Chemical Engineering Education

Volume 28  •  Number 2  •  Spring 1994

John H. Seinfeld
of the
California Institute of Technology

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CHEMICAL ENGINEERING EDUCATION (ISSN 0009-2479) is published quarterly by the Chemical Engineering Division, American Society for Engineering Education, and is edited at the University of Florida. Correspondence regarding editorial matter, circulation, and changes of address should be sent to CEE, Chemical Engineering Department, University of Florida, Gainesville, FL 32611-2022. Copyright © 1994 by the Chemical Engineering Division, American Society for Engineering Education. The statements and opinions expressed in this periodical are those of the writers and Not necessarily those of the CEE Division, ASEEE, which body assumes no responsibility for them. Defective copies replaced if notified within 120 days of publication. Write for information on subscription costs and for back copy costs and availability. POSTMASTER: Send address changes to CEE, Chemical Engineering Department., University of Florida, Gainesville, FL 32611.
John H. Seinfeld
of the California Institute of Technology

BY HIS COLLEAGUES AT
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Pasadena, CA 91125

John Seinfeld was born in Elmira, a small city in upstate New York about thirty miles from Ithaca. His studious tendencies showed themselves early, and at age twelve he was a national finalist in a public-speaking contest sponsored by the Optimist Club. As in many small towns in those days, high school athletics was king—baseball and golf became his sports. He was a good enough golfer to play on his high school golf team and, later, for the University of Rochester. After being named “most likely to succeed” in his high school graduating class, he went on to the university where he chose chemical engineering as a major because he liked math and chemistry.

He entered the freshman class at the University of Rochester and found himself a classmate of many students from New York City schools who had already had calculus and other “advanced” subjects. He requested that he be placed in the advanced math track but soon found he was swimming upstream. In the end, he managed to solve every problem in Thomas’s calculus book on his own, and received the highest grade in the freshman calculus course.

As an undergraduate in chemical engineering, he was strongly influenced by two faculty members in that department: Stan Middleman (now at the University of California, San Diego) and David Smith (now at du Pont). John recalls fondly the famous summer unit operations laboratory taught by then department chairman, Shelby Miller. Lab reports returned by Shelby, covered with corrections in his infamous green ink, were dreaded by the students and were their first experiences with critical report writing. John graduated first in the College of Engineering at the University of Rochester and decided to attend Princeton for graduate work. He had used Leon Lapidus’s book as an undergraduate and that, together with Princeton’s substantial reputation, caused him to choose Princeton.

At Princeton, he decided to work for Lapidus, who was one of the earliest to introduce mathematical methods and process control into chemical engineering. The Princeton chemical engineering department was a stimulating place under the combined ministrations of Lapidus, Dick Wilhelm (one of the early pioneers of chemical reaction engineering), and a new faculty member in the field of fluid mechanics, Bill Schowalter. Although John was pursuing a thesis in optimal control theory, he took every fluid mechanics course offered by Bill Schowalter. “He was such a good teacher that he actually made me believe that I understood all the tensorial manipulations in rheology,” John says.

While at Princeton, John shared an apartment with Steve Jaffe (now at Mobil Research and Development) and Dale Seborg (now professor of chemical engineering at the University of California, Santa Barbara). Stories of practical jokes played on one or another of the three by the other two keep Steve, Dale, and John laughing to this day. In his final year at Princeton, he received the Wallace Memorial Fellowship in Engineering, traditionally given to the most outstanding graduate student in engineering.

One afternoon at the Princeton bookstore, one of the other chemical engineers pointed out, with reverence, another shopper—James Wei, who was on sabbatical at Princeton from Mobil. Much later it turned out that John formed a professional and personal friendship with Jim.

The late 1960s were an exciting time to be a graduate student in chemical engineering at Princeton, and many of the graduate students have gone on to distinguished careers in industry and academia. The nightly midnight run to the King’s Inn for pizza and beer was almost a departmental function.

Because of the influence of Leon Lapidus, Dick Wilhelm, and Bill Schowalter, John decided he wanted to pursue an academic career. There were not a lot of faculty openings in 1967, but Bill Corcoran of Caltech had written Dick Wilhelm about an opening in that school’s department. John...
flew out for an interview, and when a position was offered he eagerly accepted it. He joined the Caltech department in the fall of 1967.

Chemical engineering at Caltech essentially started in the early 1940s under the leadership of Will Lacey and Bruce Sage and the old American Petroleum Institute Project 37 which dealt with thermodynamic properties of hydrocarbon mixtures. It had become clear by the mid-1960s that it was time to form a modern department of chemical engineering at Caltech. Bill Corcoran was appointed as executive officer (the term used at Caltech for a department chairman position), and he proceeded to hire Sheldon Friedlander from Johns Hopkins in 1964 and George Gavalas from the University of Minnesota in the same year. Fred Shair was added in 1965, and John joined the department in 1967. An exciting period of growth followed in which, within a span of five years, Bob Vaughan, Gary Leal, and Henry Weinberg were added to the department. Caltech was well on its way to having one of the premier chemical engineering departments in the country.

Having done his thesis in the area of optimal control theory, John continued his research in this area after coming to Caltech. He was particularly interested in optimal control and parameter estimation problems involving partial differential equations, such as tubular flow reactors and petroleum reservoirs. He received the American Automatic Control Council’s 1970 Donald P. Eckman Award for contributions by a young researcher in the field of control theory.

While some of his colleagues spent their lunch hour swimming or jogging, John has always been an avid lunch-goer, especially at Caltech’s renowned faculty club, the Athenaum. And it was during one of those lunches that Shel Friedlander interested him in the newly emerging field of air pollution. John immediately saw an opportunity for someone who was deeply trained in mathematical methods, numerical analysis, and modeling to apply those approaches to atmospheric air pollution. So around the year 1970, John started shifting the emphasis of his research program from control theory to air pollution. One of his research ambitions has been to introduce and apply to the analysis of air pollution the level of rigor that has characterized the traditional approach to chemical reaction engineering. The soup of both natural and anthropogenic compounds, most present only at trace levels, leads to phenomena as diverse as greenhouse warming, stratospheric ozone depletion, urban and regional smog, and acid rain. John’s research has been a broad, but deep, attack on virtually all aspects of the chemistry and physics of air pollutants in the troposphere.

The atmosphere is a giant chemical reactor, with processes occurring on spatial and temporal scales ranging from a few centimeters to thousands of kilometers and from milliseconds to tens of years. In an era when air quality was studied with box, plume, and puff models, John undertook the development of air quality models that would apply reaction engineering techniques to an entire airshed. It was natural to apply these models to Los Angeles, which, in addition to being among the most polluted cities in the United States, offered the most data on emissions and air quality. This effort produced the first large-scale urban air pollution model, the precursor of the one now used nationwide by the Environmental Protection Agency. Efficient and robust numerical techniques are of paramount importance for spatially resolved modeling of chemical reactors with volumes of several thousand cubic kilometers. Efforts to develop suitable techniques began with the 1974 thesis of graduate student Steve Reynolds, and culminated with that of Greg McRae in 1981. Those methods form the basis for most airshed modeling even today. John and his student Donald Dabdub are currently exploring how air quality models can be implemented on Caltech’s massively parallel computers to further increase the capabilities of the models.

As the airshed models were developed, it became apparent that a lot of important data were either missing or uncertain. This led John to study the details of the chemical mechanisms and reaction kinetics and to develop techniques to assess the sensitivity of complex reaction mechanisms to the rate parameters employed in the models. While John’s understanding of the atmospheric chemistry grew, that chemistry was only part of the problem. The atmosphere is full of particles, haze, fog, and clouds. Indeed, one of the aspects of air pollution that is first noticed is the haze that forms at the end of atmospheric reactions. Much less was known about the atmospheric aerosol. New instruments providing a picture of the size distribution of the atmospheric aerosol showed that the particles accumulated at diameters comparable to the wavelength of light, making them very efficient at light scattering. People had studied coagulation equations, but there were no comprehensive models to describe how aerosol particles form and grow in the atmosphere.
John set out to advance aerosol modeling to the level of the gas-phase reaction models, studying methods for solving the aerosol dynamic equations as well as the basic physics of aerosol particle formation and growth. A breakthrough was made in 1979 by John’s student, Fred Gelbard, with his development of the first codes to track the evolution of the aerosol distribution of chemical composition as a function of particle size. John’s continued work in aerosol modeling has probed the aerosol chemistry, incorporating models of chemical and phase equilibria into the description of the atmospheric aerosol.

In 1975 a young assistant professor of environmental engineering science, Rick Flagan, joined Caltech, coming from mechanical engineering at MIT where he had pursued a thesis in the area of combustion. He was interested in the generation of pollutants in combustion processes, with special interest in aerosols. Rick Flagan is widely acknowledged as a superb experimentalist, and shortly after he arrived at Caltech he and John began a close to twenty-year collaboration on experimental atmospheric chemistry and aerosols.

Following Shel Friedlander’s departure from Caltech, John and Rick joined forces to revive the smog chamber facility. Although great for demonstrating atmospheric aerosol dynamics, the existing system was ill-suited to John’s needs for better data on atmospheric reactions since all sorts of contaminants were brought into the chamber with the Pasadena air. Graduate student Joe Leone modified the air-handling system so that it would clean the air to a small fraction of a part per million and began John’s experimental studies of atmospheric photochemical reactions. The smog chamber studies were so demanding that a tradition was established of teaming a student working on the gas-phase chemistry with one working on atmospheric aerosols. The smog chamber provided tantalizing insights into the ways that homogeneous nucleation and aerosol thermodynamics influence the atmospheric aerosol.

The smog chamber studies were augmented by more controlled bench-scale studies as well as theoretical investigations. These included laboratory studies of the rates and mechanisms of gas-phase reactions, studies of the fundamentals of nucleation theory, and development of mathematical models for atmospheric phenomena. Following a recent major gift of analytical instrumentation, the focus of the atmospheric reaction studies has turned to molecular identification of both aerosol products and gas-phase intermediates. Using new instrumentation that makes it possible to make real-time measurements of the aerosol and the analytical facilities, John and Rick have just begun a new research initiative, attempting to understand the aerosol processes that act to control cloud formation and albedo over the earth’s oceans. This program will involve aircraft-based measurements of aerosols in the marine boundary layer, to be carried out by Lynn Russell, a graduate student in chemical engineering.

In addition to the graduate courses in air pollution, John has over the years taught every undergraduate chemical engineering course offered at Caltech except thermodynamics, and is the author of seven books. His 1986 text, *Atmospheric Chemistry and Physics of Air Pollution*, has been adopted worldwide as the standard senior- and graduate-level text in air pollution. The two-volume set consisting of that book and a second, coauthored with Rick Flagan, *Fundamentals of Air Pollution Engineering*, constituted Caltech’s unique year-long course sequence in air pollution, covering combustion fundamentals, gas cleaning, aerosol science, atmospheric chemistry, and atmospheric transport and diffusion.

John Seinfeld has been described by some as fanatically organized—perhaps it was this character flaw that led to his being asked to assume the...
position of executive officer for chemical engineering in 1973, only six years after he joined the department as an assistant professor. Then in 1990 the Caltech administration asked him to take over as chairman of the Division of Engineering and Applied Science, Caltech’s equivalent to dean of engineering. What makes this unusual is that chemical engineering at Caltech is part of the Division of Chemistry and Chemical Engineering, not with the other ten or so engineering departments in the Division of Engineering and Applied Science. This was just enough of a challenge to induce John to agree to take on the job. He likes to point out that at two of the three schools (Berkeley, Caltech, and the University of Illinois) where chemical engineering is not administratively grouped with the other engineering departments, the dean of engineering is a chemical engineer. (Bill Schowalter is currently Dean of Engineering at Illinois.) An inspiration for John in his administrative roles has been his academic grandfather, Neal Amundson. When a particularly burdensome nonessential memo or request crosses his desk, he frequently asks himself, “What would Neal do with this piece of paper?” The answer, of course, is that Neal would throw it away. John is known for discarding all but the most essential paperwork—which could be how he keeps such a neat office. At Caltech, perhaps uniquely among universities, when one assumes a division chairman position, one works even harder on research. Currently, John has a research group of about a dozen graduate students and postdocs. “My graduate students take precedence over everything,” he says, so short of a call from Caltech’s president, they get top priority on his time.

John has been called on numerous times for national service and has served on or chaired some of the most influential national panels in the field of air pollution and atmospheric chemistry. From 1989 to 1991 he was chairman of the National Research Council Committee on Tropospheric Ozone Formation and Measurement. This committee produced the highly influential book, *Rethinking the Ozone Problem in Urban and Regional Air Pollution*, which has had an enormous effect on redirecting the nation’s efforts toward reducing ozone pollution at the urban and regional scale. He has just accepted chairmanship of the National Research Council Panel on Aerosol Radiative Forcing and Climate. Global climate change as a consequence of anthropogenic changes in the chemical composition of the atmosphere poses scientific questions of a nature and interdisciplinary scope that are unprecedented. Uncertainties in forecasts of climate change are large and thus far have hampered development of a clear world plan for mitigating against unacceptable effects. Uncertainties in the forcing of climate by changes in atmospheric aerosol and clouds represent the most important uncertainties in this entire area, and this new panel will attempt to formulate a national multiagency research plan to address these uncertainties.

While he has received numerous honors and awards, John considers his most lasting accomplishment to be the role he has played in the education of his forty-five PhDs and his current group of ten graduate students. Faculty members alone, among his PhDs, include Don Cormack (University of Toronto), Tom Peterson (University of Arizona), Ted Watson (Texas A&M), Greg McRae (MIT), Costas Kravaris (University of Michigan), Panos Georgopoulos (Rutgers University), Gideon Grader (Technion), Sonia Kreidenweis (Colorado State University), Spyros Pandis (Carnegie Mellon), Tony Wexler (University of Delaware), Suzanne Paulson (UCLA), Barbara Wyslouzil (Worcester Polytechnic Institute), and Frank Shi (University of California, Irvine).

John was elected to the National Academy of Engineering in 1982 at the age of thirty-nine, and in 1991 he was elected a Fellow of the American Academy of Arts and Sciences. In addition to the 1970 Donald P. Eckman Award mentioned earlier, John has received awards too numerous to list here, recognizing his outstanding contributions to the profession over the years.

In 1980 John met Betty Becker of Los Angeles and they were married in 1983. Betty is a former junior high and high school home economics teacher. Their five-year-old son Benjamin keeps them both hopping. Betty is an avid quilter who, unfortunately, doesn’t have as much time as she would like to pursue quilting. A couple of years ago she was president of the Caltech Women’s Club, a social organization of faculty and postdoctoral wives and staff women.

John admits that he is a workaholic, but Betty has been able to get him to see the value of a vacation away from phones, faxes, and e-mail. John has also resumed his golfing pursuits—if there is a challenging course nearby he can be easily persuaded to hit the links.
The University of Pittsburgh is located in Oakland, a bustling business district two miles from downtown (pronounced 'dahn-tahn' in Pittsburghe) Pittsburgh. Approaching the campus by car or bus, one is greeted by the university's tremendous Gothic structure, the Cathedral of Learning (shown in the photograph above). The top of the building provides an excellent view of the community: forty floors below, Pitt, Carnegie Mellon University, Carlow College, Carnegie Institute, the University of Pittsburgh Health Center, and Schenley Park merge to form one of the most exciting and hectic areas in Pennsylvania.

The University was chartered in 1787 as the Pittsburgh Academy and the degree of "Engineer" was first offered in 1845, although the Chemical Engineering and Petroleum Engineering departments were not initiated until 1910. Eventually, these two departments merged, with the petroleum program becoming a technical elective concentration for the undergraduate chemical engineers. The department currently offers MS and PhD degrees in chemical engineering and the MS degree in petroleum engineering.

The upper section of campus is home to the Michael L. Benedum Hall of Engineering (shown in a photograph on page 88). This completely air conditioned, twelve-story building contains classrooms, offices, and laboratories equipped for modern research. Six departments have resided within this facility since 1971, with the top two floors currently housing the Department of Chemical and Petroleum Engineering.

Nearly everything needed for an undergraduate's survival, with the exception of emergency cash, can be found in Benedum Hall. The engineering library, several computing and experimental labs, endless vending machines and a small deli, and a comfortable lounge area provide the students with a home away from home during the day. A two-minute walk outside the building takes the student to the bookstore, the registration area, dormitories, hospitals, Pitt Stadium, and many fine restaurants.

Computing and Library Facilities

The campus has several computing facilities available to the students, but the most popular for chemical engineers are the computer centers in Benedum Hall where they have ready access to PCs and workstations with a wide range of engineering, spreadsheet, and word-processing software. These machines and other terminals can also access Pitt's VAX and UNIX mainframe systems. A Cray Y-MP 832 supercomputer is also available to both the University of Pittsburgh and Carnegie Mellon University.

Three software packages of particular interest to chemical engineers include Aspen Plus, PRO II, and B-JAC, which are used throughout the undergraduate curriculum in the design of units. B-JAC, for example, is a menu-driven heat exchanger design program that is introduced in our transport phenomena course and used in the senior design and chemical engineering laboratory courses. Aspen Plus and PRO II are process simulators that can be used in core courses for the
Our student enrollment has increased dramatically in the last few years. For example, only 25 BS degrees were awarded in 1990, but this year over 50 chemical engineers will graduate.

The University of Pittsburgh Health Center is a consortium of six local hospitals integrated with the University of Pittsburgh Medical School. Two members of the chemical engineering faculty, Drs. Edward Cape and William Wagner, have primary appointments in Pediatric Cardiology and the Department of Surgery, respectively, while Dr. Harvey Borovetz, an adjunct professor in chemical engineering, is also in the Department of Surgery. Another faculty member, Dr. John Patzer, has an active interest in biomedical research in the Health Center.

THE CHE DEPARTMENT

Gerald D. Holder has been the department chairman since 1987. He is responsible for coordinating teaching, research, undergraduate advising, and administrative activities of six professors, three research professors, seven associate professors, five assistant professors, two research assistant professors, three part-time instructors, and a visiting professor. The department also has an excellent staff that keeps all the administrative, educational, and research efforts flowing smoothly.

Currently, 200 of the 30,000 Pitt students are chemical engineering sophomores, juniors, and seniors pursuing BS degrees. At this time, 50% of our undergrads originate in freshman engineering. Most of the other half come from regional colleges and enter our department during the sophomore or junior year. Our student enrollment has increased dramatically in the last few years. For example, only 25 BS degrees were awarded in 1990, but this year over 50 chemical engineers will graduate.

THE CURRICULUM

The freshman and sophomore year curriculum is a busy mixture of chemistry, physics, calculus, philosophy, English literature, freshman engineering, and introductory chemical
The junior year provides a heavy dose of chemical engineering classics such as transport phenomena, thermodynamics, reactor design, and staged separations. An engineering statistics course and several chemistry courses and technical electives are also thrown in to keep everybody busy. The senior year is composed of courses in process control, professional practice, technical and nontechnical electives, and two-term sequences in undergraduate lab and design. Class sizes vary between 15 and 50 students, and most of our tenure stream faculty instruct at least one undergraduate course each year. Dr. Taryn Bayles, a visiting professor, is currently teaching two undergraduate courses each term, and Dr. Julie D'Itri will be joining our faculty this year after completing her post-doc at UC Davis. Her research interests are in chemical kinetics of atmospheric reactions, heterogeneous catalysis, and pollution abatement and waste minimization using heterogeneous catalysts.

**Bioengineering Minor** • We are currently considering the establishment of a minor in bioengineering and are confident that the proposal will be approved and the program established within a year. The requirements for attaining this minor can be satisfied by appropriate selection of electives. Chemical engineers can receive the minor within the framework of their 137-credit curriculum, with no additional time or credits required. The sequence consists of an introductory bioengineering seminar together with courses in physiology, statistics, and three bioengineering electives which include courses in orthopedic biomechanics, bioengineering signals and systems, human factors engineering, and introductory courses in biochemistry and biochemical engineering.

**ChE Sub-Specialties** • A major feature of our department is the availability of areas of concentration which add considerable breadth to the undergraduate education. Our students are free to randomly pick their elective courses from a vast array of chemical engineering, engineering, math, chemistry, physics, computer science, biology, biochemistry, and geology electives. Most of them, however, select from one of the four technical elective concentrations of petroleum, polymer, bio-, and environmental engineering. Each of these areas has an ongoing undergraduate research program associated with the faculty involved in the curriculum development.

Since interest in biotechnology and bioengineering has been strong in recent years, we have instituted a three-course bio sequence for our students. The first course, an introduction to biochemistry, is designed for students with minimal biological background and can be used as a substitute for the dreaded Physical Chemistry 1. The students then enroll in a course in biochemical engineering and must select one course from the biosciences department, such as microbiology or principles of biochemistry. The professors involved in this program and their areas of research include: Jerome Schultz and his work on biosensors; Mohammad Ataai, who is studying bioprocess engineering, large-scale cell culture, and cellular metabolism; Alan Russell, who has an extensive research program concerning enzymes in extreme environments; Eric Beckman, who has several joint projects with Drs. Ataai and Russell; Edward Cape, studying cardiovascular flow; William Wagner, who is working on artificial organs and biocompatibility; and John Patzer, who is involved in the development of an electrochemical artificial kidney and glucose sensing for an artificial pancreas.

The petroleum engineering sequence for undergraduates focuses on reservoir engineering and includes courses in waterflooding, well-test analysis, enhanced oil recovery, and petroleum production. Our PetE program, the oldest one in this country, also offers an MS degree in Petroleum Engineering which encompasses courses in reservoir fluid and rock properties, numerical simulation, advanced enhanced oil recovery, and well logging. Dr. Badie Morsi coordinates the program and is assisted in instruction by three part-time faculty members, Drs. Willard Acheson, Neal Sams, and Pietro Raimondi.

The polymer engineering concentration consists of at least three technical electives, including courses in polymer chemistry, structure-property relationships in polymers, and a material science course in polymer processing. Drs. Eric Beckman and Sindee Simon instruct the chemical engineering polymer courses. Beckman has an extremely active re-
search program which includes novel polymeric microstructure via supercritical fluid processing, thermodynamics of polymer solutions, plastics recycling technology, and the development of recyclable polymers. Simon's research efforts involve curing kinetics, structure/property relationships, and physical aging of thermosetting polymeric materials.

The University is also a leader in environmental education. Its Graduate School of Public Health has major foci on air quality, radiation protection, and industrial hygiene. One-quarter of the Civil and Environmental Engineering Department faculty devote the majority of their professional efforts to control water pollution and manage solid wastes. Our department collaborates with the Civil and Environmental Engineering Department in offering a four-course sequence of environmental engineering courses. CEE offers two courses for ChE students: an introduction to environmental engineering and a study of environmental engineering processes. Our students typically complete this sequence by taking chemical engineering courses concerning atmospheric pollution control and pollution prevention. Drs. James Cobb, Shiao-Hung Chiang, and Eric Beckman are associated with the environmental program. Cobb's research activities include environmental aspects of coal conversion and waste incineration; Beckman is involved in the development of recyclable polymers, microsorption of post-consumer thermoplastics, and the removal of heavy metals from soils with CO2-soluble chelating agents; Chiang's environmental work is related to coal cleaning technologies.

A new concentration in solids processing should be online within a year. Several of our faculty are developing this concentration in conjunction with a strong research program in the transport, processing, and separation of solids. Drs. Shiao-Hung Chiang, John Tierney, and George Klinzing are developing the academic program for this technical concentration. Klinzing is heavily involved in pioneering research in the transport properties of solid particles, and Chiang developed the LICADO process (LIquid CARbon DioXide), a non-aqueous coal cleaning technology employing CO2 as the separation medium. All of these professors have combined efforts to address coal dewatering in three manners: an overall macroview of the process, a microview of the filter cake, and computer modeling of the process.

The department's Catalysis Research group provides one of the strongest concentrations of catalytic research in any U.S. university department. The research efforts of Drs. James Goodwin, George Marcelin, Rachid Oukaci, Dan Farcasiu, and Irving Wender include the development of new catalytic materials, adsorption and surface chemistry, organometallic chemistry, chemical promotion of catalysts, reaction mechanisms, and catalyst deactivation.

The department is also a leader in multi-phase chemical reaction engineering. This effort, headed by Drs. James Cobb, Badie Morsi, and John Tierney, has resulted in significant interaction with industry, providing students with opportunities for research experience in industrial settings.

We also have one of the largest concentrations of faculty in thermodynamics in the U.S. Drs. Gerald Holder, Robert Enick, Eric Beckman, and Alan Brainard are involved in phase behavior studies of gas hydrates, various supercritical fluid systems, carbon dioxide-soluble surfactants and chelates, and emulsion polymerization in supercritical fluids.

UNDERGRADUATE LABS

Our students gain laboratory experience in organic chemistry, physical chemistry, and instrumental analysis. The seniors must also complete a two-course sequence in the undergraduate chemical engineering laboratories. These labs, located in Benedum Hall, enable the students to gain hands-on experience with experiments designed to illustrate concepts discussed in their classes. These experimental modules are associated with transport phenomena, staged separations, reactor design, process control, and the chemical engineering design curriculum. Specifically, the topics include heat exchangers, distillation and extraction columns, diffusion cells, climbing film evaporators and wetted-wall columns, free radical polymerization and crystallization kinetics and melting of polymers, CSTRs, differential scanning calorimetry, fluidization, humidification, and catalytic reactors. A computer module which simulates an AMOCO resid hydrotreater, developed at Purdue University, has also been installed on a SUN III workstation. Dr. Alan Brainard instructs most of the lab sections for our department, and is also responsible for sharpening the oral and written communication skills of the students.

Continued on page 145.
THE WILLIAM H. CORCORAN AWARD
Past, Present, and Future

JOHN C. FRIEDLY,1 C. GORDON McCARTY2
University of Rochester
Rochester, NY 14627

The Chemical Engineering Division of the American Society for Engineering Education has joined with Miles Inc. to offer the William H. Corcoran Award for the best contributed paper to Chemical Engineering Education each year. The Division Executive Committee, chaired by L. Davis Clements, accepted a Miles offer of continuing sponsorship of the award at its meeting in St. Louis on November 9, 1993. Miles sponsorship ensures the continuation of this award which has been presented annually since 1986 and enables the Division to provide a small honorarium and nominal travel expenses for the recipient.

