is needed to perform job functions of a chemical engineer. Finally, ten students ultimately linked the use of and need for math in solving different process problems.

Finally, it is of interest to note that only the freshman students reported that they were not worried about a class that semester, while all of the upperclassman indicated that there was at least one class which worried them.

Syllabus Design and Class Content

In this section we will describe each of the 14 class sessions of our ChE 1010 offering. Each session lasted 55 minutes and was held once a week. Even though this class was specifically designed for freshman, some upperclassman were so excited about this idea, that they requested to take this class. Accordingly, the class breakdown (36 students, total) was as follows: 29 freshman, 3 sophomores, 3 juniors and 1 senior.

The grading for the class was based solely on attendance. If a student missed a class without a legitimate reason, they could make up for this class by attending one of several professional development activities (normally a Departmental Research Seminar Series).

Class 1: Getting to Know You

During this initial class, a pre-assessment form was distributed to all students. After this, each faculty member was introduced and gave a brief (2 minute) oral presentation on who they were, where they came from and why they were in academia. Next, a list of all students and their advisors were provided. This was done so that students knew on the very first day of class at Tennessee Tech who their advisor was and what they looked like. This was followed by another list of Big Brothers / Big Sisters and their little sibling. Each freshman and sophomore student enrolled was provided a Big Brother or a Big Sister (comprised of upperclassman in chemical engineering). After this, each student introduced themselves, where they were from and why they wanted to be a chemical engineer. Next, the student and faculty advisors gave a brief talk about chemical engineering organizations available to students (AIChE and OXE). Finally, pizza was served and each student was requested to meet briefly with their Big Sibling and talk to the various Faculty in the room..

Class 2: Hands-on Experiment #1: *Hot-Dog!*

Seymour and Hewitt's powerful and revealing treatise on undergraduate STEM majors, *"Talking About Leaving*", [1] provides a table of factors that STEM majors have cited as reasons for switching out of STEM. The top factor provided is the students being "turned off" by science. The implication is that most likely, at some level, these students had (at one point) some intrinsic interest in science. This interest *very likely* did not come from listening to a lecture on a topic (which is typical in many engineering colleges), but either seeing a demonstration or, more likely, from doing something themselves. To this end, we attempted to address this issue by having three <u>hands-on activities</u> during the semester. The first of these activities was held on the second class session and was about heat transfer scaling.

Six groups of six students were asked the following question: *You cook a 20 pound Thanksgiving turkey and it takes 6 hours to cook. If you wanted to cook a 10 pound turkey, would it take 3 hours to cook?* At this point, groups of students postulated various scaling laws (density, length, mass, area, etc.) and were coached to use experiments with hot dogs to help verify the scaling laws they developed: three different sized hot dogs were provided to each group. Then, each group took the physical parameters of the hot dogs (weight, length, etc.). Next, they put a thermocouple inside each hotdog and cooked the hotdog in boiling water. A handheld data acquisition device recorded the temperature as a function of time. From this information, they tested various scaling laws until they arrived at the one that seemed to work the best. A large group share was conducted during the last ten minutes of class to discuss the various results from each group. Note that three professors and a graduate student were used during this class to provide guidance and general coaching directions, where required, to each group.

Class 3: Why Am I Taking the Classes I am Taking / Math Day

The first part of this class was devoted to answering the generic question "Why do I have to take <some class> to become a chemical engineer?" At the beginning of class, the motivating question was asked, "I want to make chemical C by mixing chemical A and B. All I need to worry about is mixing them together, right?" Next, students broke off to small groups to discuss some of the things they would need to concern themselves with, as chemical engineers. Following this, a piping and instrumentation diagram was provided for a system to complete this process (including separation). Then, each class in the ChE curriculum was described and it was discussed how that class would help in the analysis of the process. Such a procedure was done in an attempt to show not only the integration of each class, but why they were chosen for the curriculum.

