Early Introduction of Design Fundamentals into the Chemical Engineering Curriculum

Brian S. Mitchell
Tulane University

Introduction

In response to concerns raised by the Accreditation Board for Engineering and Technology (ABET), many chemical engineering departments have been revising the design components of their curricula. These modifications range from incorporation of open-ended problems in existing courses to the development of new, design-oriented courses. At Tulane University in New Orleans, both of these approaches have been taken, in addition to renaming some existing courses to make a unified design sequence. The course "Chemical Engineering Design I," is a first-semester, sophomore level course that was introduced in September, 1994 as part of a revised curriculum. The course content, its place in the design sequence, and the advantages and disadvantages of its inclusion in the curriculum are the subjects of this paper.

Course Content

A course outline for Chemical Engineering Design I is shown in Table 1. In its current form, Chemical Engineering Design I deals with the fundamental principles of five major topics: descriptive statistics, probability distributions, reliability analysis, quality control and engineering economics. Various components have been added and removed since the inception of the course. For example, linear regression was covered the first year, but was removed in subsequent years since essentially the same material is covered in Stoichiometry. Experimental design was introduced, including factorial analysis, but was removed in 1996 to make room for more engineering economics and an expansion of the design project. One-hour lectures on safety and engineering ethics are also incorporated as time allows. The majority of the class, however, is devoted to the five areas described above. *Statistics for Engineering and the Sciences* by Mendenhall and Sincich[1] is currently the textbook for this course.

Descriptive statistics, probability fundamentals and probability distributions are covered in the first third of the course. The textbook is used for the majority of this material, with some supplementation for probability distributions. Spreadsheets are also utilized extensively to solve homework problems in descriptive statistics, ANOVA, hypothesis testing and probability calculations. Spreadsheet examples are performed in an electronic classroom, equipped with PCs, in which students, working in pairs, can solve example problems along with the instructor.

The second third of the course deals with applications of statistics and probability to chemical engineering. Specifically, component and system reliability, fault tree analysis,, acceptance sampling and control charts are covered. Again, spreadsheets are employed, particularly for the analysis and graphing of control chart data. The textbook is augmented heavily in this section with supplemental reading on fault tree analysis, and example problems from the chemical process industry.

The final portion of the course is dedicated to the design project and an introduction to engineering economics. Cost and asset accounting, and cost estimation are taught from *Plant Design and Economics for Chemical Engineers* by Peters and Timmerhaus[2]. Concurrent with the instruction of this material, students are formed into groups of three to five (depending on class size) and given a design project to work on. Ideally, the design project is the same one they are using in Stoichiometry, which is taught concurrently with Design I. The book for Stoichiometry, *Elementary Principles of Chemical Processes* by Felder and Rousseau[3] contains several excellent case studies., any one of which can be utilized for both courses. Case studies from previous editions of the book have also been utilized as design projects. Students work in the same group in both courses. The groups are required to submit a report for Stoichiometry that addresses selected questions from the case study. The Stoichiometry report consists primarily of mass and energy balances.

For Design I, the students are required to submit two reports: a progress report due approximately two weeks after the case study is assigned; and a final report at the end of the semester. The progress report must contain the following information:

- a process flow diagram generated with PROvision software
- a fault tree diagram that corresponds to the flow diagram
- a reliability analysis based on the fault tree; *i.e.*, the probability of occurrence of the top event in the fault tree.

The process simulation software is available on the computers in the electronic classroom, and a one lecture tutorial on its use is provided. This past year, a senior chemical engineer from the capstone design course was asked to perform this tutorial. This approach proved to be successful. The final report must include all of the information from the progress report with appropriate corrections, plus the following additional information:

- quality control guidelines and acceptance sampling plan for the final product
- preliminary cost estimate for construction of a new plant, based on the flow diagram.

Only one report is required from each group, and each student receives the same grade. The design reports constitute 15% of each student's overall grade. The progress and final reports are given equal weight, and are graded on clarity, accuracy of information, ingenuity and adherence to the specified report format.