Miles Inc. is a Fortune 100 research-based company headquartered in Pittsburgh. It has businesses in chemicals, health care, and imaging technologies. Its operations throughout North America are organized into Agriculture, Industrial Chemicals, Organic Products, Polymers, Polysar Rubber, Diagnostics, Pharmaceutical, and Agfa divisions. In 1992 the company employed about 26,000 people and had sales of $6.5 billion.

The Corcoran Award was established in 1984 by action of the Executive Committee of the Division and was approved by ASEE early the following year. Deran Hanesian presided at the Division Executive Committee Meeting of November 1984 in San Francisco at which the Award was established. Dendy Sloan was vice-chair and Bill Beckwith was secretary-treasurer. The committee acted on a written suggestion from Phil Wankat that the Division establish a best-paper award. The intent was to encourage faculty to disseminate their educational contributions as well as their research. Angie Perna proposed two such awards: one for the best paper presented at the Annual Meeting and the other for the best paper published in Chemical Engineering Education during the calendar year. Beckwith moved that one of the awards be named in honor of William H. Corcoran, who had died two years earlier, and Sloan moved that the Corcoran Award be for the best paper in CEE.

It is fitting that a Division award be named for Bill Corcoran. He was a tireless ASEE worker, having received the ASEE Distinguished Service Award for "a creative, professional life devoted to excellence in engineering teaching, research, and administration" just two months before his untimely death on August 21, 1982.4 He had previously received ASEE's highest award, the Benjamin Garver Lamme Award, in 1979. He had also served as chair of the Chemical Engineering Division, and in 1978 he was president of the AIChE.

Corcoran received his BS and MS at CalTech and worked briefly at Cutter Labs before spending four years during the war working on rocket ordnance and the Manhattan Project. He returned to CalTech to earn his PhD in 1948. After spending a few years at Cutter Labs as director of technical development, Corcoran joined the chemical engineering faculty at CalTech in 1952. There he served as executive officer for chemical engineering and as vice president for institute relations. Respected both for his research and teaching, as well as for his professional service, Corcoran received a number of awards. In the year 1969-70 he won the Western Electric Fund Award for Excellence in Teaching, and the Associated Students of CalTech gave him their Teaching Excellence Award in 1977.

Rich Felder was the first recipient of the Corcoran Award. The venue was the Division Banquet at Lake Tahoe during the year 1984.

1 Past-Chair, ASEE Chemical Engineering Division
2 Manager, University Relations, Miles Inc., Mobay Road, Pittsburgh, PA 15205-9741

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Chemical Engineering Education
the Reno ASEE Annual Meeting in June 1986. Division Chair Dendy Sloan had arranged for Corcoran's widow to be there for the first presentation of a recognition plaque.

Previous winners of the Corcoran Award (see Table 1) include some outstanding educators and supporters of chemical engineering education. Seven academics and one industrialist have won the award since its inception. Noel de Nevers was the most recent recipient, receiving the award at the ASEE Centennial Meeting at the University of Illinois in June of 1993. The paper titles show the wide diversity of subjects considered worthy of the award. All have a direct bearing on education and educators. This has been a consistent criterion used by selection committees.

A three-person selection committee for the award has served at the pleasure of the Division Executive Committee. In recent years the Division Vice-Chair has chaired the committee, which also included Ray Fahien, editor of CEE, and the previous year's winner.

No nominations for the award are accepted, and all contributed papers to CEE are eligible for selection. The purpose of the award is to recognize and encourage outstanding contributions to chemical engineering education as evidenced by a published paper in CEE during the previous calendar year. The contribution may be in any area of chemical engineering teaching, practice, or theory as long as it is judged to have the potential for a significant and lasting contribution to education. The selection committee may establish its own criteria interpreting how papers fulfill the purpose of the award. The award is given to the senior author of jointly written papers, with duplicate plaques provided for coauthors.

Table 1 shows that Chemical Engineering Education has attracted some outstanding papers from some of the most prominent educators in the profession. Under the editorship of Ray Fahien for the last quarter of a century, CEE has grown into a thriving archival journal serving the entire chemical engineering community. It is the epitome of an ASEE division journal.

A long and fruitful collaboration between the Division and Miles Inc. is anticipated. Industrial sponsorship of the William H. Corcoran Award will further the goals of the award: to encourage and recognize outstanding contributions to the archival literature devoted to the improvement of chemical engineering education.

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**TABLE 1**

**Corcoran Award Winners**

<table>
<thead>
<tr>
<th>Year</th>
<th>Winner/Affiliation</th>
<th>Paper Title (and coauthors)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>E. Dendy Sloan</td>
<td>&quot;Extrinsic versus Intrinsic Motivation in Faculty Development&quot;</td>
<td>CEE, 23(3), 134 (1989)</td>
</tr>
</tbody>
</table>

Spring 1994
It has long been the custom to require chemical engineering undergraduates to design a chemical plant or some similar entity. Such a requirement serves at least two purposes: one, to impose upon the students the need to use the theoretical knowledge to which they have been exposed in their course work in a more nearly practical setting than is usual in the normal course of study, and two, to acclimate them to the kinds of designs and economic analyses which many of them will be called on to perform when they enter industry.

There is another purpose, particularly important in view of the current emphasis on engineering science in the curriculum. Many students choose to study engineering because they want "hands-on" exposure to practical problems—in contrast to the idealized versions which scientists often solve. But because there is so much information the students must assimilate and master, the curriculum tends to reinforce the need for generalization and hence for mathematical expression and manipulation of that information. Inadvertently, this draws the students away from the practical problems that attracted them into engineering in the first place.

It is very difficult to strike a satisfactory balance between a thorough grounding in the basics (physics, chemistry, mathematics, and the scientific disciplines derived therefrom) on the one hand, and on the other the descriptive material concerning filters, pumps, boilers, tanks, reactors, towers, heat exchangers, and the myriad objects which make up the engineer's world. This search for balance is our justification for attempting to have the plant-design course make up, in part, for the "hands-on" courses (machine shop, engineering laboratories, plant visits) which have been curtailed or dropped entirely from the curriculum.

Most educational emphasis is, quite properly, on the work of the individual. Yet, much of modern industry functions through the work of teams, and only rarely does an individual work alone on a project. To prepare students for this fact of industrial life, design projects are assigned to groups of students (two or three at most) who must organize the job, subdivide the effort among themselves, function effectively as a team to execute the design, prepare the written report, and deliver the oral presentation. On a few rare occasions, this has even meant that one or two members of a team had to take over the responsibilities previously assigned to others who had either fallen short or dropped out of the group. This scenario is recognized by any engineer who has been part of an industrial organization; just as in the theater "the show must go on," a working engineer knows that the job must be done—by whoever is around to do it.

Thus, the design project is more than just another course offering; it is the logical conclusion of the undergraduate chemical engineer's education, embodying a major part of the material covered in all the previous chemical engineering courses and demanding (and hopefully inculcating) skills and disciplines which the student has rarely needed previously. At Penn, and at many other schools, both written and oral reports are treated as if they were industrial reports—in effect, the results of the students' first job in "industry."

As a result of a recent ABET decision to provide flexibility in design instruction, many curricula can be expected to shift emphasis toward a more comprehensive design experience at the senior level. Furthermore, as computers enable...
students to solve more open-ended problems throughout the
curriculum, it should be possible to provide a more formal
treatment of the design approach at the senior level. A
senior-level two-course sequence has been offered in chem-
ical engineering for many years at Penn, as well as at
other schools, and now other departments will likely con-
sider such a sequence.

FALL LECTURE COURSE

The objective of the fall lecture course is to provide a
smooth transition into the spring design project. In previous
courses (which emphasized the engineering sciences) the
students have been exposed to design techniques through
the solution of several open-ended problems, often using the
computer, but they have not yet received training in a sys-
tematic approach to process synthesis, the use of flow-
sheet simulators in process synthesis, or the application
of economic principles in venture analysis. These and
other related subjects are covered in the fall lectures and are
accompanied by numerous homework problems (summa-
rized in Table 1).

The course begins with an introduction to process synthe-
sis as described by Seider. To summarize briefly: through a
case study we introduce the synthesis of reaction paths,
the distribution of chemicals, the synthesis of separation
trains, the synthesis of networks of heat exchangers, the
insertion of power-related units (pumps, compressors, and
turbines), and task integration. Then we introduce the AS-
PEN PLUS simulator, with emphasis on the synthesis of the
reactor section of a chemical plant followed by a separation
train. Here also, we use the approach described by Seider.

With one-third of the semester completed, including the
solution of three problems with ASPEN PLUS, we then
undertake a more formal coverage of process synthesis. We
present heuristics for the design of individual separators,
together with the tree of separation-train alternatives, and
then describe the ordered-branch search strategy of Rodrigo
and Seader and solve an illustrative problem.

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
</thead>
</table>

Outline of Topics: Fall Lecture Course

Lecture Hours

- Introduction to process synthesis .................................. 3
- Flowsheet simulation using ASPEN PLUS .......................... 11
- Synthesis of separation trains ........................................ 2
- Thermodynamic efficiency and lost work .......................... 5
- Heat and power integration ........................................... 4
- Heat exchanger design ................................................ 2
- Capital cost estimation ................................................ 1
- Profitability analysis ................................................... 6
- Selection of design projects (for spring project course) ........ 2

TOTAL 36

We next review the concepts of thermodynamic availabil-
ity according to Chapter 1 of an excellent monograph titled
Availability (Exergy) Analysis: A Self-Instruction Manual,[3]
and follow that by covering thermodynamic efficiency and
lost-work analysis using another excellent monograph, Ther-
modynamic Efficiency of Chemical Processes.[4] The latter
concentrates on refrigeration cycles (which most students
do not study in their thermodynamics courses) as well as
distillation. The principal sources of lost work are identi-
fied, and the students design a refrigerator that signifi-
cantly reduces the sources of lost work.

This leads naturally into the synthesis of networks of heat
exchangers, as well as heat and power integration. First, we
discuss the methods that minimize the use of external utili-
ties, including the temperature-interval method and
the graphical approach for identifying the "pinch" temperatures.
We solve a problem using the TARGET II program,[6] and
then cover the methods of stream-matching (beginning at
the pinch temperatures) as recommended by Linnhoff
and Hindmarsh.[7] Finally, the heat loops are broken and we
examine the effect of heat being exchanged across the
pinch temperatures. Here also the students design a net-
work of heat exchangers.

Since in the synthesis of a process the analysis of indi-
vidual units often involves approximations (e.g., an overall
heat-transfer coefficient), for costly units it is important to
check the approximations by developing a more rigorous
model. We demonstrate this procedure for the design of a
shell-and-tube heat exchanger for which the heat transfer
resistances and pressure drops are adjusted through the
details of the tube bundle and the baffle spacing. Chapter 14
of Plant Design and Economics for Chemical Engineers[8]
provides excellent coverage of the design procedures,
and these procedures are used by the students to design a
multi-pass heat exchanger.

Throughout the course there is a need to estimate capital
and operating costs, in addition to the simpler measures of
profitability such as venture profit and "annualized" cost.
Detailed cost and profitability calculations, however, are
postponed until the topics on process synthesis have been
completed, approximately two-thirds into the semester. At
this point, we cover the factored methods of capital cost
estimation, using Chapter 5 of A Guide to Chemical Engi-
neering Process Design and Economics.[9] The students are
also introduced to the implementation of these methods in

As a result of a recent ABET decision to provide
flexibility in design instruction, many curricula
can be expected to shift emphasis toward a more
comprehensive design experience at the senior
level. A senior-level two-course sequence has
been offered . . . for many years at Penn
ASPEN PLUS. Then the students learn the principles of venture analysis through a four-lecture sequence by Adjunct Professor R. M. Busche. They estimate the fixed capital investment and a cost sheet for a fermentation flowsheet, and compute the cash flows as well as the net present value and the internal return on investment. Dr. Busche also introduces his CASH92 spreadsheet program, which the students may use to carry out similar calculations for their spring-semester design projects.

The fall lecture course concludes with scheduling of the senior design projects and the presentation of instructions for executing the projects during the following spring. The nature of the design projects and the format of the spring course are discussed in the next sections.

We do not require the students to purchase a textbook for the lecture course since there is no existing text that follows the sequence in which process synthesis and flowsheet simulation are intertwined. Although a text by Douglas, *The Conceptual Design of Chemical Processes*, is excellent in its presentation of a hierarchical design strategy using many heuristics, it does not readily accommodate the sequence in Table 1. The heuristics are helpful, however, and are shared with the students throughout the fall semester.

**SUBJECTS FOR DESIGN PROJECTS**

During the fall semester we invite industrial consultants to suggest ideas for projects that can be undertaken in the spring semester. Interested faculty members and the students themselves occasionally suggest projects. The processes are expected to be timely, challenging, and offer a reasonable likelihood that the final design will be economically attractive. We remind the project originators that student motivation and faculty enthusiasm are directly related to the feasibility and potential impact of the final designs. Potential problems should be workable by seniors without unduly gross assumptions, good sources of data should exist for the reaction kinetics and thermophysical and transport properties, and pertinent references should be provided. In a recent project involving the reactive distillation of mixtures with many azeotropes, ARCO provided the thermophysical property data for the ASPEN PLUS simulator. With the approval of the course organizers, the students signed a non-disclosure agreement not to share the data with others.

After a process of winnowing, we prepare an approved list of projects which includes one or two more than the required number. In making a selection, each team rates each project on the list as a first-through-fourth choice, and whenever possible, we then give the team its first or second choice. If none of its choices are available, the team is simply assigned a topic by the professor in charge of the course. The pedagogical justification behind this practice is that junior engineers in industry do not have the luxury of picking jobs; they are simply assigned jobs as the jobs come up, and will be expected to do the best they can with the assignments they are given.

The design projects reflect the current interests of the people who suggest them. In some cases the projects do not involve the design of a chemical plant (e.g., the design of a heat-exchange system for a fast-breeder nuclear reactor, or of a heart-lung machine). Such projects demand assistance from consultants with specific experience in the pertinent field, and obviously such problems cannot be assigned unless consultants with that specific experience can be found.

Every design problem incorporates a requirement that environmental and safety issues be taken into account. We take note of all possible waste materials and investigate the means and cost of their disposal. We are placing increased emphasis on the cost of energy, on designs which avoid or minimize handling of hazardous chemicals, and on protection against processing accidents. We note that increasingly, projects are directly related to environmental issues; e.g., the design of a tetrahydrofuran plant to achieve "zero emissions," the reduction of NOX in boiler-stack discharges, and the partial recovery of the carbon content of CO2 from power-plant off-gases.

Table 2 lists some project titles from 1960 through 1993—the time-dependent interest in space exploration, nuclear-power generation, medical technology, ecology, and improved energy efficiency, as well as a variety of chemical or environmental projects.

**TABLE 2**

<table>
<thead>
<tr>
<th>Selected Design-Project Subjects Through the Years*</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1970 Liquid-Metal Heat Exchanger: Fast Breeder Nuclear Reactor</td>
</tr>
<tr>
<td>&lt;1970 Recovery of Minerals from a Lunar Station</td>
</tr>
<tr>
<td>&lt;1970 Design of a Heart-Lung Machine</td>
</tr>
<tr>
<td>1979 Conversion of Methanol to Gasoline in a Fluid Bed Reactor</td>
</tr>
<tr>
<td>1981 Manufacture of MTBE Anti-Knock Additive</td>
</tr>
<tr>
<td>1982 Pressure-Swing Adsorption for Separation of Air</td>
</tr>
<tr>
<td>1983 Heat Pump for Ethane-Ethylene Split</td>
</tr>
<tr>
<td>1984 Heat and Power Integration for Manufacture of Propylene Oxide</td>
</tr>
<tr>
<td>1985 Scleroglucan Biopolymer for Enhanced Oil Recovery</td>
</tr>
<tr>
<td>1985 Helium Recovery from Natural Gas</td>
</tr>
<tr>
<td>1986 Cogeneration Flue Gas Cleanup</td>
</tr>
<tr>
<td>1987 Groundwater Cleanup and Organics Incineration</td>
</tr>
<tr>
<td>1988 Thermally-Stable Amylase Enzymes</td>
</tr>
<tr>
<td>1989 Gas Processing for Ethane Recovery</td>
</tr>
<tr>
<td>1990 Ammonia Purification by Refrigeration and Membrane Processing</td>
</tr>
<tr>
<td>1991 Zero Emissions from a Tetrahydrofuran Plant</td>
</tr>
<tr>
<td>1992 Itaconic Acid by Fermentation</td>
</tr>
<tr>
<td>1992 Ultra-High Purity Oxygen Manufacture</td>
</tr>
<tr>
<td>1993 MTBE Manufacture</td>
</tr>
</tbody>
</table>

* See "Process Design Projects at Penn: 100 Problem Statements," available from W.D. Seider.

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*W.D. Seider.*

"Chemical Engineering Education."
consulting engineers, contractors, and equipment vendors
Penn faculty. Since the Delaware Valley is home to many
consultant meets with several of the design groups three or four
spring semester. Over the length of the semester, every con­
sultant’s efforts would be greatly
enhanced by exposure to other engineers in addition to the
Penn faculty. Since the Delaware Valley is home to many
companies in the chemical processing industries and to the
consulting engineers, contractors, and equipment vendors
who serve them, we have been able to secure the volunteer
services of a body of experienced and competent engineers
to serve as a source of vicarious experience for the students.

Each consultant usually spends two to four hours during
one afternoon per week on alternate weeks throughout the
spring semester. Over the length of the semester, every con­
sultant meets with several of the design groups three or four
times. They provide specific answers to those students who
know enough to ask meaningful questions, and offer guid­
ance and suggestions to those whose progress leaves some­
thing to be desired. They are particularly effective in pro-
viding advice on the best choice of processing equipment
(e.g., in selecting from among vacuum filters, centrifuges,
and hydroclones), materials of construction, plant capaci­
ties, and start-up strategies. In the past five years, our de­
partment has added an adjunct professor, Dr. Arnold Kivnick,
a retired engineer who served for over thirty years as one of
the consultants. His job is to be available as a resident con-
sultant for two days each week during the spring semester.

Over the years, the relationship between the consultants
and the students has developed to a point where the students
feel free, within reasonable limits, to call upon the consult­
ants when the need arises outside of scheduled sessions. The
students have learned that equally competent people, with
different experiences, often reach disparate opinions on the
basis of the same information. They have also learned how
competent people reach conclusions even in the face of inconsist­
ent data or when insufficient information is available.

A faculty advisor is assigned to each design team. Even
though his or her experience in the specific area of the
team’s problem may be limited, all of the faculty members
have worked as advisors at one time or another, with several of
them serving almost every year. They bring their own
expertise to the project and provide continuity and general
supervision throughout the term. Further, they use their
knowledge of the interests and strengths of their colleagues,
both inside the department and elsewhere in the University,
to direct the students to sources of information and ad­
vice best suited to their needs. As a result of having
advised design teams, all of our faculty have a better appreci­
ation of the important prerequisites that need to be
covered in their own courses.

An indirect objective of the course is to teach the need for
information networks in the development of projects, how
to set up and be part of such a network, and how to perse­
vere in the face of indifference or non-cooperation from
potential sources of information. Experienced design engi­
neers are well aware of the assistance that sales representa­
tives from equipment and material vendors can provide, and
they usually know which colleagues have expertise in areas
of importance to the project and are not shy about consult­
ing them. For the seniors, who have worked individually for
most of their academic lives, this course aims to provide a
taste of professional teamwork. Cooperation among students,
faculty, consultants, and sales representatives, who are all
motivated only by the need to solve a design problem (within
reasonable limits to the time available and the sensitivity of
the often proprietary technical information sought), helps to
build camaraderie between the students and other members
of their chosen profession, while at the same time giving the
students a sense of the value of their own efforts.

We are gratified that several former Penn students, some
of whom received graduate degrees elsewhere, now serve as
consultants in our department. Table 3 lists the current con-

| TABLE 3 |
| Industrial Consultants (1993) |

<table>
<thead>
<tr>
<th>Years Served</th>
<th>Consultant</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Dr. Rakesh Agrawal</td>
<td>Air Products and Chemicals</td>
</tr>
<tr>
<td>12</td>
<td>Dr. E. Robert Becker</td>
<td>Environex, Inc.</td>
</tr>
<tr>
<td>1</td>
<td>Dr. David D. Brengel*</td>
<td>Air Products and Chemicals</td>
</tr>
<tr>
<td>10</td>
<td>Dr. Robert M. Busche</td>
<td>BIO-EN-GENE-ER Associates</td>
</tr>
<tr>
<td>15</td>
<td>Mr. Leonard A. Fabiano</td>
<td>ARCO Chemical Co.</td>
</tr>
<tr>
<td>4</td>
<td>Dr. Brian E. Farrell*</td>
<td>Air Products and Chemicals</td>
</tr>
<tr>
<td>10</td>
<td>Mr. F. Miles Julian</td>
<td>E.I. DuPont de Nemours</td>
</tr>
<tr>
<td>5</td>
<td>Dr. Grant G. Karsner*</td>
<td>Mobil Research and Development</td>
</tr>
<tr>
<td>2</td>
<td>Dr. Frank Kelly*</td>
<td>Mobil Research and Development</td>
</tr>
<tr>
<td>15</td>
<td>Dr. Donald J. Kloecke*</td>
<td>Mobil Research and Development</td>
</tr>
<tr>
<td>15</td>
<td>Dr. Jack McWilliams*</td>
<td>Mobil Research and Development</td>
</tr>
<tr>
<td>4</td>
<td>Dr. Mark R. Pillarella*</td>
<td>Air Products and Chemicals</td>
</tr>
<tr>
<td>13</td>
<td>Dr. William B. Retallick</td>
<td>Consultant</td>
</tr>
<tr>
<td>1</td>
<td>Dr. Henry M. Sandler</td>
<td>Consultant</td>
</tr>
<tr>
<td>5</td>
<td>Dr. Andrew Savo*</td>
<td>Rohm and Haas</td>
</tr>
<tr>
<td>15</td>
<td>Mr. Peter Schneider</td>
<td>Rohm and Haas</td>
</tr>
</tbody>
</table>

* University of Pennsylvania alumnus
sultants, the companies which contribute their services, and the number of years they have been involved in the course.

Penn is, of course, fortunate to be located in an area where the process industries are very active. There are other schools of chemical engineering located near major industrial centers that could enjoy a similar advantage. Also, schools located in areas served by a local section of the AIChE should be able to get help of this kind. Even if only one consultant from outside academic circles is available, it should provide a worthwhile broadening of exposure for the undergraduate engineering students.

**EFFECTS OF THE SIMULATOR ON THE PLANT DESIGN COURSE**

In bygone years, each plant design project led to one design that satisfied the problem statement. The development and availability of design simulators and the computer spreadsheet have considerably changed that scenario. They have so accelerated the design process that it is now reasonable to require the design teams to choose from among two or more alternative designs (with the need to study all of them and to justify their choice) and to optimize the design ultimately chosen with respect to energy utilization and choice of operating conditions. In some cases, the simulator has enabled the students to arrive at more effective processes, designs that would not have been possible otherwise, with much improved profitability. Recent cases have been the reactive distillation of azeotropic mixtures and the recovery of krypton and xenon from air in thermally-coupled distillation towers.

There is a tendency, however, for students in the 1990s to depend entirely on the simulator, sometimes without understanding exactly what it is doing. We urge students to perform manually crucial parts of the design study; this may provide approximate results which serve as initial estimates for the simulator calculations. Occasionally, especially in fractionation calculations, the simulations take so long to converge that manual approximations (such as McCabe-Thiele plots based on key binaries, or the sketching of residue-curve maps and simple distillation boundaries) can rapidly provide useful insight into the problem, permitting the simulator to achieve more rapid convergence. More often, the manual procedures increase the students' awareness of the process details (e.g., whether more distillation trays are needed above the feed tray or below or where phase changes are occurring). Once convergence has been achieved, a legitimate use of the simulator is to study the effects of adding trays at various locations, or of changing the reflux ratios.

**THE INFORMATION NETWORK**

Throughout much of their prior course work, the students' textbooks presented new concepts through examples and homework exercises, but in the design lecture course we use individual chapters from several books to present the concepts in the sequence shown in Table 1. Although this helps accustom students to working with diverse sources of information, it does not involve them in the actual gathering of information from the vast literature.

To address this need, at the beginning of the spring project course the students learn to access such well-known sources as the *Kirk-Othmer Encyclopedia of Chemical Technology* and the *Encyclopedia of Chemical Processing*, edited by McKetta and Cunningham. Even more important, our librarian introduces them to the electronic media and available data bases, such as the *Science Citation Index*, the *Engineering Index*, and *Chemical Abstracts*. The students are given examples of search procedures and are introduced to sources of assistance in the library system. They also learn that library resources at other universities can be searched through electronic mail, and interlibrary loans can be used to obtain sources that are not available locally. This relative ease of information access has a major impact on the quality of the designs.

**THE WRITTEN REPORT**

Since one objective of the course is to introduce students to some of the profession's requirements, the design report must be prepared as if it were written for an industrial supervisor (for transmittal to his superiors) by a junior engineer assigned to study a potential project. The required form is a typical industrial report, beginning with the letter of transmittal. The usual sections are required: abstract, introduction, process flowsheet (including a material balance block), process description, unit descriptions, energy balance, specification sheets, equipment cost summary, fixed capital summary, economic analysis, conclusions, and recommendations. A specific requirement is that the report be so organized that a conscientious industrial supervisor can check the design of any particular item of equipment, from its functions in the unit descriptions to its details in the specification sheets and its purchase price in the equipment cost summary to the detailed design calculations (in the form of Xerox copies of reasonably legible calculation sheets) in the Appendix.

Preparing the report takes a great deal of time, so we encourage students to start writing the descriptive portions while the design computations are still under way. The report adjudged best in the class is awarded the Molstad prize (a non-negligible cash award) and is often submitted for the prestigious Ziebig Award, administered by the Delaware Valley Section of the AIChE, in competition with other area schools.