In the second part of the class, we had any student having difficulty with their current math class to stay. During an internal study at Tennessee Tech, it was determined that success or failure during the first math class (whatever it may be) was the most useful indicator of Engineering students sustaining to graduation. Accordingly, we wanted to address any potential math concerns early in the semester. About half of the class stayed back and, depending on the course, different chemical engineering faculty worked with that group. Additionally, details on the Math Lab on campus were provided to students who required some extra help.

Class 4: I Finish My B.S. in Chemical Engineering and I Can Do What?

A popular book used in Introduction to Engineering classes at various institutions (including Tennessee Tech) is "*Engineering your Future*".[6] In chapter 3 of this book they provide 30, one-page profiles of engineers in various positions. Of that 30, only one was a chemical engineer: Jack Welch, the former CEO from General Electric who not only holds a B.S. degree, but a Ph. D. as well. If these profiles are being used to provide the reader with "what it is really like to be an engineer" (as stated in the book), then providing a profile of a CEO with a Ph. D. in chemical engineering will provide the reader with a distorted view of this discipline which can, in turn, foster the development of misconceptions. Such an approach, unfortunately, is typical as society, in general, and other engineers, in particular, often struggle with defining what a chemical engineer does.

As an introduction to this topic, students at the beginning of this class were provided with a list of sixteen diverse companies and asked to circle which ones hired chemical engineers. Anecdotally, the average circled was around eight. However, several students (especially the upperclassman), figured out the assignment and realized that all of the companies hired chemical engineers. At this point, it was discussed how chemical engineers were used in those industries. Next, profiles from chemical engineers provided from the AIChE website were used as small groups of students' analyzed different profiles. A large group share ensued after this to discuss the links amongst the jobs. Finally, the issue of graduate school was discussed while M.S. and Ph. D. positions were provided.

Class 5: Soft-Skills Day

Tennessee Tech has a Freshman Experience course with a few faculty who teach this course.[7] We decided to use their expertise on the generic topic of soft skills to facilitate this session. Highlights were provided on time management skills and locus of control. Based on the content covered, future offerings of this section can be performed by chemical engineering faculty.

Class 6: Hands-on Experiment #2: *Ice Cream!*

Colligative properties are something that most people are familiar with and, of course, are important for chemical engineers. In this session, we decided to explore boiling point elevation and freezing point depression of water. For the former, we filled two, one-liter, beakers of distilled water and placed them on a stirred-hot plate with a thermometer placed inside the beaker. In one of the beakers we added enough salt to raise the boiling point 5 Celcius degrees. Next we turned on the hot plates and waiting for the liquids to boil. While this was on-going, we decided to make ice-cream. In a one-quart Ziploc® storage bag, various ice cream ingredients were added. In a one-gallon Ziploc® storage bag, a specific amount of salt was added to ice (at – 20

^{o}C). The one-quart bags were placed inside the one-gallon bags and the students "mixed" this for about 20 minutes (wearing provided gloves). During this time, colligative properties were discussed and how they were used in chemical engineering. Eventually the pure water boiled at 100 ^{o}C while the salt-water mixture boiled at 105 ^{o}C. A few students were selected to come to the front and observe the thermometer. Finally, after the ice cream was sufficiently cold, the students removed the one-quart bags and measured the temperature of the salt water solution. Many were under -10 ^{o}C. After this, the students were given plastic spoons and ate the ice cream that they made.

Class 7: Co-op Information Day

About two-thirds of the students at Tennessee Tech in the Department of Chemical Engineering choose to co-op. A Career Services office facilitates finding these positions for the students and in setting up the interviews. During Co-op day, the Associate Director of Career Services talked for about 20 minutes on various issues associated with the Co-Op program. After this, three senior students who had already returned from their co-op assignment talked (for ten minutes each) about their experiences. Each student had worked at a different company. For their presentation, they were instructed to focus on issues such as: (1) How did my co-op assignment help me when I returned to school, (2) What did I do on my co-op assignment and (3) What are things they wished they knew before they went on co-op. After all of the presentations were completed, they took questions from the audience.