The design report proves to be challenging for several reasons. First, the students must perform a library search to obtain reliability information (mean time to failure) for chemical process equipment. This past year, one group telephoned a consulting firm and requested this information, which they received. The students must also look up costs for raw materials and equipment - information that is often times lacking. The second source of frustration for the students, which is the primary purpose behind the report from a pedagogical point of view, is that there are no "right" answers to the questions, particularly for the quality control portion of the project. The students must propose a method for evaluating the quality and performance of their process and/or product, and be able to justify it. Finally, students must become accustomed to working in groups on substantial problems for extended periods of time. The sooner they begin to develop these skills, the more effectively they can work on design problems as upperclassmen.

To aid in the development of group skills, alternative teaching techniques such as cooperative learning[4], Thinking Aloud Pair Problem-Solving (TAPPS)[5], and think-pair-share are used extensively in Design I, in addition to the traditional lecture and electronic classroom demonstrations. There is a definite "activation energy barrier" that must be overcome to the alternative techniques; that is, students must shift the paradigm of the college lecture that they have from their freshman year, and open themselves to developing creative solutions and working with others during the lecture. Taken as a whole, Design I is intended to help students develop group skills, improve their technical writing, and introduce them to chemical engineering design concepts that they can utilize through the rest of the curriculum.

Course Placement in Design Sequence

Chemical Engineering Design I is part of a five-course sequence in chemical engineering design (see Table 2). Design II is a 3-credit lecture course on computer methods such as solution of linear and nonlinear equations; numerical solution of ordinary and partial differential equations; and optimization. Application of these techniques to problems in chemical engineering are employed to provide the design component to this course. Prior to taking Design II, students have been introduced to linear regression, and graphical techniques and software in Design I.

Design III and IV are unit operations laboratories, taught during the spring and summer semesters of the junior year, respectively. In addition to the tradition unit operations emphasis of these 3-credit lab courses, safety, ethics, report writing, presentation skills and career guidance are emphasized. Some of these topics have already been introduced in Design I. Ethics have been introduced during a lecture on quality control. Report writing is also emphasized in Design I.

As in most chemical engineering curricula, the design sequence is finalized with the capstone design course, entitled "Process Design and Economics." This first semester senior course attempts to integrate knowledge acquired in earlier courses and familiarize the students with the use of Simulation Science's Process computer-aided design software. Students have already been introduced to this software in Design I, and have been taught preliminary engineering economics. *Plant Design and Economics for Chemical Engineers* by Peters and Timmerhaus is utilized extensively in the capstone design course. By the time the students take this course, they have essentially been taught 25-30% of the content of this book in previous design-oriented courses.

Course Evaluation

The primary purpose behind the development of Design I was to introduce students to design concepts at an early stage in the curriculum, and the course serves this purpose well. Reliability, quality control and economics principles apply to all aspects of chemical engineering, even though they may not be dealt with explicitly in all courses. More often then not, these concepts are utilized to their greatest extent in Practice School, in which students work in groups to solve a problem posed by a local industrial partner[6]. In particular, the introduction of engineering economics into the sophomore-level course has allowed the Process Design and Economics course to be concentrated more upon computer-aided design. Familiarity with the computer-aided design software from Design I further enhances this experience.

A common design project for Stoichiometry and Design I is another attractive component of this course. Less time is required on the students' part for background development since only one project is required for both courses. Ultimately, the same project could be used throughout the entire curriculum, as has been instituted at West Virginia University[7], providing all faculty are willing to participate. This would facilitate the inclusion of design components into the unit operations, reactor design and process control courses. From an instructor's point of view, a common design project for both Stoichiometry and Design I means one less design problem is required. Although the reliability, quality control and economic questions are not included in *Elementary Principles of Chemical Processes*, once they have been developed, they can be reused and modified as necessary. Interestingly, the cost estimation portion of the project yields a different answer each year due to fluctuating cost index factors, unlike the mass and energy balances, which (hopefully) do not vary.