**THE ORAL PRESENTATION**

A lucky junior engineer may get the opportunity to attend the meeting where his or her work and ideas are presented to the decision-makers among his or her employers, but it is...
rare that he or she is required to make the presentation in person. The experience of making an oral presentation has been part of the plant-design course at Penn since its inception. Each team must present its report to an audience of classmates and as many of the faculty and consultants as can attend. All team members must participate in the oral presentation, and each team is allotted about forty minutes for the presentation, including five or ten minutes for questions from the audience. To set the appropriate atmosphere, the students attend in clothes suitable for a business meeting. The presentation covers all the salient factors of the design, including the pertinent chemistry, design problems and their solutions, equipment costs, and project economics. We encourage the use of audio-visual aids, including transparencies and slides, with suitable projectors and, more recently, computer-screen projectors.

The oral presentations are weighted in the student's grade and in the considerations for the Molstad prize. All faculty members and consultants present at the sessions contribute to the evaluations.

CONCLUSIONS

The plant design course is regarded, by students and faculty alike, as the culmination of the seniors' efforts. Since the BS degree is still considered the professional degree in engineering, this course is designed and conducted so that the students use much of what they have learned during their years of study. With few exceptions, the students will put more concerted effort into the design, the written report, and the oral presentation than they have into any other single event up until that time. It is considered a kind of final engineering, this course is designed and conducted so that chemical engineering undergraduate curriculum. In recognition of that fact, the department customarily invites the members of the graduating class, along with as many of the faculty and consultants as can be present, to have lunch together during the midday break in the presentations, to celebrate the students' success and hard-won maturity.

REFERENCES

A PROJECT-ORIENTED APPROACH to an Undergraduate Biochemical Engineering Laboratory

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Although many chemical engineering programs offer lecture courses covering various topics of biotechnology, relatively few undergraduate students receive meaningful laboratory exposure to experimental work in this important field. One of the major prohibitive factors in offering this type of educational experience is time. Although some of the pertinent technologies have been incorporated into laboratory instruction, many of the new biological methods cannot be adequately introduced and thoroughly investigated in a traditional laboratory course format that consists of, perhaps, one or two three-hour laboratory sessions per topic. Most fields of study in biotechnology, such as microbial fermentation or plant and mammalian tissue cultivation, require experimental durations of up to one month to obtain meaningful data. In addition, many of these technologies require extensive training before comprehensive investigation can take place.

To rectify this problem, we developed a biochemical engineering laboratory experience that includes long-term experimental projects in areas of plant cell cultivation, in situ bioremediation of hazardous wastes, enzymatic cellulose hydrolysis, and microbial fermentation. The course is distinctive in its use of single experimental projects (completed over the duration of one instructional quarter) that demonstrate many engineering principles related to biotechnology. The one credit-hour laboratory is offered in conjunction with a three credit-hour lecture titled, "Fundamentals of Biochemical Engineering."

COURSE ORGANIZATION

Considering the time constraints of a ten-week quarter, it was immediately evident to those planning the course contents that it would not be feasible to provide student exposure to all available laboratory projects. So we split the students into four research groups, each comprised of two to three juniors and seniors, which were then assigned to one of the available experimental modules for the duration of the course. Each group was expected to invest a minimum of ten student-hours per week in its research project. Although the university catalog list the lecture course as 3.0 credit-hours and the laboratory course as 1.0 credit-hour, the laboratory work actually comprised nearly fifty percent of the total course effort. The instructor was available for consultation at "set" laboratory hours and, in addition, each group was given a room key, thus allowing for project work at any time of the day.

To assure that all students received essentially the same educational experience, we formulated common overall objectives for all the experimental modules. These objectives, split into two groups titled "software" and "hardware," are listed in Tables 1 and 2, respectively. Hardware objectives refer to tasks completed specifically in the laboratory facility, whereas software objectives involve necessary research steps completed outside, but in support of, laboratory efforts.

We formulated software objectives as a guide for students through the necessary planning steps of any research endeavor, not merely the projects at hand. They began fulfilling these objectives in the library with a list of recommended journal articles and book chapters to read, and this material provided a foundation for a more comprehensive literature search using available on-line and off-line library data bases. This activity also enabled the students to formulate their own experimental objectives as well.
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as to set tentative dates for completion. The instructor reviewed each group's final objectives before any experimental design could be initiated.

To assure proper communication, both with the instructor and within the group, we held weekly project-planning meetings and required that bi-weekly progress reports be completed by the groups. During the weekly planning meeting, the group informed the instructor of the previous week's progress and presented a tentative plan for its upcoming activities. Bi-weekly written progress reports followed the same basic format: details of previous results, including tabular and graphic data with appropriate discussion, along with a comprehensive plan for the group's efforts over the next two weeks, including detailed designs of upcoming experiments. In addition, during the lecture portion of the course we required the students to explain facets of their project work as related to concepts studied by the entire class. This gave all the students some exposure to each project area.

The end of the quarter culminated in final oral and written presentations. Written reports had to describe the results obtained over the entire project, including an overview of the initial literature search, while oral reports focused on the group's progress toward planned experimental objectives.

Also, since each group researched a unique topic, the final oral report had to include a brief demonstration of the studied technology in order to inform the other students of the techniques that were used. We asked students who presented exceptional written and oral reports to participate in the regional AIChE Student Paper Competition.

Hardware objectives (see Table 2) were formulated to assure that although each group was involved in a different subject, all students were exposed to the same basic principles of biochemical engineering. These objectives included training in many facets of sterile technique, along with media preparation, contamination detection, and organism identification methods. The students also learned how to perform necessary measurements for substrate, biomass, and product concentration, and all the groups had to complete an analysis of data gathered through experimental studies in order to obtain estimates of kinetic parameters and to predict performance of proposed reactor configurations. The mathematical modeling and parameter estimations were completed using SimuSolv® modeling and simulation software.

INDIVIDUAL EXPERIMENTAL MODULES

Using the four experimental modules available for investigation, we separated laboratory project work into two areas: preliminary studies and objectives. Preliminary studies, to be completed within the first three weeks of the course, are designed to orient students to both literature material and routine laboratory tasks associated with the subject area. Project objectives are open-ended experimental tasks which incorporate training gained from the preliminary studies and knowledge from biochemical engineering lecture material as well as prior chemical engineering coursework.

1. Plant Cell Cultivation

This project focuses on batch studies for the measurement of substrate, biomass, and secondary metabolite concentrations in suspensions of Nicotiana tabacum and Catharanthus roseus. To provide a literature background for the study, students read portions of the text Plant Propagation by Tissue Culture41 as well as a number of pertinent articles giving an overview of plant cell culture advances,5-7 outlining necessary cultivation and analytical techniques,8-11 and discussing kinetic modeling in cell culture systems.12 While completing this literature search, students learn techniques fundamental to plant tissue cultivation, such as sterile sub

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cultivation, fresh weight and dry weight concentration determination, media preparation, and assays of substrate (sucrose, glucose, and fructose) and secondary metabolite (phenolics and indole alkaloids) concentrations. All of these techniques were previously developed by either the instructor or chemical engineering students involved in biotechnology research at Tri-State University.

After the literature search and preliminary study activities are completed, the group begins fulfilling the project objectives, starting with the formulation of a GC/MS assay for ajmalicine concentration determination. This determination is considered a main objective of the project, rather than a preliminary study activity, because details of the technique have not yet been completely developed. After this objective has been completed, students initiate batch, shake flask cultures of both cell lines, measuring concentrations of substrate, biomass, and secondary metabolites over the culture duration. The N. tabacum culture is subsequently scaled up to a 2-L bioreactor, while students determine the same parameters as before. All studies are then modeled mathematically, using simple Monod kinetics for the prediction of all measured responses. Kinetic parameters are estimated using SimuSolv, allowing for direct comparison between the two species studied as well as between the shake flask and bioreactor cultures. In addition, students learn the steps of culture formation by initiating callus culture from seedlings of Capsicum frutescens.

2. In Situ Bioremediation

This project involves remediation of gasoline components benzene, ethylbenzene, toluene, and xylene (BTEX) in liquid systems by a pure strain of Pseudomonas stutzeri and a consortium grown from local vadose zone soil. As a review of pertinent literature, students read excerpts from Environmental Biotechnology for Waste Treatment,[13] as well as several journal articles covering the use of various biological remediation techniques.[14-15] Different microbiological methods necessary for project completion are also reviewed.[16] Laboratory preliminary studies consist of learning compulsory techniques, including preparation of solid and liquid bacterial culture medium, sterile inoculation of cultures, bacterial identification methods such as gram staining, and quantitative assays consisting of viable cell counts using a hemocytometer and toluene concentration determination using GC/MS.

Project objectives begin with a series of batch studies using both P. stutzeri and the "local" microbial consortium to degrade 500 ppb toluene in a nutrient salt solution under different redox (aerobic and anaerobic) regimes and agitation levels. This initial test serves as a basis for designing further experiments to investigate the destruction of BTEX under optimal conditions. These experiments require that the group develop purge-and-trap GC/MS assays for all BTEX components. All batch degradation studies are then modeled mathematically, using SimuSolv, to obtain estimates for kinetic parameters and to suggest optimal conditions for BTEX destruction.

3. Enzymatic Cellulose Hydrolysis

This project focuses on the hydrolysis of cellulosic substrates using pure cellulase enzyme (a preparation from fungal cultures which produce different types of cellulases) and sulfuric acid. Literature for this project includes significant portions of the text Biochemical Engineering[18] and a number of important articles discussing enhanced enzymatic cellulose hydrolysis,[19-22] cellulase production by fungal culture,[23-24] and kinetic modeling of hydrolysis reactions.[25-26]

In laboratory preliminary studies, students master sterile fungal culture techniques using both solid and liquid media. An enzymatic glucose analysis technique is also demonstrated for future use in determining hydrolysis product formation. Students then complete a trial hydrolysis experiment using cellobiose (the β-1,4 dimer of glucose) as a substrate. Product formation data from this study is fit with a Michaelis-Menten response curve as estimates are made for the appropriate kinetic parameters.

The main objective of this study is to compare hydrolysis rates in long-term (eight-hour) studies using (1) pure Cellulase* addition, (2) addition of fungal preparation of T. reesei, and (3) addition of a known concentration of sulfuric acid. The extent of hydrolysis is experimentally determined by measuring glucose concentration periodically throughout each study. Hydrolysis rate constants, estimated using the SimuSolv program, are then directly compared for each method.

4. Microbial Fermentation

This project involves the study of substrate uptake, biomass formation, and product formation in two bacterial species, Escherichia coli and Micrococcus luteus. Reference materials consist of excerpts from both microbiology textbooks and laboratory manuals.[27-28] Preliminary studies consist of learning basic techniques such as preparation of solid and liquid bacterial culture mediums, sterile inoculation and culture sampling, cell strain identification methods, and quantitative assays including viable cell counts as well as glucose and ammonia concentration determinations. Because of the similarity between the two projects, student groups investigating in situ bioremediation and microbial fermentation are allowed to collaborate in completing preliminary tasks.

The overall objective of this project is to formulate a reactor configuration to maximize microbial cell density in the two cell strains studies. Several tasks leading to this main objective include initiating shake flask and 2-L bioreactor cultures of either M. luteus or E. coli and moni-

* Sigma Chemical Co., St. Louis, Missouri
toring concentrations of glucose, cells, and metabolic product (ammonia for *M. luteus* or pH for *E. coli*) throughout a batch culture cycle. In addition, semi-batch cultures of both cell strains are completed with periodic medium replacement to eliminate toxic waste products from the broth in an effort to boost cell density. To aid in cell concentration determination, students also correlate microbial cell counts to measured optical density. In addition, a portion of the batch studies is modeled mathematically to determine kinetic parameters for the individual tests. Given this information, the group then proposes and tests a reactor configuration specifically designed to yield a maximum cell density.

**STUDENT EVALUATION**

The overall student impression of the laboratory course format was extremely favorable. A survey taken at the end of the course yielded a rating of 4.5/5.0 for overall course evaluation, while laboratory teaching methods were rated at 4.7/5.0. Students specifically enjoyed the freedom afforded by the project-oriented approach of the course, as they were directly responsible for planning and scheduling experimental activities. Several participants chose to continue their projects through independent study over the next two quarters, and many students showed an interest in the possibility of a continuation course focusing primarily on laboratory methods in biotechnology.

Criticism of the course was reserved to two points: first, because of long hours spent on project tasks, students felt that the laboratory should qualify for more course credit-hours, and second, several students did not feel adequately prepared to initiate laboratory investigation in biotechnology. To rectify this concern, in a second offering of the biochemical engineering laboratory, both faculty and students from the biology and chemistry departments assisted the participants.

**CONCLUSIONS**

Using a project-oriented approach to biochemical engineering laboratory education proved to be successful in motivating students to produce quality experimental work. Participants were willing to take "ownership" of the investigations because they were intimately involved in all project planning and development steps and were able to conduct a number of experiments in a single research area over an extended period of time. This approach also stimulated students to better integrate previously acquired chemical and biochemical engineering knowledge into decisions pertinent to their project objectives. In addition, the quarter-long investigative projects gave students a more realistic picture of the research world, and they were able to use research tools such as on-line and off-line data bases and mathematical modeling software. By working for extended time periods in a research group, students received more exposure to group accountability in completing delegated experimental tasks. This type of fundamental change in approach to laboratory education has enhanced the quality of instruction in biochemical engineering and may be applicable to other fields of study within the chemical engineering discipline.

**ACKNOWLEDGMENTS**

I would like to thank Dr. James M. Lee (Washington State University) and Dr. Michael L. Shuler (Cornell University) for the respective, generous donations of *Nicotiana tabacum* and *Catharanthus roseus* plant cell suspensions. I also want to acknowledge Dr. Ira F. Jones (Tri-State University) for his assistance in developing several GC/MS assays. Partial support for this project was provided by the National Science Foundation Instrumentation and Laboratory Improvement Program. The National Science Foundation is in no way responsible for or endorses the contents of this paper. Partial support for this project was also provided by the Olive B. Cole Foundation. The SimuSolv modeling and simulation software was donated by the Dow Chemical Company.

**REFERENCES**

15. Song H., X. Wang, and R. Bartha, "Bioremediation Poten-
Objective of the book is to provide a diverse audience with detailed and easy to use.

ChE book review

ACCIDENT AND EMERGENCY MANAGEMENT
by Louis Theodore, Joseph P. Reynolds, and Francis B. Taylor

Reviewed by
Robert M. Bethea
Texas Tech University

Although the authors state that this book is "intended primarily for regulatory officials, company administrators, (practicing) engineers, ... industry maintenance personnel, and both undergraduates and first-year graduate students," I believe that it is much better suited as a reference than as a text for chemical engineering students. The primary objective of the book is to provide a diverse audience with a broad overview of the scope and interrelations of the parts and functions of accident and emergency management programs. The authors have been successful in meeting this objective.

The book is divided into thirteen chapters, each with references, a summary, and problems for discussion or homework (or term papers!). The chapters are divided into four parts: an overview of accident an emergency management (Part I, 76 pages), process and plant accidents (Part II, 181 pages), dispersion (Part III, 142 pages), and hazard and risk assessment (Part IV, 79 pages). The index is reasonably detailed and is easy to use.

Chapter 1, "Past History," presents brief descriptions of early and recent major accidents (Flixborough, Three Mile Island, Chernobyl, Bhopal, etc.) to illustrate the scope and breadth of emergencies for which the reader may need to plan.

Chapter 2, "Legislation," discusses significant Federal laws regarding air and water pollution and hazardous and toxic wastes.

Chapter 3, "Emergency Planning and Response," is a continuation of Chapter 2. It presents brief descriptions and lists some of the items to be considered in the various stages of the development and implementation of emergency response plans. I have used this material as part of a graduate course on chemical process safety for practicing chemical and environmental engineers and safety professionals.

Chapter 4, "Process Fundamentals and Plant Equipment," contains elementary and descriptive material (remember the intended audience) from stoichiometry, thermodynamics, unit operations, and design. This chapter is designed to familiarize the non-chemical engineer with terminology, equipment, processes, and concepts used in examples in Part III.

Chapter 5, "Fires, Explosions, and Other Accidents," presents an overview of fire fundamentals, types, and sources with some physical property data. Appropriate calculation procedures are presented. (Caution: the fi in Eqs. 5.2.1 and 5.2.2 are not correctly defined; they must be on an air/oxygen-free basis, i.e., a combustibles-only basis.) The sections on fire hazards, and especially on fire prevention and protection, are altogether too brief. The section on explosion fundamentals is overly short and will require consider-
CALL FOR PAPERS

Each year Chemical Engineering Education publishes a special fall issue devoted to graduate education comprising
1) articles on graduate courses and research, written by professors at various universities, and
2) ads describing university graduate programs.

Anyone interested in contributing to the editorial content of the 1994 fall issue should write to CEE, indicating the subject of the contribution and the tentative date it will be submitted. Deadline is June 15, 1994.

able supplementation when it is incorporated into chemical engineering course work. The entire realm of toxicology and industrial hygiene has been compressed into three pages which do not refer to the OSHA or EPA standards.

Chapter 6, "Accident Prevention in Process Facilities," focuses on methods of preventing and reducing the frequency and severity of accidents, with primary emphasis on the chemical process industry. It begins with an excellent discussion of the general causes of accidents and proceeds to common specific causes associated with process equipment. This chapter should be required reading for unit operations, process control, and process/plant design courses. The material on relief selection and sizing must be expanded before use. It should be noted that the relief-sizing equations on page 202 are not general; they are only valid for conventional spring-operated reliefs in gas or vapor service.

After reading the material in Chapter 6 on the use of fault trees and HAZOPs, the major difficulty in using this book as a text became obvious. There are no worked examples until you reach Chapter 10.

Chapter 7, "Process Applications," contains very good discussions of five highly toxic and reactive chemicals, each of which can serve as a case study in the techniques of evaluating candidate/alternative processing routes in plant design courses. Each section (e.g., ammonia) contains physical property data, the exposure limits and human health effects, manufacturing methods, uses of the chemical, and near-catastrophic incidents involving the compound.

Chapter 8, "Dispersion," begins with the development of the dispersion equations involved with momentum, energy, and mass transfer. Classic analytic solutions are given for the PDEs as they would be in any course in transport phenomena.

Chapter 9, "Dispersion Calculations," applies the theoretical equations developed in Chapter 8 to dispersions in water and soil, with primary emphasis on the airborne dispersion of continuous (e.g., stack) and instantaneous/puff (e.g., leaks, spills) sources. Factors affecting dispersion in air (meteorologic, effective stack height) are very clearly presented with standard empirical equations. The Pasquill-Gifford approach is clearly presented in adequate detail. The reader will find Figure 9.7.4 especially useful when estimating the location of maximum ground-level concentrations from continuous sources. This chapter also contains very useful information on the effects of aerodynamic downwash and the presence of multiple stacks not usually found outside graduate-level air-pollution texts.

In Chapter 10, "Dispersion Applications," the information in Chapter 9 is expanded in terms of various computer models developed by government (EPA), industry (CMA), and individual companies. These presentations are quite good and describe the limitations, characteristics, input parameters, assumptions, and typical applications of the models. Specific examples are provided for spills on water and soils and for plume rise, continuous and instantaneous point source calculations to match the developments in Chapter 9. The inclusion of particulate deposition calculations is a real "plus," as are those for line and area sources. The examples in this chapter all illustrate the types of calculations needed for emergencies.

Chapter 11, "Hazard and Risk Assessment Fundamentals," is mis-named. It is really a crash course in elementary statistics: probabilities, empirical distribution functions, expected values, and descriptive statistics (means and variances of samples).

Chapter 12, "Hazard and Risk Assessment Calculations," introduces the concepts of reliability and failure rates. The use of a few theoretical (standard normal, log-normal, binomial, Poisson) distributions are included, as are some fault tree and event tree examples.

Chapter 13, "Hazard and Risk Assessment Applications," is illustrated with six examples, including a runaway reaction and dispersion of a toxic chemical from a single point-source release. All these examples, as are the ones in Chapters 9 and 10, are presented in a realistic style.
A VISION OF EXCEPTIONAL TEACHING AMIDST EXCEPTIONAL RESEARCH

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NOTE
Composed for the William Resnick Memorial Issue of the I.I.Ch.E. Journal (Vol. 22, April 1993; reprinted here, in part, with permission), this article not only does honor to Bill Resnick, who died suddenly in April 1992, but it also describes the vision and something of the reality of team teaching undergraduate chemical engineers at Minnesota since the 1960s. How that teaching has impacted undergraduate and graduate education, faculty development, research collaboration, and department ambience may be of interest to others in engineering education.

Bill Resnick, an American chemical engineer who was the first department chairman at the Technion (Israel Institute of Technology, Haifa), spent the 1965-66 academic year as a Visiting Professor at Minnesota. He was drawn there by the vigorously fermenting brew of teaching-and-research in a department that was perceived more and more widely as taking the lead in chemical engineering. One of the attractions, he averred at the time, was the vision of team teaching, and the way the Minneapolis department's diverse band of professors was making the vision a reality.

That vision was an outgrowth of another—it had no clear beginnings, but a crucial stimulus was Neal Amundson's 1954-55 sabbatical in the new chemical engineering department at Cambridge University in England. There, the industry-seasoned Mr. Fox was melding an assortment of relatively young mechanical engineers, physical chemists, a surface chemist, and the odd engineer into a lively whole. (That was 'The Chiefs' first and only sabbatical from the Minnesota department since 1949, the year he was named Acting Head at thirty-three years of age.) Amundson, himself a chemical engineer who had taken his PhD in mathematics, envisioned a similar broadening of the intellectual base and vitalizing teaching and research back home at Minnesota.

Within a few years he attracted a half-dozen talented people to the faculty, most of them young, all of them inspired by the vision:

- A microbiologist, Henry Tsuchiya (1956): "...to reinforce the tradition of intimate cooperation with other disciplines (for strong connections with bacteriology, as well as with mathematics and chemistry, had existed since the 1920s)"
- A creative chemical engineer who had been in a mechanical engineering setting, Bill Ranz (1958)
- A unique hybrid of mathematician, physicist, engineer, and scholar whom Amundson had met deep in Imperial Chemical Industries in England, and with whom he later often teamed, Gus (Rutherford) Aris (1958)
- A non-Newtonian chemical engineer from the Bird school, who was soon to turn biochemical engineer and partner of Tsuchiya, Arnie Fredrickson (1959)
- A theoretical chemist of the Hirschfelder school and of the highest intellectual standards, who had been a postdoctoral fellow in The Netherlands, John Dahler (1959)
- A chemical engineer who had developed his fluid mechanical and interfacial proclivities working in the Shell Development Company, Skip Scriven (1959)

The later-comers helped attract each other, and the whole group fell into a resonance of shared goals, standards, and friendship that stimulated all of them, including the few older members of the department. That resonance was a strong attractant when the following openings were filled a few years later:

- A fire-eating chemical physicist, experimental and theoretical, who came from a postdoc in Belgium, Ted Davis (1963)
TEAM TEACHING OF UNDERGRADUATES

Chemical engineering classes of sixty to ninety students (fewer, long ago; more in most years now) are taught by teams of four faculty. In lecture courses, one professor is the lecturer and coordinator (responsible for lecturing, setting assigned problems and examinations, and coordinating the graduate teaching assistants who critique and grade student assignments). The lecturer also prepares recitation plans—outlines of lecture-related items, features of assigned and other problems to present and discuss with students (or to quiz them on) in section meetings. Each section, 15-25 strong, is headed up by a recitation leader—a professor, an instructor (a selected postdoctoral or advanced doctoral student), a visiting professor, or (in certain design, control, and laboratory courses) an adjunct professor.

The recitation leaders (and, if encouraged strongly enough, the graduate teaching assistants) attend the lectures. This is the heart of the innovation, and it violates a not-uncommon taboo against one professor sitting in on another professor's class. There are four faculty members at every lecture: one standing up front and three sitting in the back. If the lecturer is, say, a second-year assistant professor and the recitation leader is a grizzled full professor, the former is the teacher and the latter a student taking notes, jotting down ideas for recitation. Outside of class they discuss the lectures, recitations, problems, examinations, progress, and difficulties of students and grading. Everyone, including the teaching assistants, is actively involved.

With an audience as described above, a sloppy lecture is as rare as a May frost, or a January thaw, in Minnesota; a rare and embarrassing event not likely soon to be repeated. Standards are elevated—to the advantage of students. There is no uncertainty about classroom performance, nor is there any lack of constructive criticism and encouragement. Teaching is taken very seriously. Crafting lectures is arduous work, compounded by the demands of designing lesson plans and the rest. But the benefits for everyone concerned are fine.

The recitation leaders get the recitation plan a day in advance, and a couple of hours spent in preparation the night before is usually sufficient. Not infrequently they find themselves picking up the phone to straighten out some item with the other team members. An inexperienced newcomer may be given a late section in order to have the option of sitting in on some other section earlier the same day. In class the recitation leaders engage students in an intensive way not possible in lecture, and they come to know the students well. Year-in and year-out, most students have said that they especially appreciate the recitation and laboratory sections.

There is another central feature to this system: a faculty member has to have been a recitation leader in a course before she or he can lecture in that course. That means the lecturer has been immersed (if not submerged) in a complete course designed by a predecessor. He or she may then redesign it, but with full knowledge of what has been done before. So course content tends to evolve and improve, again to the great benefit of the students.

And the last central feature: a faculty member has to leave a core course after lecturing in it for three successive years, or at most four. The first year is one of tailoring or revamping the course—and getting feedback; the second year is one of polishing the new version; the third year is likely to be one of coasting a bit. Then it's time to move on to another
of the core courses. Thus, in time every professor diversifies as a lecturer into many of the core courses: stoichiometry and balances, fluid mechanics, thermodynamics, heat and mass transfer, separation processes, reaction engineering, control, and design.

The unit-operations-type laboratories are also team-taught, with sections of fifteen students divided into three-member groups. There is a professor present and in charge of each section, assisted by a graduate student, while one professor coordinates the whole course and chairs the weekly bag-lunch meeting of the entire team. In this way, almost every professor gains experience with the laboratory courses. As in the recitation section, the rotation time is likely to be just one or two years, not the longer cycle of those in charge of courses.