Class 8: Chemical Engineering Laboratory Tour

One of us is the Undergraduate Program Coordinator (UPC) for the Department of Chemical Engineering at Tennessee Tech. In this capacity, the UPC has met with over fifty high school senior students (individually) discussing the program with them during official campus visits. During the course of these visits, the students are asked whether they would like to have a tour of the laboratory. No one has declined this and, in fact, the majority is quite excited about this portion of the visit. In order to cultivate this laboratory interest, we set up four chemical engineering laboratory sites on campus. One of these locations housed the larger unit operations equipment (distillation column, pumps, heat exchangers, packed column, etc.). The other three were where research (both graduate and undergraduate) is performed, namely (1) polymers processing equipment, (2) fuel cell and battery manufacture and (3) scanning electron microscope. The class was broken into four groups and each group attended one of the locations for 15 minutes where they were given a presentation on the research performed there. For the next class period, the students were required to write a one-page summary of which experimentation they were most interested in and why. We plan to use this information to, possibly, link undergraduate research students with appropriate projects.

Class 9: Industrial Speaker Day

An adjunct member of our faculty has around 30 years of industrial experience in a wide range of companies performing various tasks. He was invited (during the week of the AIChE meeting) to discuss his vast experience to students in this class. The purpose of this particular class was to demonstrate how, in a typical career, one will normally work at several companies.

Class 10: Hands-on Experiment #3: Iodine Production.

Students were presented with a small-scale problem: a Petri dish with a potassium iodide solution, a 9V battery and two wires. Their problem is to first generate iodine from the solution electrochemically. Groups are allowed 10-15 min exploration time along with a paragraph describing the chemistry at the two electrodes. The professor then draws all attention to the board, and class members brainstorm to describe the job of a chemical engineer in a commercial plant producing iodine from seawater. What problems need to be solved? The professor helps to divide the tasks into engineering tasks and others. Engineering tasks may include separation of the iodine from the water, dissipation of heat, continuous flow, treatment of byproducts, increasing production rates, etc. Now the individual groups are asked to brainstorm to envision a design solving just one of the problems, but using inexpensive small-scale materials. A problem statement, drawing, description and cost estimate are required from each group towards the end of the class. Two professors walk around the room to provide encouragement and any requested guidance as the work unfolds. At the end, the class refocuses and we discuss the solutions generated.

Class 11: Research Day

Despite the fact that grade school teachers and college faculty are both educators, many people (students included) are not savvy to the differences in job functions. They know that grade school teachers are in the classroom for many periods every day. However, if you were to mention to someone that "you don't have a class on Tuesdays or Thursdays", there impression is that you need not come into work that day. Of course, the issue that most people miss is the fact that faculty perform research when not engaging in the task of instruction. To both make this real for the incoming freshman students as well as inform them of, perhaps, potential research projects, we held a Research Day. Here, the students were introduced to the logistics of completing an Introduction to Research elective course as well as some addition research options (fast track B.S./M.S. program and a Distinction in the Major program). After this, each faculty member gave a five-minute presentation highlighting the research done in their group, with a special emphasis on undergraduate research projects.

Class 12: Working in Teams and Active/Co-operative Learning

The faculty in the Department of Chemical Engineering at Tennessee Tech emphasizes co-operative learning in the classroom. In order to have students buy into this non-traditional mode in engineering instruction, we introduced this idea to them through the use of the Dale Cone of Learning.[8] This approach gets them to think about retention of information and various instructional methods. Once they agree that more active modes result in more retention, the axis on the Cone of Learning was changed. Now, instead of using "effectiveness in learning", the axis label was modified to "frequency of method used in engineering instruction" The result is exactly opposite to the previous cone which allows the instructor to discuss this unmatched situation in engineering education and to provide reasons for why this is the case. At this point, with the proper set-up and buy-in, active and collaborative learning techniques are described in more detail.

Class 13: Assessment

We designed an assessment vehicle, aided by one of the students in the class, to determine if progress had been made on the course objectives. After this was complete, one of the freshman students held (in the absence of any faculty) an open forum to talk about various class issues in order to flesh out any issues that were not addressed on the assessment vehicle.