No course is perfect, and Design I has its share of drawbacks. One drawback is that there are no textbooks currently on the market specifically suited for this material. *Statistics for Engineering and the Sciences* is an excellent text with many applications toward reliability and quality control, but very few of these applications are from the chemical process industry. In particular, reliability data for unit operations equipment, fault tree analysis and reliability calculations for flow systems are not dealt with. This book is also much heavier on hypothesis testing and statistical estimation than is required for Design I. As a result, there is a lot of "skipping around" the textbook, and supplementation with chemical process examples. Engineering economics is not covered at all in this book, so Peters and Timmerhaus is used for the final third of the course. This necessitates the purchase of two textbooks, and despite every assurance that they will use Peters and Timmerhaus again in their senior year, sophomore students are loath to purchase two expensive books for one class. It is this author's intent to prepare a text specifically for this course, once time allows.

The placement of this course in the curriculum is also cause for some concern. It is difficult to perform an economic or reliability analysis on a heat exchanger when the students haven't even learned what one is yet. Moreover, the concurrent instruction of Design I and Stoichiometry makes it difficult to discuss concepts that may not yet have been addressed fully in Stoichiometry, such as heat balances. We are considering moving Design I to the second semester of the sophomore year to allow some time for the students to gain some "chemical engineering maturity". This move would not necessarily adversely affect the common design project - it would simply be carried over from one semester to the other.

Summary

Chemical Engineering Design I is a required sophomore-level course for chemical engineering undergraduates at Tulane University. The principles of descriptive statistics, probability distributions, reliability analysis, quality control and engineering economics are taught using traditional and alternative teaching techniques. The use of spreadsheets and process simulation software are taught in an electronic classroom, both of which are utilized for a semester-end design project. The design project requires a fault tree analysis, quality control guidelines, computer-generated flow diagram and preliminary cost estimation for a case study in chemical engineering. The same case study is used to perform mass and energy balances for Stoichiometry, which is taught concurrently with Design I. The early introduction of design fundamentals into the chemical engineering curriculum provides a framework for design problems in subsequent courses and allows a greater emphasis to be placed on computer-aided design in the capstone design course.

Table 1 Outline of Chemical Engineering Design I Course Content

Topic		Approximate # of Lectures
Statistics and Probability		
A.	Descriptive Statistics	3
B.	Probability Models	3
C.	Probability Distributions	3
Reliability and Quality Control		
A.	Sampling Distributions, Analysis of Variance	3
B.	Statistical Process and Quality Control	3
C.	Product and System Reliability	3
Introduction to Engineering Economics		
A.	Cost and Asset Accounting	3
B.	Cost Estimation	3
Design Project, Miscellaneous Topics		7

Table 2 Chemical Engineering Curriculum at Tulane University

First Year

Fall Semester	*Credits*	*Spring Semester*	*Credits*
Chemistry I and Lab	4	General Chemistry II and Lab	4
Introduction to Computing	4	English (Writing)	4
Introduction to Engineering	1	Introduction to Engineering	1
Calculus I	4	Calculus II	4
General Physics I and Lab	4	General Physics II and Lab	4

Second Year

Fall Semester	*Credits*	*Spring Semester*	*Credits*
Stoichiometry	3	Thermodynamics I	3
Chemical Engineering Design I	3	Unit Operations I	3
Organic Chemistry I	3	Organic Chemistry II	3
Organic Chemistry Lab I	1	Organic Chemistry Lab II	1
Calculus III	4	Introduction to Applied Math	4
Elective	3	Elective	3

Third Year

Fall Semester	*Credits*	*Spring Semester*	*Credits*
Thermodynamics II	3	Chemical Engineering Design III	3
Chemical Engineering Design II	3	Unit Operations III	3
Unit Operations II	3	Electrical Instruments and Power	3
Mechanics	3	Technical Elective	3
Elective	3	Elective	3
		Summer Semester	*Credits*
		Chemical Engineering Design IV	3

Fourth Year

Fall Semester	*Credits*	*Spring Semester*	*Credits*
Kinetics and Reactor Design	3	Process Control	3
Process Design and Economics	3	Practice School I	3
Chemistry Elective	4	Practice School II	3
Technical Elective	3	Chemistry Elective	4
Elective	3	Elective	3

References

1. Mendenhall, W. and T. Sincich, "Statistics for Engineering and the Sciences," 4th edition, Prentice-Hall, Upper Saddle River, NJ, 1995.