These features, taken together, result in faculty that know much of the curriculum intimately. If a professor is, for some reason, out of touch with the current version of a course, within a few years he or she can be back in very close touch. Everyone is well-informed and capable of integrating and evolving the curriculum over the long run, and for counseling undergraduate advisees term-by-term (actually quarter-by-quarter at Minnesota).

RESULTS OF TEAM TEACHING

For Undergraduate Students • Through the recitations and the similarly sectioned laboratories, students and faculty are put into closer contact. There is more effective transmission of what is taught that is not in any syllabus: the attitudes and standards, the patterns of thought about subject matter; the approaches to study, experimentation, and problem solving; the skills and styles of communicating—in short, the framework of the discipline and of the profession. As crucial as these factors are to engineering curricula, they are hard to define and even harder to measure, and so they go unexamined in evaluations. They are also hard for undergraduates to appreciate until later in their careers.

There are additional advantages for the students. Professors broaden and freshen by rotating through the core courses and the yearly reconstituted teaching teams. Heightened interest and enthusiasm of faculty and teaching assistants brings higher standards of teaching: the courses are well organized, with carefully selected coverage, quality lecturing, effective recitation and laboratory instruction, and automatic teaching and course evaluation. Courses evolve by a kind of natural selection at the hands of successive, overlapping teaching teams, some of which include adjunct professors from industry. Overcramping a course with material has to be guarded against, but a faculty that is collectively well-informed about the details of all the courses is enviably equipped to coordinate courses and integrate the curriculum. The capstone in chemical engineering is the senior course in process synthesis and design. Notwithstanding discussions that go back to Bill Resnick's stay and earlier, the potential for making that course the integrating kernel have barely been tapped.

For Graduate Students • As part of their education, graduate students assist in one ten-week course each year after the first year. Fuller involvement than mere grading is an excellent means of reviewing course material and rectifying deficiencies, an advantage widely recognized by PhD aspirants—and their advisors. A disadvantage of the team-teaching scheme is that opportunities for stand-up teaching are lost—though this is more than offset by the advantage to undergraduate students of faculty teaching of recitation and laboratory sections. But graduate students are able to begin as assistants on the floor of laboratory courses, in office-hour tutorials of lecture courses, and in mentoring undergraduate research participants. The most promising of those interested in academic careers can also qualify as instructors.

For Faculty • It is comparatively easy to take up a new course by attending lectures and preparing for and leading recitations—all the while learning or re-learning the material and reflecting on alternatives and improvements (not only in the course but also in its relation to other courses). New faculty, not having apprenticed as recitation leaders, cannot lecture in core courses during their first year when they are occupied with establishing research programs and, often, an elective course in their specialty. But through recitation and laboratory assignments they are exposed to role models, standards and values, and the camaraderie of shared teaching. Rotation through the courses affords opportunities to change over without undue effort, and thereby to master the entire core curriculum. A professor with primary responsibility for a postgraduate course in a given semester or quarter can retain a small active role in the undergraduate program by handling a recitation or laboratory section.

More significantly, professors who lack background in a particular area or, indeed, in the discipline of chemical engineering itself, gain an education through teaching. Bill Resnick witnessed a micro-biologist, physical chemists and chemical physicists, a physical organic chemist, a mathematician/physicist/engineer, and so on in various stages of this process. It is the way to weld into a lively whole a type of faculty particularly well suited to orient students toward a future in chemical engineering, where modern developments in chemistry, molecular biology, computer science, materials science, and related fields will continue to be applied. A by-product is a milieu in which instructors, postdoctoral fellows, and visiting professors from other fields (physical chemistry, applied mathematics, physics, mechanical engineering) have prepared for academic and industrial careers in chemical engineering.

A carry-over of the scheme is its permeation, scaled down, into some jointly taught elective courses and postgraduate
courses—notably in the polymer and biochemical-biomedical engineering areas.

The most profound outcomes of all emerged over more than a decade. First was the subtle stimulation of research; then came fresh research collaborations by many of the faculty; then an exceptional atmosphere of research cooperation and collaboration. The combinations and recombinations of joint authors testify to this. So do graduate students, postdoctoral fellows, industrial fellows, and visiting and permanent faculty who have been attracted to it. The taproot of much of the exceptional research, and teaching of research, that ultimately emerged is clearly in the shared experiences, the special resonance, of undergraduate team teaching.

FINANCING

Team teaching by faculty entails greater costs than doing without recitations and relying on graduate-student teachers. The costs can be met by money from the institution to enlarge the faculty, or by subtle diversions of research funding to the same end, or by time from professors to discharge heavier responsibilities. Since Bill Resnick's stay, there has been a shift from the former to the last, with two results. One is that incremental costs are borne by professors, by sacrificing their recreational time and, all too often, their time with their families. The other is that the team-teaching scheme has been eroded by compromises, most noticeably through larger recitation sections, overcrowded laboratory sections, a greater number of graduate students appointed as Instructors, addition of senior faculty inexperienced in the scheme, and even temporary abandonment of recitation sections in a core course.

When institutional funding was less strained, enrollments were lower, and commitment to the scheme was undiluted, the class-teaching load of regular faculty in the Minnesota department was structured as follows:

- **either** be in charge of a core course;
- **or** in charge of two of the following: a graduate course, an undergraduate elective course, a recitation section, a laboratory section;
- **or** just one of those, one quarter out of three each year.

Resnick's load was a bit heavier in 1965 when he taught the graduate thermodynamics course for two quarters in addition to participating in teaching teams all year. That was an era of graduate fellowships and traineeships, more funding for post-doctorates and visiting professorships, and other sources that could be drawn upon to support team teaching. The scene has, of course, changed. Institutional accounting of faculty time and allocation of available resources have made it much tougher to convince those in authority to invest in a single department's special programs in instructional effectiveness and faculty development.

TRANSPLANTATION

The question is why something approximating the whole scheme has not sprung up elsewhere. To be sure, many parts of it exist in many places, and they did so long before the total innovation got under way in Minnesota in the mid-1950s. It would appear that a number of circumstances are probably all necessary:

- A *sizeable group of young faculty, each inclined toward working together, teaching well, and broadening and deepening his or her mastery of the subjects in the curriculum.*
- Effective leadership of the department and the core curriculum, coupled with a clear vision of the principles of the scheme.
- Older faculty with a compatible tradition, or at least with the self-confidence, flexibility, and talent to enter into a team-teaching scheme wholeheartedly.
- Some surplus of departmental resources and some commitment of faculty time to invest for the long term.

The biggest payoff of the team-teaching scheme comes over the long term. It brings unique opportunities to strengthen teaching and curriculum, followed by the integration of teaching and research, and then research itself, especially cooperative and collaborative research within the department—that is, to strengthen ultimately the whole enterprise.

A great impediment for most institutions seems to be a taboo against one professor sitting in on another professor's class. Another seems to be a reflexively negative response of entrenched faculty to the prospect of preparing new courses, and still another impediment is university accounting of apparent costs—headcount-based measures (i.e., apparent cost per student), lack of measures of benefits and effectiveness, and the common practice of using obtuse comparisons with other departments as the basis for budget decisions.

CLOSING

At the 1981 Annual Meeting of the American Institute of Chemical Engineers, I described the fruitful innovation of team teaching. Since that event I wanted to ask Bill, the consummate professor and indefatigable traveler, for his answer to the transplantation question. But we always met on short notice or in busy situations: a conference he organized in Arad, a one-day whirlwind tour together of much of Israel, a dinner given by chemical engineers in Santa Fe (Argentina), a hallway of an AIChE meeting, a review of the department at Ben Gurion University. The last was several December days in 1988 spent together focusing intensely on the inseparable teaching-and-research of an admirably dedicated faculty in our discipline. It reflected beautifully the activities and discussions of the 1965-66 academic year in Minneapolis. Bill is a friend and kindred spirit. How I would like the pleasure of catching up with him again, as usual, in some unpredictable place!
Random Thoughts . . .

THINGS I WISH THEY HAD TOLD ME

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Most of us on college faculties learn our craft by trial-and-error. We start teaching and doing research, make lots of mistakes, learn from some of them, teach some more and do more research, make more mistakes and learn from them, and gradually more or less figure out what we're doing.

While there's something to be said for purely experiential learning, it's not very efficient. Sometimes small changes in the ways we do things can yield large benefits. We may eventually come up with the changes ourselves, but it could help both us and our students immeasurably if someone were to suggest them early in our careers. For whatever they may be worth to you, here are some suggestions I wish someone had given me.

➢ Find one or more research mentors and one or more teaching mentors, and work closely with them for at least two years. Most faculties have professors who excel at research or teaching or both and are willing to share their expertise with junior colleagues, but the prevailing culture does not usually encourage such exchanges. Find out who these individuals are and take advantage of what they have to offer, if possible through collaborative research and mutual classroom observation or team-teaching.

➢ Find research collaborators who are strong in the areas in which you are weakest. If your strength is theory, undertake some joint research with a good experimentalist, and conversely. If you're a chemical engineer, find compatible colleagues in chemistry or biochemistry or mathematics or statistics or materials science. You'll turn out better research in the short run, and you'll become a better researcher in the long run by seeing how others work and learning some of what they know.

➢ When you write a paper or proposal, beg or bribe colleagues to read it and give you the toughest critique they're willing to give. Then revise, and if the revisions were major, run the manuscript by them again to make sure you got it right. Then send it off. Wonderful things may start happening to your acceptance rates.

➢ When a paper or proposal of yours is rejected, don't take it as a reflection on your competence or your worth as a human being. Above all, don't give up. Take a few minutes to sulk or swear at those obtuse idiots who clearly missed the point of what you wrote, then revise the manuscript, doing your best to understand and accommodate their criticisms and suggestions.

If the rejection left the door open a crack, send the revision back with a cover letter summarizing how you adopted the reviewers' suggestions and stating, respectfully, why you couldn't go along with the ones you didn't adopt. The journal or funding agency will usually send the revision back to the same reviewers, who will often recommend acceptance if they believe you took their comments seriously and if your response doesn't offend them. If the rejection slammed the door, send the revision to another journal (perhaps a less prestigious one) or funding agency.

➢ Learn to identify the students in your classes, and greet them by name when you see them in the hall. Doing just this will cover a multitude of sins you may commit in class. Even if you have a class of over 100 students, you can do it—use seating charts, labeled photographs, whatever it takes. You'll be well compensated for the time and effort you expend by the respect and effort you'll get back from them.

➢ When you're teaching a class, try to give the students something active to do at least every twenty minutes. For example, have them work in small groups to answer a question or solve a problem or think of their own questions about the material you just covered.* In long class periods (seventy-five minutes and up), let

* Many other ideas for active learning exercises are given in references 1 and 2.
them get up and stretch for a minute.

Even if you’re a real spellbinder, after approximately ten minutes of straight lecturing you begin to lose some of your students—they get drowsy or bored or restless, and start reading or talking or daydreaming. The longer you lecture, the more of them you lose. Forcing them to be active, even if it’s only for thirty seconds, breaks the pattern and gets them back with you for another ten or twenty minutes.

> After you finish making up an exam, even if you KNOW it’s straightforward and error-free, work it through completely from scratch and note how long it takes you to do it, and get your TAs to do the same if you have TAs. Then go back and (1) get rid of the inevitable bugs and busywork, (2) make sure most of the test covers basic skills and no more than 10-15% serves to separate the As from the Bs, and (3) cut down the test so that the students have at least three times longer to work it out than it took you to do it.

> Grade tough on homework, easier on time-bound tests. Frequently it happens in reverse; almost anything goes on the homework, which causes the students to get sloppy, and then they get clobbered on tests for making the same careless errors they got away with on the homework. This is pedagogically unsound, not to mention unfair.

> When someone asks you to do something you’re not sure you want to do—serve on a committee or chair one, attend a meeting you’re not obligated to attend, join an organization, run for an office, organize a conference, etc.—don’t respond immediately, but tell the requester that you need time to think about it and you’ll get back to him or her. Then, if you decide that you really don’t want to do it, consider politely but firmly declining. You need to take on some of these tasks occasionally—service is part of your professorial obligation—but no law says you have to do everything anyone asks you to do.*

> Create some private space for yourself and retreat to it on a regular basis. Pick a three-hour slot once or twice a week when you don’t have class or office hours and go elsewhere—stay home, for example, or take your laptop to the library, or sneak into the empty office of your colleague who’s on sabbatical.

It’s tough to do serious writing or thinking if you’re interrupted every five minutes, which is what happens in your office. Some people with iron wills can put a "Do not disturb!" sign outside their office door, let their secretaries or voice mail take their calls, and Just Do It. If you’re not one of them, your only alternative is to get out of the office. Do it regularly and watch your productivity rise.

> Do your own composing on a word processor instead of relying on a secretary to do all the typing and correcting. If you’re a lousy typist, have the secretary type your first draft, but at least do all the revising and correcting yourself.

Getting the secretary to do everything means waiting for your job to reach the top of the pile on his desk, waiting again when your job is put on hold in favor of shorter and more urgent tasks, waiting yet again for the corrections on the last version to be made, and so on as the weeks roll merrily by. If a job is really important to you, do it yourself! It will then get done on your time schedule, not someone else’s.

> Get copies of McKeachie[1] and Wankat and Oreovicz.[2] Keep one within easy reach in your office at school and the other in your home office or bathroom. You can open either book to any page and get useful pointers or answers to troubling questions, and you’ll also get research backing for the suggestions presented.

> When problems arise that have serious implications—academic misconduct, for example, or a student or colleague with an apparent psychological problem, or anything that could lead to litigation or violence—don’t try to solve them on your own. The consequences of making mistakes could be disastrous.

There are professionals at every university (academic advisors, trained counselors, attorneys) with the knowledge and experience needed to deal with almost every conceivable situation. Find out who they are, and bring them in to either help you deal with the problem or handle it themselves.

That’s enough for starters. If you feel moved to try any of these suggestions, I’d be grateful if you let me know what happens . . . and if you’ve been on a faculty for a year or more, I invite you to send me some additional ideas—tips you wish someone had given you when you were starting out. When I get enough of them I’ll put them in another column with appropriate attribution.

REFERENCES


TEACHING
STAGED-PROCESS DESIGN
THROUGH
INTERACTIVE COMPUTER GRAPHICS

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Graphical methods have long played a role in the teaching of separations processes. The classic papers of Ponchon,[1] Savarit,[2] and McCabe and Thiele[3] described graphical techniques for staged-distillation design that remain in use today more than half a century after their creation. Similar procedures are employed for absorption and extraction and for a number of the less frequently encountered processes.

While such methods are useful pedagogically and their results more rapidly assimilated than those from numerically solved processes, they are also tedious, time-consuming, and require no small amount of drafting skill. Cumulative errors due to poorly constructed lines, missed intersections, and inaccurate interpolations can alter a drawing and mask the trends one wishes to show. Moreover, parametric cases are almost impossible to construct in any reasonable period of time. Thus the benefits of these visualized designs are too often overshadowed by the difficulties involved in producing them.

Several workers in recent years have used the computer to eliminate the tedium and inaccuracy of manual graphic design. Gaskell[4] used an analog-logic computer in rep-op mode to produce McCabe-Thiele displays for systems at constant relative volatility. His examples showed variations in all of the usual operating parameters as well as misplacement of the feed tray. Calo and Andres[5] employed Smoker's method for constant-$\alpha$ distillations having both multiple feeds and multiple side-draws. Their program was interactive and yielded expandable McCabe-Thiele plots on a storage CRT.

Working in Cornell University's Computer-Aided Design and Instructional Facility, Golnaraghi et al.[6] used vector-refresh graphics to produce McCabe-Thiele diagrams on an Evans and Sutherland Multipicture System. Their scheme provided for rapid data input and recomputation of parametric cases through a stylus-tablet arrangement. More recently, Kooijman and Taylor[7] have used graphics to accompany their ChemSep program, and Fogler and Montgomery[8] have created a variety of separations modules with associated visuals.

At Iowa State we have developed a method that applies computer graphics to the three major separations procedures and to several process types within each. Using the FLOWTRAN simulator[9] to solve the balance and thermodynamic equations for each operation, we have written pre- and post-processing software to simplify data entry and to

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Chemical Engineering Education
display the numerical results of the simulations in a variety of standard formats. For single-solute absorption and stripping, for extraction with and without reflux, and for several configurations of binary distillation, our program allows for interactive building of input files, execution of the FLOWTRAN runs, and display of the computed results using medium-resolution color-graphics devices. Auxiliary COST blocks are combined with the FLOWTRAN separations blocks ABSBR, EXTRC, FRAKB, AFRAC, IFLSH, and BFLSH to retrieve the computed stream properties and store the data in display files. After each simulation run a menu of graphical options lists the displays available for the particular process involved.

Our program is called "Simulation Graphics," and it provides all computing support for the undergraduate mass-transfer course at Iowa State. Working in small groups, students use the program to generate graphical solutions to problems involving the three separations processes noted above. During a typical term, five such problems are assigned, each in absorption and extraction and three in distillation. The problems are worded so as to correlate with the current course textbook (Treybal\textsuperscript{10}), and each problem concludes with a process specification for which an optimum design must be found.

To use the program, students choose the process, indicate the run conditions (feed properties, number of stages, reflux ratio, etc.), execute the FLOWTRAN simulation, and then select the type of display that they wish to see. For distillation they can view either Ponchon-Savarit or McCabe-Thiele plots, an overall block diagram or the stage-by-stage details for selected regions of the tower, or other diagrams showing zoomed and logarithmic plots and displays of the stream details for adjacent trays provide complete definition of a process and allow for verification of energy and material balances and physical-property relationships. Manual methods, especially when executed carefully, are far too slow to be effective vehicles for showing trends.

Visual accuracy is guaranteed by the direct plotting of computed results onto medium-resolution graphics devices. While the program currently produces displays on Tektronix hardware, we plan ultimately to port it to other systems of comparable graphic quality (EGA-equipped PCs, DEC stations with color graphics, etc.). Color is an important attribute in this method because it distinguishes the various components of a staged-process display—equilibrium and operating curves, rays, feed and product lines—and also clarifies the accompanying text that reports the numerical results for each run.

Chemical accuracy follows from the way in which phase-equilibrium data are entered. As with other process simulators, FLOWTRAN contains a data-regression utility (VLE) that accepts data in various formats and generates best-fit activity-coefficient parameters based on user-specified thermodynamic models. Various options are available for vapor pressure, fugacity, activity coefficients, liquid density, and the like. The procedure is simple and fast and guarantees that subsequent operations performed on a system are based on a realistic equilibrium function. The repeated assumption of ideality, as is often the practice when teaching basic separations techniques, sends students the wrong message about the value of chemical accuracy. Using VLE we have successfully modeled nonideal and azeotropic vapor-liquid systems for distillation as well as partially miscible liquid-liquid equilibria for extraction.

In designing this software we have attempted to give graphical support to many of the process variants that can be handled by FLOWTRAN. Dual feeds, side streams, tray heaters and coolers, inefficient stages, and partial condensers can not only be simulated but will also be represented in the computer-generated displays through the correct graphical constructions. Alternate graphical modes involving zoomed and logarithmic plots and displays of the stream details for adjacent trays provide complete definition of a process and allow for verification of energy and material balances and physical-property relationships.

**CLASSROOM USE**

Graphical design for staged processes is traditionally carried out before the fact. Diagrams are constructed to deter-
mine the operating conditions for a process—number of trays, L/G ratio, heating and cooling loads, and other parameters that specify the operation. "Simulation Graphics" provides after-the-fact information. Conditions are supplied to the simulator, and if the separation is successful the results may then be plotted in any of the standard forms. While traditional methods yield the number of stages needed for a separation, simulators require such numbers before runs can be made. Manual methods set reflux and L/G ratios on the basis of predetermined limits. "Simulation Graphics" must be given those ratios before it can run.

This subtle but important distinction influences the way that this software is used in the classroom. Our assignments always begin with cases that work—sets of operating conditions that cause FLOWTRAN to converge the balances, effect a solution, and build a display file for subsequent plotting. Variations are then imposed upon these base cases to achieve the actual operations desired.

We feel that there is little pedagogical loss in this approach. The advantages gained from students being able to introduce process variations quickly, easily, and with full graphical support far outweigh any effort required by a shift in teaching style. With this software we have been able to assign problems of greater significance, having more complexity, requiring less student effort, and offering a higher expectation of performance than was possible with classical methods. Moreover, it exposes our students to the benefits of computer-based visualization early in their development and in a context uniquely associated with chemical engineering.

Students learn to use "Simulation Graphics" quickly. Each group has an introductory session with the instructor before running the first (absorption) assignment. Handout materials lead the students through the procedure and complement the prompts that appear on the screen. Learning the operations for the distillation and extraction problems that come later in the course requires only a small additional effort.

In the remainder of this paper we will show selected displays from among those generated in our current group of assignments. The figures were produced with a Tektronix model 4696 printer with all colors set to dark blue for maximum contrast. Where information has been lost because of the absence of color, callouts have been added for clarity.

GAS ABSORPTION

Figure 1 shows the mole-fraction-based equilibrium curve and operating line for the removal of dilute (1.0%) benzene vapor from nitrogen using n-hexadecane as the absorbing liquid.* Seven equilibrium trays are used with a liquid/gas ratio of 0.22 (L/Gs is the solute-free ratio). A regular solution model yielded the near-Henry's law equilibrium curve, and the small amount of solute transferred accounts for the limited temperature increase and the straight operating line on fraction coordinates.

* The basic FLOWTRAN data base contains physical properties for 180 compounds, but it may be expanded at will using information from standard sources.

Figure 1. Absorption of dilute benzene.

GAS ABSORPTION

Figure 2. Absorption of concentrated benzene.
Students learn to use "Simulation Graphics" quickly. Each group has an introductory session with the instructor before running the first (absorption) assignment. Handout materials lead the students through the procedure and complement the prompts that appear on the screen.

Figure 3. Heat removal using tray coolers (x, y denotes mole-fraction benzene).

Figure 4. Absorption with inefficient trays.

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column and also the thermal conditions and (optimum) entry-points for the two-phase feeds. Nonequilibrium trays may be specified as an option. The Ponchon-Savarit diagram in Figure 6 adds thermal information and permits confirmation of the difference points for the three sections of the tower. (Individual feed conditions are shown by the square symbols.) Students mount these plots on large, identically ruled graph sheets and extend the truncated rays to their intersections at the actual Δ points. Heat duties are noted in both the accompanying text and also in the stage details for the top and bottom sections of the tower. (The latter appears in Figure 7.)

For simplicity, pressure in this problem was held constant at one atmosphere throughout the column. A linear pressure profile may also be imposed by setting the pressures for the top and bottom trays to suitably spaced values. Effluent compositions from each tray are then determined from the local pressure value and the physical-property model in effect. The property model in the example shown here comprised Antoine vapor pressures, Redlich-Kwong vapor and liquid fugacities (the latter Poynting-corrected), and Van Laar activity coefficients evaluated so as to minimize K-value error between experimental and predicted data. [13]

The concept of entropy increase on mixing may also be illustrated in this problem by having students combine the two feeds and distill the composite in a separate, single-feed column. The (adiabatically) combined feed-state lies on the line connecting the individual feeds in Figure 6 and is shown by the diamond symbol. With other variables held constant, the reflux is increased until the purity of

"McCabe-Thiele" is a generic name for this diagram. The operating lines connect rigorously determined stream compositions and are straight only if the L/G ratios do not vary. Similar comments also apply to the q-line construction.

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**Figure 5.** Acetone-isopropanol distillation, McCabe-Thiele analysis

**Figure 6.** Distillation with two feeds.

**Figure 7.** Lower stages and (partial) reboiler.

**Figure 8.** Open-steam distillation of methanol (1) - water (2).
the single-feed distillate matches that obtained when the feeds are separated. The added heat load is then related qualitatively to the energy needed to "demix" the composite (approximately a 20% increase in this example).

Figure 8 shows the results of open-steam distillation of a two-phase feed in the methanol-water system. Wet steam at 50 psia and 10% moisture is fed to the bottom of a 16-tray tower with the feed nozzle at tray 3 and a side-stream port (for liquid withdrawal) at tray 6. The McCabe-Thiele diagram shows the large concentration-change at 40% of the liquid flow. The accompanying numerical data (not shown here) report the condenser duty and the conditions of the entering steam to give the energy and cooling requirements for the process.

Tray compositions at the top of the tower are given by a separate logarithmic plot (seen here as an inset to Figure 8). High-purity bottoms products may also be represented in this way.

**SOLVENT EXTRACTION**

As a final example, pure isopropyl ether is used to separate acetic acid from aqueous solution in a countercurrent extractor with four perfect stages. Isothermal conditions are assumed. Phase-equilibrium data were obtained for the acetic acid-water-ether ternary, and Renon activity coefficients were fitted to the experimental coexistence curve to include acid compositions well in excess of those involved in the extraction.

Figure 9 shows the right-triangular diagram for the process. The bulk-mixing point (□) reflects the mass balance among the terminal streams, and the position of the difference point gives a solvent-to-feed ratio approximately 2.7 times the minimum.

The same information may be plotted on solute-distribution coordinates, where raffinate/extract flow ratios may be obtained from the local slope of the operating curve (or from the actual flows given on the plots of individual stages). Other display modes include coordinates for solvent-free and immiscible-liquid flows, as well as for the basic ternary phase diagram.

**IN SUMMARY**

For each of the above processes, the FLOWTRAN block diagram is constructed by "Simulation Graphics" instead of by the user. Two-feed distillation uses the FLOWTRAN unit FRAKB in a normal configuration—the feed conditions, the fraction overhead, the reflux, and the number of trays of specified efficiency determine the rates and compositions of the products. The open-steam example employs the block AFRAC, but in a less conventional mode, where internal control loops yield an effective total condenser and a reflux-dependent product. But these connections are unseen by the user who specifies the process by responding to separations-language prompts and is thus shielded from detailed interaction with the simulator.

Graphical operations in the program are independent of the simulations. All numerical results are written to display files which are used separately to produce the various drawings available. The usual FLOWTRAN output files (histories, FTO files, etc.) are turned off during normal operation but may be re-enabled within the program for purposes of debugging.

"Simulation Graphics" will continue to grow as we add more algorithms to assemble the FLOWTRAN blocks in new and more varied ways. The principal efforts at present involve creating interactive access to the FLOWTRAN physical-property base and employing additional control loops to expand the ways in which processes may be specified.