Class 14: Fun Mixer

Like the first class session, we ended the semester with a pizza party that all faculty attended. Additionally, a "Who Wants to Be a Millionaire" type of game was performed where students had to answer questions based on the course content. The prizes awarded were departmental T-shirts with the College logo. Overall, students performed well in this "review" and seemed to enjoy the contest. It was a fun and positive way to end the semester.

Post-Assessment

During Class #13 we distributed a post-assessment form. This form had two parts. The first part assessed 12 individual class sessions (excluding #13 and #14) on a Likert scale as to whether progress was made on the course goals, which were as follows (and listed on the survey):

> "*Information is provided to potential chemical engineering majors in a variety of areas including: curriculum linkages, the profession, collaborative work environments, faculty interaction, mentoring opportunities, professional societies and laboratory skills*"

The options provided were 1, 2, 3, 4 and 5 where 1 indicated "strongly disagree", 2 indicated "disagree", 3 indicated "neutral", 4 indicated "agree" and 5 indicated "strongly agree". Table 2 provides these results with the associated standard deviation.

Table 2: Results of the Post-Assessment per class topic (N = 36)

	Class Topic	Score	SD
Class 2:	Hands-on Experiment #1: Hot-Dog!	4.7	0.5
Class 7:	Co-op Information Day	4.6	0.7
Class 6:	Hands-on Experiment #2: Ice Cream	4.5	0.8
Class 8:	Chemical Engineering Laboratory Tours	4.5	0.7
Class 4:	I Finish My B.S. in Chemical Engineering and I can do What?	4.4	0.8
Class 1:	Getting to Know You	4.4	0.7
Class 3:	Why Am I Taking the Classes I am Taking / Math Day	4.3	0.8
Class 10:	Hands-on Experiment #3: Iodine Production	4.3	0.9
Class 11:	Research Day	4.1	0.8
Class 5:	Soft-Skills Day	3.8	0.7
Class 12:	Working in Teams and Active/Co-operative Learning	3.7	0.8
Class 9:	Industrial Speaker Day	3.7	1.1

Overall, the average for all topics was a 4.24 which indicates that students agree that progress has been made on the course objectives as a result of this class. On a per topic basis, it is clear that the experiments were well received. Note that, although the Laboratory Tours rated out only 4^{th} of 12 topics, it was identified (in the second part of the survey) as the best topic by 12 of 36 students. On the other end of the spectrum, students rated the Industrial Speaker their least favorite topic. They felt the presentation itself was not very exciting (re: boring) and suggested a younger person from industry who they could relate to better.

The second part of the survey asked the students nine different questions. As some are not relevant to this particular paper, we provide highlights here as opposed to the table used (Table 1) for the pre-Assessment. Note that all of the numbers provided are out of 36 students.

- 29 students said that they were more likely to stay in chemical engineering as a result of this course, with 5 indicating that this course had no effect or they were not sure. Two respondents indicated that they were likely going to transfer out of chemical engineering.
- 33 students indicated that they learned what they were hoping to learn as a result of taking this course.
- 35 students indicated that Tennessee Tech had lived up to their expectations with 10 of them citing the challenging curriculum as the main reason.
- The most common response to the question as to what a student would do with their B.S. degree was "not sure", listed by 10 respondents.
- When the question was asked about additional topics for when this course was offered next year, the following were the most popular responses:
  - Field trip/Plant Tour
  - Design project
  - Chemical engineering in the news
  - More experiments

As had been previously mentioned, a freshman student held an open forum to discuss issues related to this class not mentioned on the assessment form. No new information not revealed during the surveys was reported.

Conclusions

In this work we report on an Introduction to Chemical Engineering course started at Tennessee Tech in an attempt to inform our freshman students about chemical engineering and cultivate their intrinsic interest in the subject. Based on assessments performed, it is clear that this class met the course objectives. From pointed feedback from students, subsequent class offerings will contain additional hands-on experiments as well as a design project and a plant tour. Note that we might add a laboratory component to this class in order to address computing issues and to provide additional class time for the design project. Overall, this type of course seems to be quite helpful to inform students about chemical engineering as a profession and to avoid misconceptions among freshman students as a result of misinformation.

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