2. Peters, M.S. and K.D. Timmerhaus, "Plant Design and Economics for Chemical Engineers," 4th edition, McGraw-Hill, NY, 1991.

3. Felder, R.M. and R.W. Rousseau, Elementary Principles of Chemical Processes," 2nd edition, Wiley, NY, 1986.

4. Johnson, D.W., R.T. Johnson and K.A. Smith, "Active Learning: Cooperation in the College Classroom," Interaction Press, Edina, MN, 1991.

5. Whimbey, A.E. and J. Lochhead, "Beyond Problem Solving and Comprehension," 3rd edition, Lawrence Erlbaum Assoc., Hillsdale, NJ, 1984.

6. Walz, J.Y., "The Chemical Engineering Practice School Program at Tulane University," *Chem. Eng. Ed.*, **29**(3), 246 (1995)

7. Bailie, R.C., J.A. Schaeiwitz, and W.B. Whiting, "An Integrated Design Sequence," *Chem. Eng. Ed.*, **28**(1), 52 (1994)

BRIAN S. MITCHELL is Associate Professor of Chemical Engineering at Tulane University in New Orleans, LA. He obtained his B.S. in Chemical Engineering from the University of Illinois, and his M.S. and Ph.D. degrees in Chemical Engineering from the University of Wisconsin. His research interests include fiber technology and materials processing. In addition to Design I, he teaches Heat Transfer, Unit Ops Lab, and Materials Science.

Engineering curriculum design and continuous programme improvement 5.2.Â The introduction of the third generation of the Federal Education Standards (FES) in 2011 provides Russian HEIs with new opportu-nities for the development of programmes (both bache-lor programmes, but mainly master programmes that are currently being widely introduced in Russia) which correspond to the requirements of both national and European standards.Â The de-velopment of programmes, the design of curricula and the enhancement of teaching Introduction and Integration of Chemical Engineering Topics: The text provides an integrated, holistic view of chemical engineering. WEBSITE The Web site for this book, located at www.wiley.com/college/solen, includes the fol- lowing helpful materials for instructors: Sample Syllabus with suggested course coverage and organization.Â Transfer 131 Reading Questions 139 Homework Problems 139 CHAPTER 9 REACTION ENGINEERING 141 9.1 Describing Reaction Rates 141 9.2 Designing the Reactor 146 Reading Questions 154 Homework Problems 155 CHAPTER 10 HEAT TRANSFER 157 10.1 Energy Balances for Steady-State Open Systems 157 10.2 Applications of the Steady-State Energy Balance 164 10.3 Heat-Exchange Devices 173 Reading. Design of chemical reactors and process plants. Development of sustainable products. Pollution control and treatment of industrial wastes. Man has utilized chemicals for a long time but chemical engineering was recognized as a separate field only a century ago. Egyptians developed certain types of papers as early as 2000 BC and glass is presumed to have been invented close to 5000 BC. Perhaps the single most important pursuit in chemistry was the â€˜manufactureâ€™ of gold. As soon as man discovered this metal he became obsessed with it.Â Up till 1910, the chemical industry had to rely mainly on mechanical engineers and chemists. Figure 1.1 Typical chemical process plant. Chemical engineering is a branch of engineering that uses principles of chemistry, physics, mathematics, biology, and economics to efficiently use, produce, design, transport and transform energy and materials. The work of chemical engineers can range from the utilization of nanotechnology and nanomaterials in the laboratory to large-scale industrial processes that convert chemicals, raw materials, living cells, microorganisms, and energy into useful forms and products. Energy Processes Division (TEP) Chemical Engineering & the Law Forum (ChE&L) Computational Molecular Science & Engineering Forum (CoMSEF) Nanoscale Science & Engineering Forum (NSEF) North American Mixing Forum (NAMF) Particle Technology Forum (PTF) Pharmaceutical Discovery, Development and Manufacturing Forum (PD2M) Sustainable Engineering Forum (SEF) Upstream Engineering & Flow Assurance Forum (UE & FA).Â AIChE Engage connects AIChE members with each other and their chemical engineering communities.