Inclusion of the data-regression utility within the interactive shell is also planned.

Future enhancements will include utilities to model continuous-contact processes and also expanded graphics capabilities for representing various aspects of multicomponent separations. Extensions to other process simulators and to other computing systems are likewise being considered.

Our goal in developing this software has been to create a precise pedagogical tool, undiluted by limitations and simplifying assumptions, yet fast and easy enough to use for a typical undergraduate separations course. Computer-assisted instruction should broaden a student's experience, first by removing the tedium of repetitive and mechanical operations and second by filling the time saved with work that

*Figure 9. Liquid-liquid extraction.*

*Continued on page 139.*
This column provides examples of cases in which students have gained knowledge, insight, and experience in the practice of chemical engineering while in an industrial setting. Summer interns and coop assignments typify such experiences; however, reports of more unusual cases are also welcome. Description of analytical tools used and the skills developed during the project should be emphasized. These examples should stimulate innovative approaches to bring real world tools and experiences back to campus for integration into the curriculum. Please submit manuscripts to Professor W. J Koros, Chemical Engineering Department, University of Texas, Austin, Texas 78712.

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The DuPont Design Internship in Pollution Prevention at The University of Tennessee is an honors course in which source reduction is incorporated into the design of industrial processes. The internship project described here focused on future systems for the production of HCN and was supported by the DuPont Company. The student design team consisted of six chemical engineering seniors; it was supported by both faculty and industrial advisors. The output was a design report on HCN processes for the future. An important benefit of the activity was the intensive process design experience for the students that emphasized pollution prevention concepts.

The design internship proceeds through the following typical steps for preliminary process synthesis and evaluation:
- Project definition
- Flowsheet development
- Design of equipment sufficiently for cost estimating
- Economic analysis
- Reporting

The activity described here is honors experience in industrial process design where pollution prevention through basic flowsheet development and equipment selection is emphasized rather than the more conventional treatment of effluent waste streams. This was the third such internship; the course is now a permanent component of the curriculum—a 3-semester-hour alternative to the capstone senior design course. Student selection is based on academic achievements and completion of an informal interview. Providing equal opportunity for all chemical engineering students having appropriate prerequisite course work is an important consideration.

The chemical engineering faculty involved in this activity have typically been one full-time tenured faculty member and an emeritus faculty member; other faculty members have also been involved. Salary recovery for the full-time faculty member and reimbursement of other faculty through consulting arrangements or salary recovery is typical. Full financial support for the project was provided by DuPont.

Successful activities such as this one require considerable faculty time, and non-tenured faculty should carefully consider whether their involvement will endanger promotion

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Chemical Engineering Education
and tenure. Faculty from other departments are extremely valuable in helping the students gain a suitable working knowledge of a subject that is commensurate with their educational background. Professor G.K. Sweitzer of the UT Chemistry Department was quite helpful in the current study. Students typically communicated frequently with industrial project advisors via email and fax messages; the industrial project advisors for the current study were the DuPont authors of this paper. Again, input from the industrial project advisor is necessary to insure that a high quality experience for the students and a useful design study be accomplished.

The focus of the faculty and industrial advisors is providing the necessary conditions and support for a student-directed process design team. This is usually the student’s first significant project involving a team rather than individual effort, and they have typically had limited exposure to environmental regulations or waste management operations. They alternate weekly as group leaders and communicate frequently with their advisors. There are usually three hours a week of scheduled group meetings (with faculty advisors present) where goals are formulated, accomplishments presented and reviewed, and a few supplemental faculty lectures are presented. The students contribute a great deal of time to successful conclusion of the projects—similar to the time and effort required of a typical engineering capstone design experience.

**PROJECT DEFINITION**

The Andussow process for HCN production with NH$_3$ recycle was used as a base process for cost comparison. Since the details of the actual study are proprietary, this discussion will use information on the Andussow process with NH$_3$ recovery from *The Encyclopedia of Chemical Technology.*$^{[1]}$ The Andussow process uses the catalytic reaction

$$\text{CH}_4(g) + \text{NH}_3(g) + 1.5 \text{O}_2(g) \rightarrow \text{HCN(g)} + 3 \text{H}_2\text{O(g)} + 115.2 \text{ kcal} \quad (1)$$

The major steps of the Andussow process with NH$_3$ recycle are illustrated in the block diagram of Figure 1. The HCN synthesis step of the Andussow process was common for all the alternative designs considered; this study focused on variations of the ammonia recovery step and the HCN refining step. The base case process, the Andussow process with NH$_3$ recycle, is illustrated more completely in Figure 2. Typical reactor operating information and yield are provided in Table 1. Figure 2 shows unreacted NH$_3$ recovered from the reactor product gas by the reversible reaction

$$\text{NH}_3(g) + \text{H}_2\text{NH}_4\text{PO}_4(1) \leftrightarrow \text{H(NH}_2\text{)}_2\text{PO}_4(1) \quad (2)$$

The forward reaction of Eq. (2) removes NH$_3$ from the reactor product gas while the reverse reaction allows the recovery of NH$_3$ and regeneration of the phosphate solution.

**TABLE 1**

<table>
<thead>
<tr>
<th>HCN Production by Andussow Process$^{[1]}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical Reaction Conditions</strong></td>
</tr>
<tr>
<td>- Temperature = 1100°C</td>
</tr>
<tr>
<td>- Pressure = 2 atm</td>
</tr>
<tr>
<td>- Precious Metal Catalyst</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Typical Off-Gas Composition from Reactor (mol%)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>N$_2$ 46.5%</td>
</tr>
<tr>
<td>H$_2$O 15.0%</td>
</tr>
<tr>
<td>HCN 22.0%</td>
</tr>
<tr>
<td>CO 5.0%</td>
</tr>
<tr>
<td>CO$_2$ 0.5%</td>
</tr>
<tr>
<td>CH$_4$ 0.5%</td>
</tr>
<tr>
<td>NH$_3$ 2.5%</td>
</tr>
</tbody>
</table>

**Figure 1.** Block diagram for Andussow process for HCN production with ammonia recycle.

**Figure 2.** Andussow process for HCN production with ammonia recycle.$^{[1]}$
The project was initiated at a DuPont HCN production facility; the facility was toured, information on HCN production was provided, and the ground rules for the project were established. Prior to this meeting, the project had been selected through discussions involving faculty and DuPont personnel, and some introductory material had been given to the students. Subsequent projects have used other formats, including a visit to the industrial site later in the project and a student presentation on their thoughts about the most appropriate design alternatives for the project.

At the initiation meeting for the current project, some alternative designs were suggested and supporting information was provided, as available; still other alternative designs were developed by the students later in the study. The supporting information included desired product purity, relevant reaction rates and yields, reaction and phase equilibria information, by-product formation data, operating and pilot plant data, and safety and toxicity information. More supporting information was available for some alternative studies than for others.

Incorporating pollution prevention techniques in the design of chemical production facilities leads to processes in which non-product streams are either eliminated or have a minimal impact on the environment. The focus of the pollution reduction activities of this study was on aqueous waste. The design activity sought to reconfigure the ammonia recovery and HCN refining steps while retaining HCN product purity and providing aqueous waste streams that could be effectively treated with biological techniques. The typical incineration techniques for off-gas treatment from these facilities were retained for this study. Processes based on revision of the basic Andrussow process shown in Figure 2, as well as developmental and conceptual processes, were included in this activity.

**FLOWSHEET DEVELOPMENT**

Much of the nature and the input-output structure of alternative flowsheets may be found from an examination of the HCN production reaction and the product gas from the reactor. Water is a by-product of this reaction; the reaction does not go to completion so that CH₄ and NH₃ are present in the reactor product gas. Both gas and aqueous waste streams are likely to be hazardous due to the presence of HCN, NH₃, sulfates, and phosphates. Recovery and in-process recycle of NH₃ provide an opportunity for source reduction. Additionally, an acidic stabilizer added to the stripped HCN, as shown in Figure 2, contributes to the aqueous waste from this process step. Recovery and reuse of the stabilizer provides a source reduction opportunity. Additional components used in the process shown in Figure 2, such as the H₃PO₄, were selected based on the ability to recover and recycle these components.

The development of alternative flowsheets was based on the specifications of the reactor product gas and on the effluent streams from the recovery and refining areas. Generally, all alternative flowsheets begin with the recovery of NH₃ and HCN from the reactor product stream (removal of water is associated with this step). The remainder of the flowsheet development focuses on the purification of the HCN product stream, the recovery and reuse of NH₃ and stabilizer, and the associated phase splits and other liquid recovery systems.

Some streams designated as waste streams in flowsheet development are inherent in the fundamental process, while others are associated with by-product formation and the more ancillary aspects of the process. The ease in identification of waste streams varies greatly; some wastes can be identified from the macroscopic material balances, while others can only be identified by actual process experience.

Information on some waste streams required discussions with knowledgeable DuPont personnel in order to get a total view of the wastes generated in the current process. This designation of waste streams is discussed further by Berglund and Lawson.

The window for creativity in this activity comes after the students understand the process and its constraints and begin formulating their flowsheets. The semi-structured brainstorming activities of this phase may take a considerable amount of time. As a result of the increased time for flowsheet development in the study described here, the economic analysis portions were compressed so that the project could be accomplished in one semester.

**COST ESTIMATION**

The factored approach has generally proven reliable for preliminary estimates of fixed-capital investment by persons other than an expert. In this method, the purchased cost of the major equipment items is estimated and the total fixed capital investment is estimated by applying a multiplier (Lang factor) to the purchased cost of the major equipment items. For the current activity, a less time-consuming approach was used, based on an approach by Zevnik and Buchanan.

\[ TFCI = 1.33 \text{ NFU (CPF)(CE/102)} \]  

where

- \( TFCI \) = total fixed capital investment
- \( NFU \) = number of functional units (a functional unit is all the equipment necessary to carry out a significant process step)
- \( CPF \) = cost per functional unit
- \( CE \) = chemical engineering plant cost index

Estimation of the cost per functional unit and identification of functional units were validated by comparison with actual plant costs in the student’s analysis. This total fixed capital investment was calculated for the traditional func-
tional units, such as distillation equipment, and this value adjusted to account for those process equipment items thought to be “nontraditional,” such as membrane processes. Annual operating costs were then estimated by taking into account the annual cost of capital and other expenses. A comparison of the estimated cost of the alternate processes with current process technology was then made to establish economic viability.

REPORTING

The design report from the current study was a confidential document wherein both students and faculty signed a “limited term” secrecy agreement with DuPont. Secrecy was necessary so the students could have access to proprietary information and thus develop as useful a study as possible. The final report was reviewed first by the university advisors, and after their comments were addressed, it was reviewed a second time by both university and DuPont project advisors. Oral reports by the students design team at the midpoint of the activity provided an opportunity for midcourse corrections. The midpoint meeting is very important in focusing the study to meet the needs of the sponsor. A final oral report by the student design team was made at the conclusion of the project.

CONCLUSIONS

The type of activity described in this paper provides for student and faculty involvement in significant and challenging projects involving pollution prevention. The expected benefits to the students are:

• Developing solutions to existing chemical engineering problems under realistic industrial considerations and tight time constraints.
• Experiencing group problem-solving where they establish their own group structure and assign their own responsi-

bilities for the results.
• Learning to develop flowsheets and material balances when they have incomplete process information.
• The studies emphasize pollution prevention through basic process flowsheet and equipment modifications rather than through conventional waste effluent treatment applications.

The successful completion of projects such as this one supplements corporate design activities, particularly when emerging technologies are involved. This project and similar activities have been well received by the students. Their enthusiasm, perseverance, and overall quality of work is sincerely appreciated by their advisors and sponsors. Participants in these activities typically begin industrial careers soon after project completion, while a small number of them go to graduate school.

ACKNOWLEDGMENTS

This activity was supported by a grant from E.I. DuPont de Nemours and Company. The students participating in the activity described here were Linda K. Frazier, Mark A. Guimond, L. Meera Krishnan, Philip D. Moler, S. Antony Stagnolia, and Philip A. Wisnewski.

REFERENCES


ChE book review

NETWORKING: How to Enrich Your Life and Get Things Done
by Donald R. Woods, Shirley D. Ormerod
Pfeiffer & Company, International Publishers, 8517 Production Avenue, San Diego, CA; (1993)

Reviewed by
Eugene R. Seeloff
University of Virginia

This book, coauthored by a professor of chemical engineering and a program assistant at McMaster University in Hamilton, Ontario, is an excellent tool for students, alumni, and faculty, as well as for career planning and placement professionals. Because NETWORKING skills have become increasingly important to anyone trying to develop and realize professional or personal goals, this book will greatly assist, and motivate, the reader to understand what NETWORKING really is and to learn how to NETWORK effectively.

In addition to their own ideas and experiences, the authors have drawn on other published materials to create an easy-to-read workbook complete with interesting and thought-provoking exercises for the reader to complete. They have Continued on page 139.
TROUBLESHOOTING IN THE UNIT OPERATIONS LABORATORY

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At times troubleshooting seems inherent in the unit operations laboratory; the instructor and students are often confronted by leaking pumps, malfunctioning thermocouples, unreliable water and steam supplies, and other trouble-prone equipment. This article, however, addresses the structured use of troubleshooting experiments to develop students' ability to diagnose and correct unacceptable process performance.

The importance of troubleshooting is readily apparent to engineers working in manufacturing and technical sales. They are often confronted by malfunctioning hardware or processes, and they must correct the problem despite severe limitations on their resources (primarily time, money, and information). A recent series of papers and at least one book also attest to the significant role of troubleshooting in chemical engineering practice.

The general importance of problem solving in engineering education and practice is well recognized (for example, see Lubkin and Sears, et al.). But troubleshooting is not often considered on a distinct basis, although Woods has provided some good examples of using troubleshooting exercises in chemical engineering courses. Unfortunately, however, most laboratory courses do not incorporate troubleshooting experiments into their structure (a recent exception is Fujii's use of troubleshooting experiments in an introductory circuit analysis laboratory).

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I have used troubleshooting experiments in the unit operations laboratory and believe that this course represents the ideal point in the curriculum to introduce such material, primarily because it is hardware-oriented and one of its objectives is to demonstrate that real-world equipment and processes do not always function in the manner described in textbooks.

The basic concept of troubleshooting, or diagnostic, problem solving is straightforward. When faced with a malfunctioning system, the problem cause must be identified, corrective action must be taken, and any recurrence of the problem must be prevented. The idea of using experiments of this type in the unit operations laboratory followed Macias-Machin, et al.'s proposal to improve undergraduate chemical engineering laboratories through the use of research-type experiments. Both research and troubleshooting experiments enhance the laboratory experience by confronting students with realistic situations in which they must formulate their own strategy, carry out a plan, and evaluate the success of their efforts—skills that should be developed in upper-level engineering courses.

EXAMPLE OF TROUBLESHOOTING EXPERIMENT

Every department would have to develop its own set of troubleshooting experiments because of the differences in hardware, but almost any unit operations experiment could be used for this purpose. I have developed experiments in the areas of chemical reaction engineering, plastic injection molding, spray drying, and agitation.

To clarify the concept, this paper will briefly outline an agitation troubleshooting experiment. Note that two or three students work as a group on this project and that they are given two five-hour laboratory periods to complete their work. Also, troubleshooting experiments are used to enhance the course—they are not the focus of the course. Each group is given only one project of this type during the term and only after the students have completed a number of more traditional experiments.

Troubleshooting experiments provide an excellent oppor-
tunity to sharpen students' ability to communicate through brief memorandums, perhaps the most common form of written communication for practicing engineers.\textsuperscript{[12]} The following is the assignment memorandum for the example (note its official tone):

### MEMORANDUM

**DATE:** Today  
**TO:** Operations Laboratory  
**FROM:** Plant Manager  
**SUBJECT:** Catalytic Reactor Failure

During start-up of a new process, we have been experiencing unacceptable performance in the stirred-tank catalytic reactor. The problem seems to be caused by insufficient agitation to suspend the catalyst. This results in permanent piles of catalyst forming on the base of the tank, which in turn leads to the formation of hot spots and the production of undesired side products. The product could represent a profit in excess of $1 million per year and these impurities are not acceptable.

The reactor has a volume of 25 m$^3$ and a diameter of 3 m. It is equipped with a standard pitched-blade turbine of 1.1-m diameter located at an off-bottom clearance of 0.9 m. The liquid phase has properties similar to water, while the catalyst, which accounts for two mass percent of the slurry, has a diameter of 780 micrometers and a specific gravity of 1.053. A sample of the catalyst has been included for your inspection.

The reactor agitation system was designed to achieve just-suspended conditions. Examining this problem and presenting a solution within two weeks.

At this point the students begin working in a manner similar to the methods used in any upper-level engineering laboratory. After a brief literature search they should be able to find Zwietering's\textsuperscript{[13]} correlation (or a similar one) for estimating the agitator speed required to suspend solids so they do not rest on the tank base for more than two seconds:

$$
N_p = \left[ \frac{S}{v^{0.45}d^{0.3} \left( \frac{g(\rho_s - \rho)}{\rho_1} \right)} \right]^{0.13}
$$

The parameter $S$ is dependent on impeller type and system geometry, and the students can determine its magnitude by performing experiments with a few solids in a laboratory-scale agitator. Armed with this information, they can then estimate the speed required to suspend the catalyst in the laboratory-scale apparatus. Subsequent experiments with the catalyst sample will indicate that much higher levels of agitation are required to achieve adequate suspension. The troubleshooting begins at this point as the students attempt to determine the cause of this unusual behavior.

After struggling with the problem, the students should submit a memorandum similar to the following:

### MEMORANDUM

**DATE:** Two Weeks Later  
**TO:** Plant Manager  
**FROM:** Operations Laboratory  
**SUBJECT:** Solution to Catalyst Suspension Problem

We have reached a conclusion concerning the catalyst suspension problem. Applying Zwietering's correlation, we predicted that an agitator speed of 1.5 revolutions per second would be required to achieve just-suspended conditions in a scaled-down model of the catalytic reactor (a geometrically similar tank with a diameter of 0.4 m). When tests were performed at this level of agitation we encountered a similar problem with suspension.

Because of the dependence of the just-suspended speed on the physical properties of the solid, it was our decision to determine the catalyst's physical properties and to compare them with the data provided. We soon discovered that the catalyst sample consisted of two discrete materials—one with the expected properties and the other an impurity that has a much higher specific gravity. Cursory visual inspection of the sample does not reveal the presence of the impurity because it is approximately the same size and color as the catalyst. When the impurity was removed from the catalyst sample we found that the design level of agitation produced satisfactory results.

We suggest that you contact the catalyst supplier to obtain a charge of pure catalyst. Additional details of our experimental program are attached [omitted here for brevity].

This example demonstrates that troubleshooting experiments require students to perform many of the same functions carried out in other experiments—among other things, becoming familiar with the literature, planning and executing an experimental program, and reporting the results.

Troubleshooting experiments also provide an opportunity for students to develop their problem-solving skills while working on challenging, realistic problems while, at the same time, giving the instructor an opportunity to teach the students about problem-solving strategies,\textsuperscript{[14,15]} heuristic problem solving,\textsuperscript{[16]} creativity and idea-generation techniques,\textsuperscript{[17,18]} and decision-making strategies.\textsuperscript{[15,17]}

### CONCLUDING REMARKS

The basic troubleshooting experiment as described in this paper is easy to develop. It is also very flexible and can be readily changed from year to year to provide variety. A number of variations can be incorporated, such as: giving the students a budget, then charging them for performing experiments and asking questions (as suggested by Squires, Continued on page 127.
Most chemical engineering education is delivered in a conventional three-mode structure of lectures, supervised problem-solving sessions, and predefined experimental work in the laboratory. In some cases these activities are combined in an integrated approach, strengthened by a variety of classroom organizations, and complemented with extracurricular activities by faculty concerned about ways to increase students' perceptions of the importance of effective human interactions in the engineering profession. This approach has been generally accepted because it produces engineers who are knowledgeable about existing technology. Employers have overcome any lack of necessary skills and/or professional orientation of new employees through additional on-the-job training. It has been estimated that it takes two years after schooling for a graduate to become a fully effective engineer.

Past concerns of the chemical industry about the need to change undergraduate engineering education have increased recently because organizational behavior is affected by the rapidly occurring technological changes. Also, industries must implement these changes while at the same time remaining competitive in a global market strongly influenced by societal issues.

There has been ample documentation that even well-trained graduating engineers sometimes lack the skill and experience to apply their knowledge in a way that contributes to the solving of an actual problem, whether it be on an individual basis or in a group situation. One possible explanation is the fact that traditional engineering education is an artificial process—the students are passive, listening subjects who memorize individual facts and technical procedures taught in separate courses; they are seldom encouraged to ask questions or analyze available evidence.

Students first learn the basic sciences and mathematics that are necessary for understanding engineering principles and processes. Then, if they want to become chemical engineers they study, for example, various principles and operations used to change raw materials into useful products. In this context, a chemical engineer can be considered an expert in the calculations, design, construction, and operation of equipment or installations where matter undergoes a change of state, energy, or composition. Understanding topics such as thermodynamics and kinetics, the physico-chemical properties of matter, heat transfer and fluid flow, etc., is essential to their success.

In our traditional artificial approach, each of these topics is studied as a separate discipline, taught by professors who are experts in their field. The implied assumption is that if a student understands the various individual subject principles...
... concerns about the real-world problems in engineering education suggest the possibility of taking a more professional and issue-oriented holistic or integrated approach to engineering education. This does not mean simply incorporating a project or a research period into the standard course... but rather signifies a total reorganization of the approach to instruction and assessment.

and processes, he or she will be able to apply them to real-world problems—the essence of engineering. Feedback from the real world where these engineers go to practice their craft, however, indicates that initially they are not very efficient in synthesizing what they have learned into an integrated approach to solving a problem.

Also, our synthetic approach to engineering education focuses on the role of the individual student as learner and practitioner since each individual is evaluated separately and the goal is to do better on an individual basis. Rhinehart substantiates these points of view. This individual focus is quite different from the actual practice of engineering today where group efforts are common and an individual with expertise in a specific field contributes to the solving of an interdisciplinary problem.

The need to modify the traditional lecture approach has become more apparent in recent years. We increasingly expect today's engineer to deal effectively with the environmental and other public policy issues that are an integral part of modern engineering activity. This, in turn, demands a capacity to synthesize one's thinking since the engineer must go beyond the science and at least be cognizant of the public policy issues involved in his or her work. These concerns about the real-world problems in engineering education suggest the possibility of taking a more professional and issue-oriented holistic or integrated approach to some or all of engineering education. This does not mean simply incorporating a project or a research period into the standard course as suggested by many (see, for example, Miller and Petrich[9]), but rather signifies a total reorganization of the approach to instruction and assessment.

The chemical engineering faculty of the former University of Barcelona in Tarragona, Catalunya, Spain, decided in 1985 to fully implement a holistic approach in an introductory chemical engineering major taught in the college of chemistry. One reason for accepting the challenge of changing educational methodologies at that time was a diminishing interest of the students enrolled in the College of Chemistry toward chemical engineering.

The introductory course was organized around a theme, such as the preliminary design of a chemical plant. Students focused their attention on several issues of engineering and societal interest that could be analyzed while learning the basic principles of chemical processes, unit operations, and transport phenomena. A cooperative goal structure was adopted as the basic instructional method for the course since cooperation is most effectively used for learning conceptual and theoretical skills, for open-ended problem solving, for reasoning assignments, and for problems involving technology and society. A description of the basic elements of cooperative learning may be found elsewhere.

The specific methodological objectives were to

- Incorporate practicing-engineer skills and public-policy issues into the first course where basic chemical engineering principles are taught
- Integrate effective project management and relevant behavioral experiences into the classroom via cooperative group learning
- Introduce decision making and work interdependence as the basis for achieving the two previous goals
- Prepare students for a commitment to continuing education throughout their professional life
- Involve chemical engineering faculty, as well as staff from industry, in this educational effort
- Encourage both students and professors to have fun in this challenging and responsible learning environment

The introductory course was also designed to illustrate the roles and opportunities for chemical engineers, while at the same time providing a perspective for subsequent classes. In addition, it considered environmental issues as part of the everyday practice of chemical engineering.

The following sections describe the organization of the course, the procedures we followed, and the opinions of the faculty and industry with respect to the results of the holistic approach adopted. The specific guidelines and evaluation, along with the students' opinions of the course, will be presented in the second installment of this paper to be published in the next issue of CEE.

**ORGANIZATION**

The content of the course and all class work were organized into several activities. The modular structure facilitates an educational approach tailored to the student's needs (which may change every year). It also encourages the participation of these students in deciding their own objectives, i.e., students assume responsibility for their own learning when defining the course activities and deciding their goals. This latter aspect is very important because the course is intended to be a simulation of real workplace situations that most practicing engineers face in industry.
Within this framework, students can learn the process of asking questions—the basic scientific and technological approach for discovery and understanding. Also, learning new concepts and skills when the need arises rather than in a predetermined sequence favors student motivation and the learning process itself. Simulating a real daily workplace environment requires a non-standard schedule for the course. Since the students are no longer passive receptors, weekly class work was usually carried out in two separate sessions of three and two hours, respectively. Thus, all activities were developed during one or several class periods or sessions of five hours, with the following organization and characteristics:

- **Activities began and ended with a session.** Students played an active role, either individually or as members of a team or group. A combination of individual and team effort was adopted in some activities to emphasize the need for sharing and collaboration with others when moving from a creative to an applied level. The groups were formed by five students (i.e., twelve groups for a class of sixty) or by four members when enrollment was lower.

- **The decision about what to do next (i.e., asking a pertinent question and defining the objectives of a new activity) was the result of a decision made by the class during the closing discussion of the current activity.** Instructors helped students reach a decision by matching the different class requests with the general conceptual framework of the course. Students were not constrained about the type, duration, and number of activities to carry out, but were encouraged to be specific and realistic in setting their common goals.

- **The instructors involved in the course, the professors, and the teaching assistants met weekly to plan the development of each new activity as well as to correct time deviations as necessary.** Also, the need for complementary seminars and/or lectures was determined and the corresponding time was allocated according to the depth of analysis expected by the instructors for that particular activity.

- **Students had access to resources outside the classroom to encourage individual or team use of whatever was required to continue asking more and more questions about a given problem or situation.** Those resources included the departmental library, computer rooms, other faculty members, industrial staff, and laboratories during pre-scheduled periods each semester. Library access was necessary since no specific textbooks were recommended for this course.

- **Laboratory work was not a separate entity from the class work.** About half of the experimental work was pre-programmed by the instructors and was carried out by all students either in the laboratory or in the field. The other half was used by each group of students to complement their class work, following an integrated approach. Students were encouraged to experimentally verify published data or to explore new subjects by using innovative research approaches.

A detailed description of the guidelines and activities of the introductory chemical engineering course taught at Tarragona will be given in the second installment of this paper. Activities always began with a general question: *i.e.*, Will the chemical plant require external energy supplies? During the development of the activity this initial question would be followed by more specific questions, such as: Which equipment and/or operations will be donors or receptors of energy? Therefore, work aimed at asking further questions was carried out by teams (or in some specific cases by individuals) using available technical information and under the supervision of the group leader. Before the activity and the class session ended, group leaders handed in a report to the professor covering all the work done and the performance of group members.

One-third of the leaders then gave short oral presentations (five minutes each), in a rotary fashion, reporting the results and conclusions reached by their teams. This was followed by a closing discussion that allowed us to reach common conclusions and to propose the next activity. With this information the instructors outlined the worksheet for the next activity, specifying its main goal, the procedures, and the rules (see, for example, Goldstein). This was handed to each student or group leader at the beginning of the next session when the new activity started.

**PROCEDURES**

**Individual and Teamwork**

The main objective of organizing the classroom into groups was to create a learning opportunity where professional and behavioral values could come into play. It is well known that teamwork facilitates learning the skills necessary for dealing with real engineering situations. This type of organization smooths the future integration of a junior engineer into a corporate culture. In addition, issue-oriented engineering education (e.g., education related to societal issues), is best performed when students assume responsibility for learning and participate in decision making so that they can become a part of role-taking and role-playing under a variety of circumstances.

The transmission of old knowledge to students in the traditional approach to education does not favor creative thinking, self-reliance, or cooperation. For example,
creativity is fostered by openness to experience and questioning. Individuals who are open to experience can deal with open questions, (i.e., those with conflicting information and ambiguity) with independent thought. Creativity is also fostered by the ability to play (experiment). This explains why new trends in engineering education point toward introducing research in undergraduate engineering education.

In the present introductory course, the groups were organized so that each had a leader responsible for the work involved and for the presentation of results. All members of each group occupied this position through rotation. During the stage of gathering evidence, the group leader was allowed to assign work to each member or to let each choose the role he or she wanted to take and play, depending on the activity to be carried out and on their preferences and abilities. In any event, all students were supposed to carry out a part of the group's work, to be aware, to understand the work done by the group or by any individual member, and to participate in the process of using all the evidence. When, for any reason, work was not finished during the assigned class sessions, it was completed as homework. This allowed all groups or individuals to proceed at their own optimal learning pace.

This type of organization encourages

- Implementation of student-centered discussions
- Building a sense of culture and organization
- Self-motivation through involvement
- Setting up effective communication while establishing and sharing goals, procedures, and rules
- Developing ways of seeking, gathering, assessing, and sharing information.

Also, students made choices, participated in decision making with a creative and critical attitude, and learned how to identify and generate alternatives to a given situation. They experienced the process of continuous learning, which is of more lasting value than specific content in a rapidly changing society.

Once the class had decided on an activity at the end of a class session, the instructors handed in, at the beginning of the next session, a worksheet with the leading question(s), a set of procedures and rules, and a tentative schedule. Then, under the responsible coordination of the group leaders, each team of four to five students:

- Brainstormed to explore different possibilities, to get ideas and to gain insight about the activity in order to set up appropriate goals.
- Identified actions to be undertaken so that tasks and roles could be defined and assigned to group members. Students were encouraged not to repeat

the same type of task and role in each activity so that they could explore their own abilities.

- Planned the activity. The importance of work interdependence, collaborative information gathering, and processing to achieve a goal was stressed.

- Used the information and evidence to attain the objectives of the activity. This step usually required individual efforts by group members working together in the classroom and learning within the team of peers through continuous questioning of each others' results. The instructors and invited lecturers circulated throughout the classroom to discuss issues with each group of students when the need arose, as suggested by Blanks. The rule in this step is never to ask a question of the professor before the group has thoroughly discussed it.

- Prepared the group report and the corresponding oral presentation. The group leader reported to the professor the different roles taken and played by each team member, related any incidents of importance, and gave an evaluation of the work done by the group under his or her coordination.

A group member evaluation procedure similar to that suggested by Rhinehart was adopted. The weight of all classroom and laboratory activities, including projects, was 70% of the final grade. The other 30% reflected the ability to solve unknown problems during three open-book tests per semester. A more detailed account of the student grading will also be included in the second part of this paper.

The Role of the Instructors

In a cooperative learning environment the professor creates opportunities or situations where technical skills (or values) and experience come into play (i.e., the professor is mainly a resource). In the educational sense, the professor is a facilitator of learning because he or she sets up learning situations that help students identify what they want and need. In this course the instructors also helped students use all available information as well as any available external resource so that they could develop technical skills with a creative and critical attitude. Visits to industry and discussions with technical staff there were common. The professor was no longer an infallible expert who "knows everything" but instead, was merely a person who may not know everything the students wanted to learn or needed to know during the course.

The professor operated in the classroom environment according to the values (skills) he or she planned to teach. As a part-time researcher, he or she is knowledgeable about scientific methodologies and values through having applied them in everyday experimental work. A researcher learns by...
asking pertinent questions when facing any real-life scientific and/or technological problem. Since this is so, research becomes an integral part of classroom activity and the methodology applied is coherent with the nature of the subject being learned. At times the professor acted as a project manager or supervisor, and at other times as an external consultant when professional values came into play.

The instructors also dispensed knowledge to single groups or to the whole class as a response to student requests, or helped the students learn by structuring situations. A listening-only type of situation was thus avoided and students assumed full responsibility for their own learning. Experts in the specific topic being treated were invited to participate and discuss with the class any additional information required to complete the group activity or project. This also enabled other faculty and professionals working in industry to get to know students in advance, and vice versa, while students in turn had the opportunity to experience various professional approaches to some specific engineering problems.

A general and exhaustive overview of the instructor’s role is given by Johnson, et al. [14] It should be noted that in this course, the students assume responsibility for their own learning through defining the activities and their goals, planning materials, assigning roles, and sharing with the instructors the evaluation of the completion of tasks, among other things.

**RESULTS**

Faculty who taught engineering courses to these students in the following years felt that the students knew "less" contents than before, when the traditional approach to teaching was used, but that they were able to handle new learning situations with greater success. Also, they reported that the attitude of the students was more open and interactive than it had been in previous classes. The students’ final performance, based on knowledge, seemed comparable. As a result of the present initiative, teaching of other chemical engineering courses has also been progressively modified to integrate some of the methodologies and procedures mentioned above.

The personnel departments of the most important chemical manufacturers in the area of Tarragona (such as Dow Chemical, Repsol, Hoechst Iberica, BASF, Bayer, ASES, and Shell) have expressed the opinion that under real situations those students who took the holistic-approach course perform best. Also, their integration within a given corporate culture is accomplished smoothly and in a shorter period of time. The Chemical Manufacturers Association of Tarragona has collaborated with the present initiative by offering resources (visits, seminars, etc.) to the classroom. As a result of this partnership and the change in educational approach, the number of chemical engineering students hired from our University during the past five years has been one of the highest among Spanish engineering schools.

Departmental concern about preparing undergraduate students for the rich world of engineering led to the initiation of new educational experiences. Sustained student enrollment during eight years, faculty and industry involvement in the teaching, and industrial interest in hiring the graduates has proven that a professional and issue-oriented approach to higher education is effective in preparing students for the technical and societal complexities of present and future times. We were also very pleased to find that initiating this course motivated students to elect chemical engineering as a profession and significantly increased enrollment. The number of women enrolled in engineering and graduating with majors in chemical engineering also increased, from 10% to 35%.

**ACKNOWLEDGMENTS**

The collaboration of Professors A. Fabregat, X. Farriol, J. Giralt, J. Grifoll, F. López-Bonillo, and J.A. Ferré and the support from the Chemical Manufacturers Association of Tarragona (AEQT) are acknowledged and appreciated. The comments and suggestions made by Profesor J.A.C. Humphrey of the University of California, Berkeley, are also acknowledged.

**REFERENCES**


17. Cohen, Y., W. Tsai, and S. Chetty, "A Course on Multime-
dia Environmental Transport, Exposure, and Risk Assess-


TROUBLESHOOTING IN UNIT OPS

Continued from page 121.

et al." [19]: developing general troubleshooting charts for a
given apparatus (such as those provided with most house-
hold appliances, particularly electronics); or instructing the
students to develop their own troubleshooting experiments
to reinforce what they have learned through application [16]
(and to provide experiments for future classes).

The troubleshooting type of experiment is an excellent
method of improving the unit operations laboratory by pro-
viding an opportunity for students to develop and apply
their problem-solving skills to realistic problems. I have
found that this type of experiment adds enjoyment to the
laboratory experience for the students and for the instructor.

Perhaps the best advice that I can give to anyone inter-
ested in using troubleshooting experiments is to assign mean-
ingful problems—then stay out of the students’ way except
to provide occasional guidance and encouragement. The
challenge of the experiments and the students' interest in
applying their skills in realistic situations will ensure a re-
warding educational experience.

ACKNOWLEDGMENTS

I gratefully acknowledge the assistance of numerous stu-
dents in developing and using troubleshooting experiments.
The support of the University of Dayton Fund for Educa-
tional Development was also instrumental in the completion
of this work.

NOTATION

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Impeller diameter (m)</td>
</tr>
<tr>
<td>d_p</td>
<td>Particle diameter (m)</td>
</tr>
<tr>
<td>g</td>
<td>Acceleration of gravity (m/s²)</td>
</tr>
<tr>
<td>N</td>
<td>Just-suspended agitation speed (s⁻¹)</td>
</tr>
<tr>
<td>S</td>
<td>Proportionality constant</td>
</tr>
<tr>
<td>X</td>
<td>Solids loading in slurry (solid weight/liquid weight)</td>
</tr>
<tr>
<td>v</td>
<td>Liquid kinematic viscosity (m²/s)</td>
</tr>
<tr>
<td>ρ</td>
<td>Liquid density (kg/m³)</td>
</tr>
<tr>
<td>ρ_s</td>
<td>Solid density (kg/m³)</td>
</tr>
</tbody>
</table>

REFERENCES

1. Kister, H.Z., G. Balekjian, J.F. Litchfield, J.P. Damm, and

D.R. Merchant, "Absorber Troubleshooting: Systematic In-


INTRODUCING
INDUSTRIAL PRACTICE IN THE
UNIT OPERATIONS LAB

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One of the major goals in an engineering laboratory course is a demonstration of the principles and theory which are presented in lectures and textbooks. In the chemical engineering curricula, laboratory classes are usually first scheduled in the student's junior year, and they include student preparation of extensive technical reports concerning the experiments conducted in the lab.

Feeling that the Unit Operations Laboratory could serve as an introduction to "good engineering practice" in industry, we tried to modify that course in such a way that it would introduce students to the industrial workplace. Based on our experiences from that effort, this article suggests changes in existing laboratory methods that will make the Unit Operations Laboratory course more closely simulate industrial work practices.

The following general premises for modification were used:

• Experiments should be performed to obtain, immediately, the results required for solving simulated industrial problems; they should not be performed simply to demonstrate the validity of principles or theory.
• Student engineers should be encouraged to know (or find out) how to obtain the required results within a specific time frame.
• Laboratory reports should accurately and concisely communicate the results of the students' work.

These premises led to a review of the existing procedures used in conducting experiments. Four key procedural items were considered: operating instructions, flow diagrams, practical problems, and laboratory report writing. In the following paragraphs we will show how each of these items was modified so as to introduce student engineers to industrial practice.

OPERATING INSTRUCTIONS

Operating instructions were written in "layman's" language and included all the data necessary for calculations. Since industrial operating instructions are usually written for technicians with, say, two years of college and/or several years of experience, they should not simply state, for example,

... turn valve A until you get 6 on the rotameter.

That kind of instruction should be, and was, rewritten to state

... the globe valve just upstream of the exchanger on the cold water supply is used to manually control the cold water to the exchanger; slowly open this valve until the rotameter indicates your initial flow rate.

The idea behind rewriting instructions in this manner is to encourage students to appreciate the why and how of each step. The latter instruction helps the student to focus on the function of each piece of equipment and to realize how each piece fits into the overall process. The revised operating instructions for all the experiments had a consistent format typical of an industrial operating manual. The procedures were organized into the following five major sections:

• Checkout Prior to actually conducting the laboratory experiment, students must make a first-hand inspection of the apparatus. Their objective is to become familiar with the process and its components, controls, and utilities (see Table 1). The students then generate a system flow diagram for checkout purposes.
• Start-up The start-up procedure takes the system from "cold" conditions, with utilities (water, air, electricity) essentially dis-
connected, to steady-state conditions. Operations that may be dangerous are noted and safety precautions are highlighted, as they would be in industry.

- **Operations** Steady-state operations are listed for the experiment. Limits on operating temperatures, pressures, and power are noted both for safety reasons and for equipment protection.

- **Shutdown** The system should be shut down in a safe and orderly manner and should be left in its original condition. This responsibility is assigned to one student (in industry the student becomes the group leader). During shutdown, component deficiencies should be written down or the instructor should be advised in order to make the appropriate repairs.

- **Emergency Actions** Certain operating instructions are given for cases when someone is injured or the process conditions go out-of-control. The student engineer is shown how to quickly and safely shut down the system. For example, in a steam-heating water experiment, the emergency action instruction would be to close the steam valve at its supply header.

---

**TABLE 1**

Example of Checkout Procedure Instruction

In checking out the system, ascertain the following:

1. The location of the supply water to the inlet valve
2. That the inlet valve is in fact closed
3. That the outlet water valve is open
4. That the flow meter is in working condition

---

**TABLE 2**

Laboratory Report Outline (2-page limit for text)

1. **Title Page**
2. **Introduction** (3-4 sentences)
   - Experimental assignment
   - Purpose (experiment and practical problems)
3. **Summary**
   - Specific answers to requested information (tabulate or graph)
4. **Results and Discussion** (several paragraphs)
   - Experimental
   - Practical problem
5. **Conclusion** (2-3 sentences)
6. **Recommendations** (2-3 sentences)
   - Indicate deficiencies in equipment

**APPENDIX**

1. Original data
2. Sample calculations, including assumptions taken
3. Physical data from references used
4. Assessment of the quality of data collected

---

**Feeling that the Unit Operations Laboratory could serve as an introduction to "good engineering practice" in industry, we tried to modify that course in such a way that it would introduce students to the industrial workplace.**

**FLOW DIAGRAMS**

Prior to our revision of the operating instructions, students were given flowsheets. We feel, however, that an experiment is sometimes best understood through the construction of one's own process flow diagram, so we required that the students themselves draw the diagrams of the experimental apparatus or of the system for which the experimental information was to be applied. The "checkout" diagram did not have to be "professional," but it had to reflect an understanding of the system. We required that the laboratory report be neat and accurate and that the flow-diagram symbols be the same as used in industry; for this purpose we supplied the students with the proper equipment and instrument symbols.

**PRACTICAL PROBLEMS**

In addition to the usual laboratory demonstrations of engineering theory, we added practical problems to the experiments. Each experiment was redesigned to require specific data that would help solve a practical industrial problem. For example:

**Convective Heat Transfer Experiment**

Production department ABM wants to speed up reactor washing by heating the wash water from ambient (70°F) to 150°F. Obtain the heat transfer film coefficient using our wash water and specify the surface for this exchanger. The heat exchanger must operate with water flows of 5 to 20 GPM and steam at pressures of 5 to 40 PSIG.

A test heat exchanger is available in the pilot plant (laboratory).

**REPORT WRITING**

In previous years, laboratory reports were often lengthy documents of twenty-five or more pages. Unfortunately, much of the student's effort was expended in simply copying theory and procedures into that report, so we decided to reduce the report writing requirement by a factor of about ten! We devised a descriptive outline of the required report and gave it to each student during the first lab lecture. As a result, the reports now have a fixed format with a firm two-page limit on the number of "text" pages (see Table 2).

The revised format requires that the original data sheet for experimental observations and calculations be included, and that it had to be prepared by the students in advance. This forced the students to determine exactly what data were needed and how the data would be converted to the needed results.

The revised report also requires a brief discussion of the practical problem. The problems were slightly different for each group of students, which had the effect of minimizing plagiarism and making the reports more meaningful. The reports also contain a succinct statement regarding experimental observations applied to a practical problem.

**CONCLUDING REMARKS**

The procedures used in a typical Unit Ops Laboratory course were modified to more closely reflect actual industrial practice, and included some applied problems and industrial-type instructions. These modifications were implemented with minimal cost.
APPLICATION OF AN INTERACTIVE ODE SIMULATION PROGRAM IN PROCESS CONTROL EDUCATION

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In a paper titled "Process Control Education in the Year 2000,"1 strong emphasis was put on the importance of mathematical modeling and computer simulation with interactive graphics as key pedagogical tools in both the present and the future of process control education. Since computer simulation has been used in control education for at least twenty years now, it is valid to ask what has changed and what additional roles an interactive simulation package can play in process control education.

In the past the most commonly used packages have been control-oriented packages such as ACS2 or industrial control systems.3 These packages are appropriate for demonstrating the behavior of practical control systems and are quite suited for use as "add ons" for a traditional control course. A major deficiency, however, is that these programs behave as a black box, giving results when input is provided but hiding the mathematical model from the user.

There are now available some new interactive simulation packages which accept the mathematical model of the control system as input in addition to the numerical data of the process. The user must provide the model, thus creating the desirable connection between control theory and practical application. Using this type of package can become an integral part of the control course and not just an add-on as it has been in the past with the older packages.

In order to take full advantage of the many desirable capabilities of the new simulation tools, however, the content of the traditional undergraduate control course should be substantially revised. One of the needed revisions, for example, is a reduced emphasis on linear systems theory. Most process control textbooks were written before the advent of user-friendly, interactive simulation packages, and as a result many of them put too much emphasis on linear systems and linearization methods. Most current mathematical and control packages employ numerical solution methods which can solve simultaneous nonlinear ordinary differential equation (ODE) systems as easily as they solve linear ones. That means that the traditional dependence on linearization could and should be reevaluated and substantially reduced.

Another curriculum revision would be in the required use of block diagrams within the control package. Such diagrams were absolutely necessary when analog computers were used, and they can be very helpful in demonstrating the behavior of linear systems; but their importance should be carefully reevaluated in light of the new simulation packages. The differential equations (which are the basis for the block diagrams) can now be inserted directly into the simu-

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lation program, and the required conversion to block diagrams becomes unnecessary.

Modifying and reorganizing an existing control course to embrace the new tools is an evolutionary process and can present an interesting challenge for the instructor. In this paper we will offer several practical examples for using an interactive simulation package in different sections of an undergraduate control course.

There are several interactive simulation packages which can be used as a learning tool in the control course, but it is not our intent to review all of them. We will demonstrate some applications using the POLYMATH software (which was developed by two of the authors, Shacham and Cutlip), but we want to emphasize that other software (such as the widely used MATLAB package) can also be used for the same purposes.

The POLYMATH software package was originally developed for the mainframe Plato education computer system. The current version of POLYMATH (2.1.1.PC) is distributed by the CACHE (Computer Aids for Chemical Engineering Education) Corporation, a non-profit organization that disseminates educational computer programs to chemical engineering departments. This version runs on the IBM Personal Computer, PS/2, and most compatibles.

Various forms of POLYMATH have been in use for almost a decade in support of chemical engineering education. Some important features are:

- It is a general purpose program now in use in over one hundred chemical engineering departments. In several departments the students are introduced to POLYMATH in their first chemical engineering course, so that when they reach the control course it is a familiar calculational tool for them. Students can also put this software on their own personal computers for easy access and use.
- The user works directly with the model equations which provide a direct link between the physical phenomena and the control system. This is in contrast to many control-systems simulator programs where the user only provides parameters to "black box" models (such as ACS[5] or UC Online[5]) or the user is required to convert the equations into block diagrams prior to solution (such as Tutsim[6, p.352] or UCAN II[7]).
- Problem set-up, solution, and modification times are very short. This is especially important in educational use where a long wait for the result often discourages exploration and curiosity.

**EXAMPLE 1**

**Control of a Stirred Tank Heater**

The dynamics and control of a stirred tank heater are discussed in several popular textbooks.[6,9] This simple system includes the stirred tank and a PI controller and is depicted in Figure 1.

The feed stream at constant rate (units: W kg/min) flows into a stirred tank equipped with a heating device; we want to heat this stream to a higher temperature \( T_R \) (°C). The outlet temperature is measured by a thermocouple, and the required heat supply, \( q \), is adjusted by a PI temperature controller. The control objective is to maintain \( T_o = T_R \) in the presence of a load due to an inlet temperature, \( T_i \), which differs from the design value, \( T_i^d \).

The model equations are:

\[
\rho V_C \frac{dT}{dt} = WC(T_i - T) + q; \quad T_o(0) = T_R
\]

**The thermocouple dynamics as described by first-order lag + dead time:**

\[
T_o(t) = T(t - \tau_d)
\]

\[
\tau_m \frac{dT_m}{dt} + T_m = T_o; \quad T_m(0) = T_o(0) = T_R
\]

The heat supply as manipulated by the PI controller and actuator can be defined as

\[
q(t) = q_i + K_c(T_R - T_m) + K_R \int_0^t (T_R - T_m) dt
\]

where \( q_i \) is the heat supply in design condition

\[
q_i = WC(T_R - T_i^d)
\]

The numerical values of the parameters are

\[
\rho V_C = 4000.0 \text{ KJ/°C}
\]

\[
WC = 500 \text{ KJ/(min°C)}
\]

\[
T_i^d = 60°C
\]

\[
T_R = 80°C
\]

This simple process can be used to demonstrate various concepts in different sections of the control course. Three possible applications are:

1. **Closed loop dynamics**

   Demonstrate stable and unstable regions for PI control using

\[\text{Figure 1. Stirred tank heater} \]

Spring 1994
\[ K_c = 10000 - 10000, K_t = 0 - 5000 \text{ without } (\tau_m, \tau_d = 0) \text{ and with } (\tau_m = 0 \text{ min}, \tau_d = 1) \text{ measurement deadtime.} \]

2. Controller Tuning

Tune the PI controller using Aström's "ATV" method\(^6\) and the Ziegler-Nichols\(^6\) settings.

3. Reset Windup

Investigate the controller behavior if the output from the heating tank is limited to twice the design value (q 20,000 KJ/s) and the inlet temperature reduced to half of its design value and then is restored to the steady state value after thirty minutes.

## Solutions

Most of the equations needed to solve this problem can be typed directly into POLYMATH without any modification. But since POLYMATH is a general-purpose software program, it does not have functions which are specific to the control area, such as step, ramp, time delay, etc. Most of these functions can be generated, however. The generation of a step change at \( t = 1 \), for example, is accomplished by the equation

\[
\text{step} = \frac{(t-1) + \text{abs}(t-1)}{2(t-1) + 0.000001} \quad (4)
\]

This equation generates: \( \text{step} = 0 \) for \( t < 1 \); \( \text{step} = 1 \) for \( t > 1 \). The value 0.000001 is added to the denominator in order to prevent division by zero when \( t = 1 \).

The integral of the error, required in Eq. (3a), is obtained by solving the differential equation

\[
\frac{d(e_{\text{sum}})}{dt} = T_R - T_M; \quad t = 0, \quad e_{\text{sum}} = 0 \quad (5)
\]

Padé approximation\(^{[6, p.103]}\) can be employed for representation of time delay. For instance, the first-order Padé approximation

\[
e^{-t_d} \approx \frac{(1 - t_d/2)}{(1 + t_d/2)}
\]

yields in the time domain a first-order differential equation for the measured temperature

\[
\frac{dT}{dt} = \left[ T - T_0 + \frac{\tau_d}{2} \left( \frac{dT}{dt} \right) \right] \frac{1}{\tau_d}; \quad t = 0, \quad T_0 = T_R \quad (6)
\]

Nonlinear and nonideal aspects can be demonstrated using the limits on the operation of the controller. The basic PI controller may require negative or inaccessibly high positive values of heat input, \( q \), for some combinations of controller setting and magnitude of the step change in the input temperature. Limits can be put on the variables using equations similar to Eq. (4). For example, the operation

\[
q_1 = \frac{q + \text{abs}(q)}{2} \quad (7)
\]

gives \( q_1 = q \) if \( q > 0 \); \( q_1 = 0 \) otherwise.

1. Closed loop dynamics of the stirred tank heater

Figure 2 shows the mathematical model, numerical constants, and initial values as they were entered into the POLYMATH ODE solver program for the case where \( \tau_d = 1, K_c = 10,000, K_t = 0 \) (P-only controller) and a step change of -20°C in the feed is introduced at \( t = 1 \) sec. The options available to the user at this point are also shown: they include solution or modification of the problem, storage in a library, request for additional information regarding solution methods used, etc. If the "solve the problem" option is selected, the equations are numerically integrated, and the program selects either the explicit Euler or the 4th-order Runge-Kutta method, according to the required accuracy. For stiff systems, the user may ask to use the implicit Euler method. All of these methods include algorithms for estimating the integration error and changing step size if necessary. Solution times may vary from several seconds (for a PC without a math co-processor) to less than one second.
Figure 3 gives the history of the integration error. The information in this chart can be used to assess the accuracy of the results and reduce the final time if more accurate results are needed. User options shown at the bottom include display as well as change, storage, and retrieval options. The display options include graphical ('g') or tabular ('t') presentation and output of the results to a DOS file ('d'). If graphical display of the temperature is selected, the graph shown in Figure 4a appears, indicating that the specified parameter values the response is indeed unstable.

The mathematical model can be made more realistic by introducing Eq. (7) into it to prevent the heat input from becoming negative. The growth rate of the oscillations is more moderate in this case, as shown in Figure 4b, but the system is still unstable.

This first part of the example problem can be used as an introductory example in an undergraduate process control course. Students can introduce changes to the system and observe for the first time the difference between systems with and without control, P vs. PI controller, effect of system parameters (time constants, dead time) and can familiarize themselves with the concepts of offset, stability, etc. Most of these concepts are shown in the textbooks, but the fact that the student can introduce the desired change and immediately observe the results can contribute considerably to an understanding of the material.

2. Controller tuning using Aström's "ATV" method

When using this method, a relay of height, h, is inserted as a feedback controller. This nonlinear controller will cause the system to produce limit cycle of the controlled variable. The relay type change of the manipulated variable is achieved by two equations similar to Eq. (7) which generate (1,0) and (-1,0) values according to the sign of the error. The equations typed into POLYMATH for this assignment are shown in Table 1 for parameter values ($\tau_t = 1$; $t_m = 0$). A small change in the controller set-point is introduced ($T_R$ is increased to 81°C). The behavior of the manipulated and controlled variable during the "ATV" procedure is shown in Figure 5. The period of the limit cycle is the ultimate period ($P_u$). Thus, the ultimate frequency is

$$\omega_u = \frac{2\pi}{P_u} \quad (8)$$

and the ultimate gain is

$$K_u = \frac{4h}{a\pi} \quad (9)$$

where $a$ is the amplitude of the primary harmonic of the output.

The ultimate period and gain, as found above, can be used with the standard tuning formulas. The process response to a 33% step change in the inlet temperature obtained with a PI controller tuned using the Ziegler-Nichols controller settings[6,p.223] is shown in Figure 6.
3. Reset Windup

The model equations for the case where the output from the heater is limited and there is a substantial drop in the inlet temperature are very similar to the system shown in Figure 1, except that an equation similar to Eq. (7) has to be added to limit the heater's output.

The simulation results show that the PI controller on the heating coil will cause the heat output to reach its maximal value shortly after the inlet temperature is reduced. Since the heat output is not enough for reaching the set-point temperature, the error term in the integral part of the controller continues to increase until the inlet temperature is restored to its steady-state value. Because of this accumulated error term, the controller keeps the heat supply at its maximum long after the restoration of the inlet temperature. This causes the outlet temperature to reach a much higher value than the set point, as shown in Figure 7a.

Many industrial controllers have anti-windup provisions. This feature can be demonstrated in this example by switching off the error accumulation when the required heat supply exceeds the bounds. The outlet temperature response is shown in Figure 7b. In this case the outlet temperature will rapidly reach the set-point value, after the inlet temperature is restored to the steady-state value.

EXAMPLE 2
Dynamics of a Nonlinear Liquid-Level System

The liquid-level control system is frequently used in process control textbooks to demonstrate the difference between linear and nonlinear systems, where emphasis is put on linearization of the nonlinear system around the steady state.

For this example, consider the system, shown in Figure 8, which consists of a tank of constant cross sectional area, A, into which a valve with flow resistance characteristics, \( q_v(t) = c h^{1/2} \), is attached, where \( h \) is the liquid level in the tank and \( c \) is a constant. The flow rate into the tank, \( q \), varies with time.

The following numerical and steady-state values are appropriate:

\[
A = 1 \text{ ft}^2; \quad c = 20 \text{ ft}^{2.5} / \text{min}; \quad q_s = 60 \text{ cfm}; \quad h_s = 9 \text{ ft}
\]

Using these numerical values, the response of the system to small and large (up to 90%) step changes in the inlet flowrate should be observed and the response using the nonlinear and linearized model should be compared.

Solution

The equation representing the liquid-level system is

\[
(q - q_s) - \frac{h - h_s}{R_1} = A \frac{dh}{dt}
\]

(10)

where \( R_1 = 2 h_s^{1/2} / c \).

Equations (10) and (11) can be introduced into the POLYMATH ODE solver with only slight modification. The response to reduction of the inlet flow to 10 cfm is shown in Figure 9.

We know that linearization is likely to yield close approximation of the dynamics of the system near the state around which the linearization is done. Indeed, when there is a 10% change in the inlet flow, responses of the nonlinear and linearized systems are very similar. The initial slope is the same, and the difference between the process gains that are calculated using the two models is only 5%. But using the linearized model far from the steady state may give very unreasonable results. If, for example, the tank's wall is much higher than the steady-state level and one tries to predict the maximal inlet flowrate that can be used without tank overflow, the difference between the predictions by the two models can be considerable. An even more interesting result occurs when the inlet flowrate is drastically reduced—the linearized model may predict a negative level at the new steady state, which is of course impossible. Such is the

![Figure 5. Change of the manipulated variable and the controlled variable in "ATV" tuning.](image)

![Figure 6. Response of the heating tank with PI controller and Ziegler-Nichols settings.](image)
situation in Figure 9. The nonlinear model predicts the new steady-state level as 0.25 ft and the linearized model predicts -6 ft as the new level.

It should be noted that reducing the flowrate even further may cause difficulties with even the nonlinear model. Because of integration errors, \( h \) may become a small negative number, which makes it impossible to calculate the \( h^{1/2} \) term. This can be prevented by putting a limit on \( h \) by applying an equation similar to Eq. (7). The same method can be used when the linearized model is solved by numerical simulation, but not when it is solved analytically.

A comparison of the nonlinear and linearized solutions by students should reinforce the following conclusions:

- It is important to remember the difference between a system which can be represented by a linear model and linearization of a nonlinear model. Linearization can represent the system well only near the point of linearization.
- It is always advisable to compare results from the nonlinear and linearized models in order to be able to appreciate the magnitude of error introduced by linearization.
- Results obtained from computer solution must always be carefully checked. Equations used outside the bounds of their validity, or numerical integration errors, may lead to incorrect or even absurd results.

CONCLUSIONS

We have demonstrated several interesting applications of an interactive ODE simulation program in this paper. Experience has shown the following important benefits of using such programs in process control:

1. There are many aspects of dynamic process behavior that can be studied only by using nonlinear models that include, for example, limits on variables.
2. Interactive simulation complements analytical methods very nicely by ensuring better understanding and allowing more realistic problems to be considered.
3. The strengths and weaknesses of analytical solutions and numerical simulation can be clearly demonstrated. This is important in particular when linearizing nonlinear equations where the restrictions of the linearized model must be well understood.

The examples and exercises given in Figure 1 and Table 1 can be put into immediate use in the classroom. Additional examples of applying an ODE solver for comparing analytical and numerical solutions and for more complex phenomenon could not be included in this paper because of space limitations. Information on these examples can be obtained from any one of the authors.

REFERENCES

PRACTICAL APPLICATIONS OF MASS BALANCES AND PHASE EQUILIBRIA IN BRINE CRYSTALLIZATION

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Mass-balance applications and a good level of phase-equilibrium knowledge, among other things, are required for a full understanding of brine-crystallization phenomena. Brine multi-component systems are complex, and phase diagrams are useful tools for explaining their behavior and designing crystallization processes. In the problem presented here, mass balances and phase-equilibrium criteria are combined to solve a practical application that is suitable for classroom presentation.

PROBLEM

A chemical plant is being planned for the manufacture of anhydrous sodium sulphate in crystalline form, starting from a saturated aqueous solution at a temperature of 25°C. For process-design purposes, we have available a binary solubility diagram for Na₂SO₄—H₂O,¹ and a ternary solubility diagram for Na₂SO₄—NaCl—H₂O at 25°C.² From the available information, suggest different alternatives for the production process, indicating in each case the final mass of anhydrous sodium sulphate, based on 1,000 kg of feed solution.

SOLUTION

Three processes for obtaining the desired result will now be presented.

ALTERNATIVE 1
Cool, then dry crystals.

As shown in Figure 1, point F denotes the feed solution at 25°C. The overall process is shown diagrammatically in Figure 2. The cooling process, which ends at 5°C, is represented by the line Fa. Point a is in the two-phase zone, with points b and c representing the solution and crystal phase, respectively.

An initial solution of mass F = 1,000 kg is considered. Total substrate and total mass balances then give

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Here, C and S are the masses of the crystal and solution, respectively.

From Figure 1, the following mass fraction values, denoted by X with appropriate subscripts, are obtained:

(a) \( X_F = 0.22 \)
(b) \( X_S = 0.06 \)
(c) \( X_C = 0.44 \)

The amount of the dehydrated sodium sulphate mass can be calculated from a combination of Eqs. (1) and (2):

\[
C = 421 \text{ kg } \text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}
\]

As anhydrous crystals are the desired final product, \( \text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O} \) must be subjected to a drying process, resulting in 185 kg of \( \text{Na}_2\text{SO}_4 \). Most impurities that are present in the initial solution will remain in the mother liquor.

**ALTERNATIVE 2**

*Heat, then vacuum evaporate*

The overall process is presented in Figure 3. The initial solution is first heated to 40°C, and then, under vacuum evaporation, 90% of the water is eliminated. Referring to Figure 1, \( F \) is again the starting point, and \( F_d \) and \( d_g \) represent the heating and evaporation steps, respectively. If \( V \) denotes the mass of the water evaporated, the total mass balance is

\[
F = S + C + V \tag{3}
\]

The solute balance is similar to Eq. (2), although the mass values are different. Considering that the mass of evaporated water is 90%, then \( V = 702 \text{ kg} \). A combination of Eqs. (2) and (3) then gives

\[
FX_F = (F - C - E)X_S + CX_C \tag{4}
\]

Since anhydrous salt is the end product of this process, \( X_C = 1 \). The corresponding saturated solution is designated by point e, so that \( X_S = 0.33 \). The mass of \( \text{Na}_2\text{SO}_4 \) crystal is \( C = 181.6 \text{ kg} \). Again, most impurities remain in the mother liquor.

**ALTERNATIVE 3**

*Add NaCl to crystallize*

As a third option, summarized in Figure 5, the same initial saturated solution \( F \) is mixed with sodium chloride at 25°C; this salt and aqueous system now being represented by the ternary diagram of Figure 4. Referring to Figure 4, the selected process is a result of mixing the initial solution \( F \) with sodium chloride, producing a two-phase mixture represented by the point p. The two components of this mixture are a saturated solution
s and crystallized sodium sulphate. Point $p$ should be as close as possible to the tieline $b$-$Na_2SO_4$, in order to obtain a maximum amount of crystals, which is proportional to the ratio $sp / pNa_2SO_4$.

The final point $p$ in Figure 4 must fall within the two-phase area $a$-$b$-$Na_2SO_4$, denoted as "$y$"; in this way the amount of salt to cause crystallization can be determined. This process, in which a third component is added to displace the saline equilibrium, is termed salting-out.

The mass-balance calculations are made from Figure 4 by the center-of-gravity or ratio-scale-moment method. The mass $N$ of sodium chloride that is required can be calculated by considering the proportionality between the masses of the streams, giving

$$N = F \left( \frac{F_P}{pNaCl} \right)$$  \hspace{1cm} (5)

In Figure 4, the line-segment ratio $F_P / pNaCl$ is 0.234. Thus, the required mass of sodium chloride is 234 kg, and, considering a total mass balance, the mass $P$ of the solution at point $p$ is obtained:

$$P = F + N = 1,234 \text{ kg}$$ \hspace{1cm} (6)

By a similar procedure, the mass $C$ of $Na_2SO_4$ crystal can be obtained as follows:

$$C = P \left( \frac{ps}{sNa_2SO_4} \right) = 128 \text{ kg}$$ \hspace{1cm} (7)

**CONCLUDING REMARKS**

The creativity of the student is stimulated as a result of examining the different strategies for obtaining sodium sulphate by various alternative combinations of unit operations. For each such alternative, there are associated mass balances and phase-equilibrium equations, and operating conditions such as temperature, composition, and total mass of product. In order to discover the best alternative, this problem can be extended by the further use of energy balances, equipment design, and economic evaluations.

In the chemical engineering department at the University of Antofagasta, it is normal practice to give homework problems involving the development of mass and energy balances, to be verified later in the Crystallization Laboratory. Finally, it is important to note that the design of this problem corresponds to a general policy regarding a link between industrial reality in the North of Chile and the chemical engineering curriculum.

**REFERENCES**

INTERACTIVE COMPUTER GRAPHICS
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expands his or her understanding of the subject. "Simulation Graphics" does both. Not only are the tedious details of manual graphic design eliminated, but also the scope of assignable problems is greatly increased, even to include open-ended examples where students must search through many solutions to satisfy a constraint or find some optimum.

An advantage also arises from exposing students to computer-based visualization. Chemical engineering has moved less rapidly than other engineering fields to capitalize on the enormous conceptual boost offered by visual thinking—particularly in the classroom.[15] Visualization models abound in thermodynamics, in transport phenomena, in reactor design, and in other core areas of the discipline.[16-18] This application to graphical models of staged processes is a natural and significant step toward accelerating that movement.

A CLOSING NOTE

Over seventy years ago, Marcel Ponchon[1] described his graphical method for binary distillation design. His introductory remarks, translated in part below, are as valid today as they were then. The efforts reported here and by those working before us have attempted to make those ideas more accessible through modern computer graphics.

"The theory of distillation columns is rather complex, requiring long and difficult calculations. But it is possible, without going into the theory, to replace those calculations with graphical constructions that permit the solution of a rather large number of problems."

ACKNOWLEDGMENTS

Support for this work came from Iowa State University, Union Carbide, and the Camille and Henry Dreyfus Foundation. Janet Rohler Greisch edited this paper and managed Plagge and Kurt Whitmore prepared the figures.

REFERENCES

18. Bird, R.B., personal communication ✐

BOOK REVIEW: Networking
Continued from page 119

presented conceptual frameworks that help the reader to grasp why NETWORKING is so vital in today's rapidly changing and diverse environment, what needs to be done to be an effective NETWORKER, and how to develop their own NETWORKING prowess.

Many of the NETWORKING principles can come fairly easily to gregarious, highly self-motivated and self-confident people. However, for the other (~) 95% of us, the idea of initiating contact with friends, neighbors, friends of friends—perfect strangers!—can be intimidating to the point of paralysis! This book can help anyone muster the courage and conviction to become an effective NETWORKER.

Some people will prefer to work through this book on their own. Others will realize greater benefit by working with a partner or in groups (e.g., AIChE). The reader should have time to contemplate many of the ideas presented and to complete the recommended assignments in order to maximize full learning potential. Dialog, discussion, and sharing ideas with others should also prove beneficial.

In summary, NETWORKING is an important life skill for all of us. This book will prove very valuable to everyone who reads it. It should be required by those responsible for educating young people who are preparing to enter the professional world. ✐
Any undergraduate curriculum committees around the country are seeking to create science and engineering requirements in university curricula which were liberalized during the 1960s when technical requirements were the first to go. National recognition that science and engineering classes are worthwhile for all undergraduates has created a renewed demand for these courses. The widening gap of technical literacy between science or engineering majors and non-science majors is due, in part, to preexisting academic and administrative structures. In fact, the National Science Foundation has identified the development of "mechanisms to enhance the technological literacy of all students" as an important goal. The challenge is to create nontrivial engineering courses which

- **Emphasize the basic tenants and practice of science, engineering, and technology without loss of technical content**
- **Are suitable for nonscience majors who attend the course**
- **Are intellectually stimulating for the students and instructor**

Engineering schools seeking to contribute to the university-wide educational mission should consider a course in biotechnology—a subject that naturally attracts students. As issues of health care costs become ever more critical, the general population strives to understand the pharmaceutical and biotechnology industries. Similarly, these industries are likely interested in communicating their activities and new products to a consumer who is educated and is not fearful of biotechnology.

The course described in this paper has proven successful with non-science majors, engineers in general, and our own chemical engineering undergraduates. Contrary to expectations, the technical course was of interest to a university-wide audience. This past spring we attracted twenty-three juniors and seniors from non-science majors ranging across the university: performing arts, management, economics, history, and legal studies.

Recognizing the novel makeup of this class, we carefully selected and tailored topics from our standard senior-level biochemical engineering course to suit non-majors who had little scientific background. As an overall goal, we wanted the students to understand in detail how biotechnology affects their lives in areas ranging from health care decisions to selections at the grocery store. We felt that issues such as AIDS, animal rights, and genetically engineered foods were relevant and would be interesting to this broad base of students. These topics served as a suitable "vector" to communicate scientific and engineering information such as viral genetics, recombinant DNA technology, large-scale pharmaceutical production, as well as experimental design and statistics. Along the way, important biotechnologies were presented, such as: immunodiagnostics and hybridoma culture, genetic diagnostics (DNA fingerprinting and PCR analysis), production and clinical testing of recombinant proteins, and agricultural biotechnology.
COURSE CONTENT

A novel approach we used in this course was avoiding the traditional lecture format. Instead, we used a Case Study/Group Learning approach—[12,13]—with much success, judging from student participation. The course outline is given in Table 1. Each case provided a framework in which students immediately understood the real world application of the technology. In this context, the material seemed less abstract, less intimidating, and more comprehensible.

At the beginning of the course, students were divided into permanent groups of four to six students each. As groups, they had to analyze raw data sets using their knowledge of the technical information, experimental design, and statistics. Before each case study a mini-lecture was given to expand on key concepts. Mini-lectures given during the first few weeks of the course included discussions of DNA-RNA-protein biochemistry, cell division, the human immune response, and antibodies. Throughout the entire course, emphasis on the applications of biotechnology made it identifiable as an engineering course as opposed to a pure science course. These real world applications, in part, helped enhance the students’ willingness to work with such new technical concepts.

We covered cases which highlighted particular technologies or sciences of the biotechnology industry. The first case study was the use of enzyme-linked immunosorbent assay (ELISA) and Western blotting to detect HIV-associated effects of false-positives on the analysis. This case was an excellent example of a naturally occurring biological molecule (an antibody) serving as a basis for a commercial application. Throughout the course, students repeatedly saw this paradigm of biomolecule discovery, characterization of structure and function, and final utilization of the biomolecule as a foundation for a technology. As the first case of the course, students extended their preexisting knowledge of viruses, immune response, and antibodies into new areas of measurement and detection of viral antigens. The case also reinforced the basic fundamental concepts of proteins, cells, and viruses which were to be used later in the course.

To give an example of a more involved case study (which required four class sections of eighty minutes each), we explored recombinant CD4 (reCD4) therapy as a treatment against AIDS. After hearing mini-lectures on retroviruses and receptor-ligand binding, students working in groups had to develop strategies for manufacturing a significant quantity of reCD4, design in vitro testing methodologies for evaluating reCD4 efficacy, and design a protocol for a Phase I trial. They had to apply their basic understanding of expression systems and protein purification/characterization toward an end goal of conducting a Phase I trial with reCD4.

Although topics of bioreactor and separation design were not suited for non-engineering majors, we discussed the manufacturing techniques at a level corresponding to an introductory chemical engineering course. As part of this case study the groups had to conduct a statistical analysis of raw data reported from real Phase I and II trials.[7,8]

By the end of the case study, students had some sense of how in vitro data and in vivo data could be in conflict.[9] They identified the sources of high costs associated with drug design and FDA approval. Through this case study, the learning process moved from the scientific observation that the HIV viral coat protein gp120 binds the T-cell membrane protein CD4 to the hypothesis that soluble CD4 may interfere with HIV virulence. To test the hypothesis required the manufacture and purification of reCD4, in vitro testing, and the design of Phase I trial.

At each stage of the discussion, the goal of drug design and AIDS treatment was appreciated by the students. A challenge for the students was deciding how to test CD4 given the existence of an FDA-approved reverse transcriptase inhibitor AZT. The benefits of AZT are transient and the use of placebo control groups would not likely be tolerated by AIDS patients enrolling in a clinical trial.[10]

Another case study in DNA fingerprinting involved the use of Restriction Fragment Length Polymorphism (RFLP) analysis of VNTRs (variable number of tandem
As an overall goal, we wanted the students to understand in detail how biotechnology affects their lives in areas ranging from health care decisions to selections at the grocery store. We felt that issues such as AIDS, animal rights, and genetically engineered foods were relevant and would be interesting to this broad base of students.

Repeat) to examine forensic evidence obtained at a rape crime scene and from potential suspects. A mini-lecture on DNA hybridization probes, chromosomal structure, and the human genome set the stage for this problem. The students reviewed copies of the autoradiographs that the jury saw in a real trial* of a 1985 rape/murder case in Arlington, Texas.\textsuperscript{11} Issues of reagent quality control, interpretation of DNA bandshifting, and state regulation of RFLP became quite important in making final judgments using evidence that was originally claimed to identify a rapist with 1-in-50 billion certainty.

Also covered in this case was the rapidly expanding technology of Polymerase Chain Reaction (PCR) for DNA amplification. Chapters from the National Research Council on DNA Technology in Forensic Science\textsuperscript{12} were very clear and useful for the students. Other forensic cases were drawn from the literature.\textsuperscript{13} Although forensic DNA analysis is not a typical research area in chemical engineering, the case study was an exciting way of teaching about the human genome and the molecular biology techniques frequently used in biotechnology. With this appreciation of human chromosome structure, other topics such as the human genome project or patenting genes\textsuperscript{14} could easily be covered.

The next case focused on blood clot dissolving therapy using recombinant tissue plasminogen activator (tPA). Again, students saw this pattern of a naturally occurring molecule being used as the foundation for an entire industry. Tissue plasminogen activator (whose functionality was described decades ago) was cloned in \textit{E. coli} using reDNA techniques in 1983 and then expressed in CHO cells by Genentech for clinical trials. As part of this case study, students had to identify the limitations of \textit{in vitro} testing of these recombinant compounds. They also had to design experimental protocols for the humane testing of recombinant blood clot dissolvers in animal models to gain data unattainable by \textit{in vitro} tests.

Moving toward examples from agricultural biotechnology, we used a case study on bovine growth hormone (bgh) also known as bovine somatotropin (BST). This is an excellent example highlighting the role of societal influences on the ultimate use and acceptance of a biotechnology product.\textsuperscript{15,16} Students had to debate the issues and write position papers from the points of view of the FDA, the consumer, the farmer, and the agricultural business. The use of bgh has been shown to be generally safe and effective for elevating milk production and improving the efficiency of production, but dairy cows with high milk production, regardless of bgh use, tend to have more infections of the udder (mastitis). This case reinforced previous understanding of gene cloning, expression systems, and receptor-mediated events of cell regulation by hormones. By this point in the semester, students readily appreciated the distinction between scientific information (bgh and human growth hormone effects on humans), scientifically based disputes such as increased bovine mastitis and antibiotic feeding, unsupported claims, and economic issues—matters which are typically jumbled together in media coverage.

The final case study of the course was on the use of antisense RNA technology for preventing tomato spoilage. A mini-lecture on energy metabolism in cells and the autocatalytic rise of ethylene production in ripening tomatoes helped formulate the problem. In this case, expression of antisense RNA against the rate-limiting enzyme ACC synthase was used to block ethylene synthesis and subsequent ripening in tomatoes.\textsuperscript{17} The class discussed the safety of a transgenic plant and formulated some guidelines by which safety could be evaluated.\textsuperscript{18} Through this case, issues of biochemical metabolism and gene regulation can be covered in a context which is easily approached by students.

\textbf{GROUP LEARNING}

We structured the course in a group-learning context modeled on a team-learning approach developed by Dr. Larry Michaelson at the University of Oklahoma.\textsuperscript{3-5} The group structure consists of permanent small groups, group exam taking, and group-based assignments in the application phase of each case study. In addition to their group work, students also complete individual tests and assignments. Grading was based on group and individual performance in addition to peer evaluation. Although unusual to the students at first, they quickly learned to value the knowledge base of their peers and realized that the group's understanding of the material greatly exceeded the knowledge of any individual member. When students took the exam individually and then in the groups, the mean on the group exams was typically 15% points higher than the mean on the individual exam. Larger and broader assignments were given for group work, but care was taken to avoid assignments which could be easily partitioned by the groups, thus circumventing the goal of the group work. Perhaps it is too early to tell whether group-based learning is an educational fad or is relevant to the problem-solving orientation of the chemical engineering

\* Courtesy of Dr. Randall Shortridge, Department of Biological Sciences, SUNY at Buffalo
and C. Herreid, in preparation, as modified from A.B. Champagne\(^{[20]}\)

The most marked changes were found in content-based knowledge (see Table 2). The Scientific Process Survey contained fifty terms and phrases that fall into three categories: experimental design, statistics, and the process of science. Students were asked to assess their knowledge of each term on a scale from 1 to 5, with 5 being the most familiar with the term. The mean for all items at the beginning of the course was 3.02—this corresponds to a level of understanding where students understand the idea vaguely. At the end of the term the mean for all the items was 3.83, corresponding to a level of understanding where students feel they have a pretty good understanding about the idea. Twenty-three of the fifty items had changed significantly over the course of the term (p < 0.05).

Analyzing the items in the three categories also revealed significant differences (see Table 2).

The World View Survey was a measure of the student's world view that is polarized between a holistic (context-based) and a mechanistic way of looking at the world. We found that, on average, the class had a slightly holistic world view at the first week of the course which did not change significantly over the term of the course. These results were consistent with other university groups at The State University of New York.

The Scientific Attitudes Survey had forty-eight items organized into the following six categories: science as a theory-building vs. data-gathering activity; basic vs. applied research; scientists as moral/amoral beings; usefulness of science in everyday life; abilities needed for success in science classes; personal ability to succeed in science class. We found that class averages in each of the six categories were very similar to other university student populations. These averages did not change during the course.

The Scientific Literacy Survey contained forty items relating to behaviors relevant to a scientifically literate adult. Students were asked to rate how valuable each of these items are. The scientific literacy items that students most valued were interpreting graphs, defining terms, applying scientific information in personal decision making, being able to evaluate medical claims, engaging in a scientifically informed discussion, and locating scientific or technological information. These were still their priorities at the end of the semester.

Overall, we believe that students' perceptions toward science and science education change as they become more
familiar with the basic terms, ideas, and processes of science. One way to promote positive attitudes of non-majors toward science and engineering is to teach these topics more effectively. The case-study/group-learning approach used in this course may be a suitable method to achieve that goal.

**SUMMARY**

By the end of the course, students had a general understanding of the breadth of the biotechnology industry, from pharmaceuticals to agriculture. They had a basic familiarity with recombinant DNA techniques, large-scale expression and purification of proteins, and product testing. By discussing how biotechnology companies operate in a scientific, legal, and economic environment, students became interested in material not normally accessible to them. The use of case studies made the material approachable and more easily comprehended, organized, and remembered. The group work allowed for much of the scientific learning to occur beyond the borders of the classroom. By the end of the semester, biotechnology no longer seemed like a brave new world to these students—they occasionally brought in their own newspaper clippings and provided insightful commentary on the technology or criticisms of the reporting.

This type of course is especially important in the context of the lack of scientific literacy among college students. The students not only learned important aspects of biotechnology, but also learned to appreciate and understand the process of science and engineering, especially as it affects their lives. We consider this an improvement over the "list of facts" approach of the lack of scientific literacy among college students.

**REFERENCES**

1. *The Liberal Art of Science: Agenda for Action*, American Association for the Advancement of Science (1990)
DEPARTMENT: Pittsburgh
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Undergraduate Research Positions

Cooperative Education Experience • Four years ago the School of Engineering reinstituted the cooperative education program. The benefits of alternating terms of academic study with practical engineering experience in industry have been obvious. Enhanced communication skills, an appreciation of the value of education, a strong dose of problem solving that does not include finding copies of last year's exams, and a greater chance of full-time employment upon graduation are a few of the benefits. The financial rewards are also appealing — salaries currently range between $1200 and $2600 a month.

Our program has been designed to permit students to enter as early as halfway through their sophomore year and as late as the end of the junior year. Each student must complete at least three four-month rotations in order to satisfy the program requirements. Currently, 40 of our 200 students are in the co-op program.

The program has also caused a dramatic change in the level of undergraduate activity on campus during the summer. We offer a full slate of courses in the summer to permit the completion of the coop program in four years and eight months. The additional eight months have been a small price to pay in return for the 100% job-placement rate of those who complete the program.

Internships • Summer internships are also encouraged. These opportunities are usually handled by Pitt's placement center. It does an excellent job of arranging interviews, publicizing openings, assisting in resume preparation, and arranging mock interviews.

Undergraduate Research Positions • Another opportunity for experience is undergraduate research. The level of funded research in our department is typically between $1.8 and $2.5 million per year. Although these projects are usually associated with graduate students, our faculty has also aggressively recruited undergraduates to become involved in the laboratory (shown in the photograph). About twenty students are involved with the faculty each term, either working for credit or for a salary. We also organize a formal program each summer for undergraduate research opportunities. This year a generous NSF grant will greatly enhance our ten-week program. About twenty undergraduates will be involved.

International Opportunities • Several exciting avenues of undergraduate research opened last year for the more adventurous students. Two chemical engineering coop positions involved extended assignments (four to six months) in Germany, and one of them will subsequently involve a term-long visit to Spain. The University Center for International Studies also helped us place a student in Japan for an eight-month internship. Several departments, including chemical engineering, are currently planning to initiate coop positions in Mexico this year that will involve both educational and employment for participating students.

OTHER EDUCATIONAL ACTIVITIES

We have integrated several activities into our program that provide students with a perspective that cannot be achieved in the classroom or laboratory. A plant trip is arranged each term to familiarize students with the appearance and operation of a chemical plant. During the visits, engineers familiar with the facility's design and operation share their experiences and answer questions. Industrial participants that have participated in this program include Calgon Carbon's activated carbon regeneration facility, ARCO Chemical's styrene and polystyrene plant, USX Steel's continuous caster, and Waste Technologies, Inc.'s hazardous waste incinerator.

JOB PLACEMENT

The University of Pittsburgh has an excellent placement service. Students are provided with resume preparation, interview practice sessions, campus interviews, resume referrals, and an extensive compilation of small and large engineering firms and high-tech companies. The placement rate of our graduates in engineering jobs or graduate school during the past six years has ranged from 71% to 100%, and the average starting annual salary over this period has increased steadily from $30,100 to $38,500, with some undergraduate salaries in excess of $41,000.

SUMMARY

We feel that the University of Pittsburgh provides a unique, exciting, and challenging environment for undergraduate chemical engineers. The faculty and students are enthusiastic about the undergraduate research, cooperative education, summer internship, and international co-ops and internship programs. Each of these programs receives strong support from the School of Engineering. Our department has vital links to other institutions on campus, such as the Biotechnology Center and the University of Pittsburgh Health Center. Our curriculum provides a thorough foundation in chemical engineering while providing flexibility in the selection of technical electives. Our active research efforts have resulted in a popular set of technical elective sequences and research opportunities. Our computing facilities and software packages are state-of-the-art, and our undergraduate laboratories are spacious and well-maintained. Our faculty is accessible to the undergrads and is committed to excellence in both teaching and research. Finally, our department and the University make a diligent effort to assist recent graduates with job placement and resume referrals.
THE SYNTHETIC-DATA METHOD

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Thermodynamics; statistics; process design. Few courses are viewed with as much trepidation by chemical engineering students (and faculty) as these are. Yet we generally admit that more understanding of these topics (even if not more courses) is essential to the success of our students.

The synthetic-data method provides a framework for integrating these fields and thereby making them more "real" for chemical engineering students. The fundamental principle of the method is optimization: making the most and best use of limited experimental data. As such, it involves error analysis, statistics, thermodynamics, and process design.

SYNTHETIC-DATA METHOD

We are often faced with the problem of too few experimental data and too simplistic models in chemical engineering; a classic example is fluid-phase equilibria. Our measurements of fluid systems (temperature, pressure, composition, etc.) are quite good, but our models are simplistic: cubic equations of state, activity-coefficient models, etc. A further complicating aspect of the problem is that we have too few of these experimental measurements. It is not feasible, even for common systems, to have complete physical property data at all temperatures, pressures, and compositions of interest. There are no data at all for many systems. Over the years, a set of procedures has been developed to solve this problem—the synthetic-data method.

The general idea is to generate artificial (synthetic) data for the system of interest from group-contribution or other methods. One then regresses these synthetic data to determine the parameters in the thermodynamic models that one wishes to employ. Group-contribution techniques are not new, and we routinely expose undergraduates to, for example, the Lydersen technique\(^1\) for estimating critical temperatures and pressures from the molecular structure of the compound. Of course, it is not the critical constants that are important—they are merely synthetic data. But, from these, we derive the set of parameters that we need for our equation of state.

An increasingly important technique in industry is the use of a group-contribution activity-coefficient technique (UNIFAC) to generate synthetic vapor-liquid equilibrium data, which are then regressed to determine equation-of-state parameters.\(^3\) Many applications and variations of this technique have been reported in the literature.\(^4\) Recently, a related approach was presented\(^5\) in which very limited infinite-dilution activity coefficient data plus the Wilson equation are used rather than the group-contribution idea to create synthetic data sets for regression of equation-of-state parameters.

The steps in the synthetic-data method are shown schematically in Figure 1 and are described below.

- Determine the best available primitive model and the data available. When data are sparse (the usual case), a group-contribution technique is chosen. In our application we use the UNIFAC model for liquid-state activity coefficients.
- Generate synthetic data from the primitive model chosen. These data should be as close as possible to the range of conditions of interest in the problem to be solved, but they must be within the range of validity of the primitive model. Typi-
cally, group-contribution techniques are much more limited in application range than are the models that are needed to solve the problem. For example, the UNIFAC model is good only for low pressures and near-ambient temperatures.

The parameters in the final model to be used are regressed from the synthetic data generated. In the regression, these data are weighted according to the needs of the problem. In our examples we use the Mathias version of the Soave-Redlich-Kwong equation of state.

The synthetic-data method is powerful and adaptive. It is, in effect, a "bootstrap" procedure. From only the chemical structure of the substances in the mixture, data are created for one set of conditions. The parameters for the more general model are regressed from these synthetic data, and predictions of phase equilibria over a broad range of conditions are then made. The engineer chooses which synthetic data to use and how to weight them in the regression of the final model parameters. Thus, the higher levels of engineering judgment (analysis, synthesis, and evaluation) must be used by the engineer or the engineering student.

The importance of these synthetic-data methods in teaching is that they create a framework for the integration of thermodynamic models, experimental data, statistics, and process design.

**THERMODYNAMICS**

We teach thermodynamics because we want students to understand its great unifying concepts: energy, mass, entropy, phase equilibrium, reaction equilibrium. But the test of that understanding in their profession is if they can use thermodynamic models for simulation of processes, whether or not the context of the assignment is plant operations, research, design, or sales. It is difficult to put these models into perspective in a short four-year curriculum. But it should be getting easier.

With user-friendly computer programs now available, our students can try different models, compare them to data, and experience the reality that these models, as elegant and complex as they may seem to be, are only crude approximations of reality and should be treated as such. The synthetic-data method is a good vehicle for this instruction.

The students are given a typical problem: they are asked to calculate the vapor-liquid equilibrium for a binary system of dimethyl-ether/methanol. (Any system may be chosen, but the results for this system are given in Figure 2.) To accomplish this, the students must choose a thermodynamic model, and they must know the parameters in that model. The choice of the model and the calculation of the compositions for which the fugacities are equivalent in the two phases are important, and non-trivial, assignments. The instructor provides the data. Of course, the data could be found easily in the literature (especially for this system), but we suggest that synthetic data be generated from, for example, the UNIFAC model and presented to the students. Depending on the students' backgrounds, we suggest that the ensuing parts of the problem be made more interesting by "errorizing" the data with a simple Gaussian distribution of "experimental" error.

The students submit their solutions, which should include the parameters that they have regressed, the vapor-liquid equilibria that they have calculated, and some measure of the deviations of the calculated results from the experimental data that were provided. During the discussion of their results, which
should be a "reflection in action" about what they have done, some or all of the following concepts can be brought in—concepts that would normally seem esoteric to the students but which are now of vital importance:

Experimental Error. • The instructor has introduced this artificially, but the students will be able to estimate (to varying degrees) what the experimental error was. The discussion can easily range from random to systematic errors, to the replication of experiments, to techniques for evaluating which model is best, to consequences of inaccurate model predictions, to sources of experimental data.

Statistics • Many people (including ABET and industrial advisory committees) decry the lack of statistical understanding of our students. But clearly the solution is not to ship the students off to mathematics or statistics departments for the types of courses that have created fear and anxiety about statistics in generations of students. Why not use statistics in existing courses? Chemical engineering students have a compelling need for statistics in, for example, thermodynamics. One can discuss experimental error, quality of physical-property models, statistical significance of differences between them, confidence regions of the parameters, maybe even thermodynamics consistency in the context of statistics. If we want to be sure that students will have the motivation for this discussion, we can give them different sets of the binary data for the problem and have them compare their results with one another.

Choice of Thermodynamic Model • The very different results that students get from their chosen models naturally leads to this important discussion.

Synthetic-data method • At some stage in the discussion described above, the instructor can explain how the data were generated for the problem, and the discussion will quickly turn to an examination of the synthetic-data method: how it can be (and is) used; when it is an appropriate choice; what its limitations are. Asking students to come up with other examples of the synthetic-data method can lead to even more unifying discussion.

PROCESS DESIGN

The ubiquitous use of process simulation programs in chemical engineering design courses presents exciting opportunities for students to acquire experience. Again, we suggest the synthetic-data method as a unifying concept for acquiring this experience.

When students are designing a process, a major stumbling block is typically the thermodynamic model. Encouraging students to use the default model is dangerous and unnecessary. Instead, we encourage students to choose the "best" model and give them synthetic data as described above. In this way, they use the regression skills they learned in previous courses as well as the thermodynamic concepts that they have mastered.

Each of the design groups chooses a different model, either on its own or through instructor encouragement. An active class discussion ensues in which the different designs of their process units are compared. The direction of this discussion follows the example given above for the thermodynamics class, but here the focus is not just on the disparity between the data and the vapor-liquid equilibria, but also on the apparent discrepancy between any of the designs and the actual operation of a real plant.

As was the case in the thermodynamics example, the final discussion here involves the students finding examples of the synthetic-data method—but this time they try to find examples in the various thermodynamic property options of the simulator.

WHAT HAVE THE STUDENTS LEARNED?

In the thermodynamics example, the students may not have learned what entropy is, and in the process design example they may not have learned anything about eigenvalues. But they certainly have learned about how to choose thermodynamic models, how important thermodynamics really is, and how much faith to have in the results. They have developed an expertise that they are likely to remember and to use when the need arises. Perhaps (we think definitely) they will have learned some statistics, again, in a way that they will remember and use.

CONCLUSION

The synthetic-data method provides a framework for unifying thermodynamics, process design, and statistics in such a way that students gain valuable experience in using the concepts they are learning.

ACKNOWLEDGEMENT

We appreciate the partial financial support of the U.S. Department of Energy through the Consortium for Fossil Fuel Liquefaction Science.

REFERENCES

3. Schwartzentruber, J., and H. Renon, "Extension of UNIFAC to High-Pressures and Temperatures by the Use of a Cubic


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**ChE book review**

**INTRODUCTION TO PHYSICAL POLYMER SCIENCE, 2nd Edition**

by L.H. Sperling

John Wiley & Sons Inc., New York, NY; 594 pages, $64.95 (1992)

**Reviewed by**

Eric A. Grulke

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Polymer physical science (the combination of polymer physics and polymer physical chemistry) forms the basis for interpreting and solving a wide variety of polymer processing and polymer performance problems. The first edition of Sperling's *Introduction to Physical Polymer Science* provided a good introduction to the field for chemical engineers and material scientists alike. The second edition has been expanded in several important areas: the amorphous and crystalline solid states, liquid crystalline systems, and mechanical behavior. It is a valuable reference for industrial practitioners as well as a good introductory textbook.

The book begins with a short overview of polymers, followed by descriptions of chain structures and configurations, and molecular weight distributions. The middle chapters provide descriptions of concentrated solutions and polymer blends, the amorphous state, the crystalline state, liquid crystalline polymers, and thermomechanical transitions. The final chapters cover mechanical and flow properties, including the elasticity of crosslinked polymers, polymer rheology and viscoelasticity, mechanical behavior, and some selected topics.

The introductory material in Chapter 1 provides the reader with an adequate background and vocabulary to read the rest of the text. Chapter 2 deals with chain structure and emphasizes stereochemistry, isomerism, copolymer types and morphologies, and photophysics. Descriptions of chain structure analytical methods provide an introduction to polymer characterization techniques.

Polymer molecular weight determinations are covered in Chapter 3. Polymer solution thermodynamics forms the basis for these measurements and is covered early in the chapter, an improvement from the first edition. Colloidal, light scattering, solution viscosity, and gel permeation chromatography techniques are presented. The second edition includes worked example problems starting in Chapter 3—an important improvement for classroom use and self-study alike.

Phase separation behavior (Chapter 4) has received much better coverage in the second edition. There are additional phase diagrams, an expanded discussion of polymer-polymer miscibility, and a good summary of the kinetics of phase separation. The section on diffusion and permeability in polymers should be helpful to those interested in packaging applications.

The material on bulk states (amorphous and crystalline) has been expanded into separate chapters (Chapters 5 and 6) and a new chapter has been added on liquid crystals (Chapter 7). These changes have made this edition of *Introduction to Physical Polymer Science* one of the best single references for the physical science description of solid and solid-like polymer systems.

The discussion of amorphous polymers includes short-range interactions and long-range order, the conformation of the polymer chain and macromolecular dynamics. Two models for linear polymer motion are presented: a bead-and-spring model (Rouse-Bueche theory) and the reptation model (de Gennes). In addition, the motion of nonlinear chains is described.

Chapter 6 on the crystalline state includes analytical methods for determining crystal structure, unit cells, chain structures, crystallization from the melt, crystallization kinetics, and the thermodynamics of fusion. There are also good sections on the re-entry of chain segments in lamellae, the effect of chemical structure on the melting temperature, and fiber formation and structure.

Chapter 7 on the liquid crystalline state is new to this edition. There are sections on mesophase types and morphologies, fiber formation, comparison of major polymer types, and the requirements for liquid crystal formation.

The material on thermal-mechanical transitions (Chapter 8) and rubber elasticity (Chapter 9) is about the same as in the first edition. The five regions of viscoelastic behavior are explained well, and there is a good section on theories of the glass transition. There are three laboratory/lecture demonstrations that help illustrate concepts of rubber elasticity.

*Continued on page 152.*
A PROGRAM FOR TEACHING ORAL PRESENTATIONS

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A recent survey of University of Oklahoma engineering graduates who are now in industry revealed a very interesting result: out of twenty-seven subjects they rated as "essential for all engineers," oral communication was rated number one.[1] Since I have spent a total of fifteen years in three industrial jobs, I was not surprised at this high rating of the importance of oral communication. Chemical engineers are expected to give many different types of oral presentations in their jobs, including impromptu speaking at small group meetings with peers and managers, presentations to larger groups of peers and managers, and presentations to small and large groups of technicians. A strong case could be made that the ability to communicate well is more important for a chemical engineer's success in an industrial job than any other single factor.

Despite the significance of oral communication for success in industry, few chemical engineers take a course on the subject as part of their BS degree. This is undoubtedly because chemical engineering curricula are already overloaded with courses.

Hanzevack and McKean have recognized this problem and have developed an instructional program on oral presentations as part of the senior design course at the University of South Carolina.[2] It consists of a brief lecture component accompanied by a written handout of guidelines. Each student orally presents a major paper involving design and economics.

An even more intensive instructional program on oral presentations has been put into place for seniors in process design at the University of Oklahoma. In this program, each student gives four different types of presentations, and the presentations are videotaped so that the students can analyze and improve their speaking. The program is incorporated into two process design courses: Process Design Laboratory and Process Design I. In the Process Design Laboratory, students work in teams to obtain experimental data for three unit operations and do a large-scale process design for each. This course is taken concurrently with Process Design I, where the fundamentals of process design are taught. Lectures on how to make an oral presentation are given in Process Design I, and students then give four oral presentations in one of the sections of Process Design Laboratory.

PLANNING AND PREPARING PRESENTATIONS

A key component of this program is the presentation of information on how to plan and prepare an oral presentation. The author gives two lectures, systematically explaining all the steps involved in the process. A twenty-two page outline of this information (also available upon request to anyone reading this article) is handed out at the beginning of the lectures. The information is based on the author's experience in giving oral presentations and on a short course the author took at Phillips Petroleum Company (given by Shipley Associates, Bountiful, Utah). The author also has found a book on public speaking by Osborn and Osborn to be very helpful.[3]

The first part of the lectures is spent convincing the students of the importance of oral communication. Personal experience and observations are delivered extemporaneously, both to help create interest and to give a good example of an extemporaneous talk.

A central idea in planning and preparing a presentation is to decide early on the method of presentation. Although students have three methods they can use—memorized,
Chemical engineers are expected to give many different types of oral presentations in their jobs... A strong case could be made that the ability to communicate well is more important for a chemical engineer's success in an industrial job than any other single factor.

manuscript, and extemporaneous—we teach them that an extemporaneous delivery is almost always the best choice; it comes across as being spontaneous and avoids such problems as the stilted or inflexible delivery characteristic of memorized or manuscript presentations. We teach students to develop a key-word outline on only one sheet of paper or an index card and then to talk extemporaneously about each point on the key-word outline.

We also teach students how to organize a talk. A typical organization is

- **Introduction**
- **Transition**
- **Body**
- **Transition**
- **Conclusion**

Both the introduction and the conclusion should be given without the use of notes. Listeners quickly lose confidence in a speaker who has to refer to notes during the introduction or conclusion to a talk. A key objective of the introduction should be to interest the audience in the topic. This can be accomplished by any number of approaches, such as telling a story, using an analogy, or using humor. The introduction should also give a preview of the rest of the talk. The conclusion should reiterate the main ideas of the talk and provide a sense of closure. Techniques for doing so include such things as closing with a quotation, a statement of personal intention, or a story.

The main points should be presented in the body of the talk. There should be about three main points in a short talk and about five in a longer one. These main points and any sub-main points do not have to be memorized since they are included in the key-word outline.

Transitions are needed in any talk in order to link the various parts of the speech together. They give coherence to the talk and guide the listeners along the way. When transitions are not planned, overuse of words such as "well," "you know," and "okay" can result.

Visual support materials are also necessary for most presentations. In my lecture on preparing talks, I discuss the various strengths and weaknesses of the different types of visual support materials, including chalk boards, overhead transparencies, and slides. I warn the students that a common tendency is to try to put too much material on a transparency or a slide. I emphasize two points taken from "The Speaker's Pledge," by Lubberoff:

- When using overhead transparencies, prepare them with letters that are at least four times the size of those on a typewriter.
- When using slides, fill them only with what can be typed, double-spaced, on a 3x5 card, and no more (approximately nine lines).

A final point that I stress is that the student must practice the presentation several times, and that practicing should be carried out using the key-word outline. This is important for making the presentation sound natural.

**STUDENT PRESENTATIONS**

A description of each of the four types of talks the student must give follows.

**Impromptu Talk** This is a one- or two-minute talk on a topic announced at the start of class. The topic is one that any student can readily speak on, such as "Tell us something interesting that happened to you when you were growing up," or "Tell us something about yourself that the rest of us probably don't know." The objective of this talk is to enable the students to give an impromptu talk in a relaxed setting. They are then given feedback on their speaking style, captured on videotape. The videotape viewing gives students the opportunity to discover distracting gestures and speech habits that they may not have been aware of.

**Introduction to a Longer Talk** This introduction, three to four minutes in length, is delivered without notes. The main point here is to capture the attention and interest of the audience and to preview the rest of the talk. The students select their own topics and develop points for the body of the talk, but actually only give its introduction.

**Talk Using at Least One Transparency** This covers only one part of the body of the talk, is three to four minutes in length, and must be delivered using only the key-word outline. The students again select their own topic. The focus of this talk is learning how to use transparencies effectively.

**Talk on a Portion of a Process Design Laboratory Report** Each group of four students gives a twenty-minute presentation on the last of the three projects they did in the course, which means that each of the students has five minutes to speak. Typically, each student would use three to four transparencies in his or her presentation. In preparing for this talk, the students practice before the other members of their group, which gives them valuable feedback from peers. Furthermore, this additional talk involving transparencies helps to increase the students' confidence in using visual aids.

The instructor jots down brief comments, both positive and negative, for each talk, and the notes are then given to Spring 1994
the student at the end of the class. A grade is assigned to all talks except the impromptu talk. Students are also assigned a grade for viewing their videotape (full credit if viewed and zero credit if not viewed); this viewing must be done before their next talk. Students view one of their videotapes in the presence of the instructor and they then discuss the student’s performance.

FEEDBACK FROM STUDENTS

After the last oral presentation the students are asked to evaluate the program. The responses have been overwhelmingly positive. Representative student comments are given in Table 1.

The comments reveal several interesting insights about the program. The students appreciated both the information on how to make a presentation and the opportunity to practice in front of their peers. Also, the videotaping was considered to be a useful tool in discovering how they could improve their next presentation, confirming the adage "a picture is worth a thousand words." Since more than half of the students had not taken any previous speech course, this program is definitely filling an educational need.

APPLICATION FOR OTHER DEPARTMENTS

This program could easily be used in an adapted form in other chemical engineering departments. For departments where the senior design class is relatively small (less than twenty), the lectures and the student talks could all be done in the design class. (It was successfully done this way at the University of Oklahoma for two different semesters.) Another approach would be to incorporate the student talks in the sections of unit operations lab and give the lectures in a chemical engineering course running concurrently with the lab.

ACKNOWLEDGMENTS

I appreciate the support of Richard Mallinson, Associate Professor, and Bruce Roberts, graduate student, in implementing this program in the sections of the process design laboratory course that they taught. Arletta Knight, formerly an instructor in the Department of Communication at the University of Oklahoma, gave helpful suggestions and support in the development of this program.

REFERENCES


REVIEW: Physical Polymer Science

Continued from page 149.

Polymer rheology has now been included in Chapter 10 with polymer viscoelasticity. Example calculations and the laboratory experiments in these sections are well thought out. There is a new section on fracture and healing in Chapter 11 (polymer mechanical behavior), and Chapter 12 introduces polymer surfaces and interfaces, electrical properties, and nonlinear optics.

References, general reading, and study problems are included in each chapter. The study problems are well-chosen. There are both qualitative and quantitative problems, problems dealing with analytical methods, problems addressing theory, practical questions, and some problems that can be answered with the aid of simple experiments. Students may be perplexed, but they won't be bored with this homework.

In conclusion, polymer physical science is an area that is often neglected in polymer course sequences in chemical engineering—this book can be used for an introductory course, or could even be used as the basis for a graduate course on the topic. Because of its good treatment of amorphous, crystalline, liquid crystals, rubber elasticity, and thermalmechanical transitions, it is also a valuable reference for the industrial polymer scientist working on performance properties of solid polymer, polymer blend, or liquid crystal systems.
AUTHOR GUIDELINES

This guide is offered to aid authors in preparing manuscripts for *Chemical Engineering Education* (CEE), a quarterly journal published by the Chemical Engineering Division of the American Society for Engineering Education (ASEE).

CEE publishes papers in the broad field of chemical engineering education. Papers generally describe a course, a laboratory, a ChE department, a ChE educator, a ChE curriculum, research program, machine computation, special instructional programs, or give views and opinions on various topics of interest to the profession.

• Specific suggestions on preparing papers •

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**ACKNOWLEDGMENT** • Include in acknowledgment only such credits as are essential.

**LITERATURE CITED** • References should be numbered and listed on a separate sheet in the order occurring in the text.

**COPY REQUIREMENTS** • Send two legible copies of the typed (double-spaced) manuscript on standard letter-size paper. Submit original drawings (or clear prints) of graphs and diagrams on separate sheets of paper, and include clear glossy prints of any photographs that will be used. Choose graph papers with blue cross-sectional lines; other colors interfere with good reproduction. Label ordinates and abscissas of graphs along the axes and outside the graph proper. Figure captions and legends will be set in type and need not be lettered on the drawings. Number all illustrations consecutively. Supply all captions and legends typed on a separate page. State in cover letter if drawings or photographs are to be returned. Authors should also include brief biographical sketches and recent photographs with the manuscript.
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