JOHN FRIEDLY
of Rochester

Instruction in Scaleup
KABEL
An Option in Applied Microbiology
LEE
Creativity in Engineering Education
FELDER
ChE Education in Japan and the United States
FLOYD
ChE and Instructional Computing: Are They in Step?
SEIDER
The Operations and Process Laboratory at Wisconsin
SATHER, COCA
Calculation of Pre-Exponential Term in Kinetic Rate Expression
MAHESHWARI, AKELLA
Simulation Exercises for an Undergraduate Digital Process Control Course
REEVES, SCHORK

and ChE at
CLARKSON UNIVERSITY
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Clarkson University is a private co-educational institution located in the village of Potsdam in upstate New York, twenty miles from the Canadian border and the St. Lawrence Seaway. The university was founded by three sisters as a memorial to their brother, Thomas S. Clarkson, a local businessman and humanitarian who was accidentally killed in his sandstone quarry in 1894. The first classes were held for seventeen young men and women on September 2, 1896.

Chemical engineering was inaugurated at the Thomas S. Clarkson Memorial School of Technology in 1903, and the first chemical engineering degree was awarded in 1904. In 1913, the charter was amended, authorizing the awarding of graduate degrees and changing the name to the Thomas S. Clarkson Memorial College of Technology. The first masters degrees were awarded in 1916. It was not until 1964 that the first PhD was awarded (in chemistry). The first PhD in chemical engineering was awarded one year later in 1965. Continued growth and development resulted in the New York State Board of Regents designating Clarkson as a university in 1984.

For many years, chemistry and chemical engineering were combined as one department. In 1958, this association was dissolved and Herman L. Shulman became the first chairman of chemical engineering. Shulman was committed to expanding the graduate program, and under his leadership, graduate activity increased from three to twenty-three full time graduate students and the department increased in size from three to seven faculty members. By 1965 Shulman was Dean of the Graduate School and Head of the Division of Research, and William N. Gill from Syracuse University was appointed as the new chairman of chemical engineering. Exciting times were in store for chemical engineering over the next six years. In 1968 Shulman became Dean of Engineering. In September 1969 the department was awarded a $590,000 NSF development grant. That same month Eli Ruckenstein joined the department as an NSF visiting foreign scientist, and in the spring semester of 1970, T. Brooke Benjamin, F.R.S., joined us as a Distinguished Visiting Professor. By 1971 the department had doubled in size to fourteen full time faculty members and the graduate enrollment had risen to forty-
In September of 1971, Gill left Clarkson to become Provost of Engineering and Applied Science at SUNY Buffalo. Gill had built a strong department with many outstanding faculty members, and for the next few years, Joseph Estrin, E. James Davis, and Richard J. Nunge successively occupied the chairman's position. In 1975, William R. Wilcox from USC was appointed as Gill's successor. At USC, Wilcox had been professor of both chemical engineering and materials science. This latter area of expertise, combined with the strength in transport phenomena left by Gill, was to shape the nature of the department and the school of engineering for years to come. With the resurgence of NASA and the successful launch of the space shuttle, many of the faculty, with the help and encouragement of Wilcox, found themselves involved in one way or another with NASA's "Materials Processing in Space" program. Simultaneously, undergraduate enrollments recovered from the early 70s, the graduate program flourished (reaching a high of seventy-six), and the faculty increased in number to a maximum of twenty-one. During this time period, Estrin, Davis, and David O. Cooney left to become chairmen at the universities of Rhode Island, New Mexico, and Wyoming, respectively. Joseph L. Katz and Marc D. Donahue also left the department and, in succession, took over the chairmanship at Johns Hopkins University. Nunge was appointed Dean of the Graduate School and head of the Division of Research at Clarkson. In July of 1986 Wilcox stepped down as chairman and became director of the newly formed "Center for Advanced Materials Processing" (CAMP) and the "NASA Center for the Commercialization of Crystal Growth in Space," both at Clarkson. Shortly afterwards, Clarkson's CAMP was designated as a "Center for Advanced Technology" by the State of New York.

In January of 1987, R. Shankar Subramanian was appointed chairman of the Chemical Engineering Department. On July 1 of 1987, Wilcox was appointed Dean of Engineering. Since 1971, the Chemical Engineering Department at Clarkson has been consistently ranked in the top ten in the U.S. in terms of numbers of BS degrees awarded annually. The undergraduate program is the foundation upon which the strength of the department depends, and the graduate program builds upon that strength. Undergraduates are encouraged to become involved in research projects to discover "what it is all about." In 1986, new external research support in chemical engineering climbed to well over one million dollars annually. The key to the future of chemical engineering at Clarkson is "flexibility." We must be prepared to direct our expertise to new and upcoming fields, both in terms of research effort and in undergraduate course offerings. At Clarkson, this will no doubt be influenced by "CAMP," which has already guided our activities toward such areas as fine-particle processing, polymer processing, electronic fabrication processing, micro-contamination control, and materials processing in space.

FACILITIES

Since 1948, chemical engineering has been located in Peyton Hall, a three-story structure having a total of 32,000 square feet of floor space. Originally, the building contained the college library on the third floor and strength of materials and machine tool laboratories on the first floor. The unit operations laboratory occupied the second floor, and the traditional well, which occupied 1650 square feet of floor space on the ground floor, rose the entire height of the building. By the mid 1960s, chemical engineering was the exclusive occupant of Peyton Hall, and with the continuous expansion of the graduate program and increase in faculty size, many modifications of the interior have been required in order to provide sufficient laboratory and office space. The most significant of these have perhaps been the covering over of the well at the third floor level to create research laboratories, the partial covering of the well on the second floor to create both faculty offices and research laboratories, and the renovation of the basement area to create additional laboratories. Today, the building houses twenty-one faculty offices, twenty-seven laboratories, two departmental offices, two fifty-student classrooms, a computer laboratory for the design course, a computer terminal room for the graduate students, the departmental machine shop, and the chemical engineering senior laboratory which still occupies a major portion of the second floor plus the well.

Every undergraduate student entering Clarkson is issued a personal computer. In the first year of this...
program, 1983, all entering freshmen were issued a Zenith Z-100 microcomputer. In subsequent years, the Z-100 was updated annually to keep pace with rapid developments in computer technology. By September 1986, every Clarkson undergraduate had a Zenith computer. The class entering in 1986 was issued a special version of the new IBM AT compatible Z-248 computer. This special version was also Z-100 compatible. In 1987, the entering class was issued the enhanced graphics version of the Z-248 and compatibility with the Z-100 was eliminated. Each faculty member is also issued a microcomputer, the version depending upon undergraduate teaching assignments. For example, all faculty teaching freshman courses in 1987/88 received new EGA Z-248 computers to replace whatever version they were previously using. Many of the faculty members in chemical engineering find that the capabilities of the current microcomputers are now quite sufficient for their research needs. Unfortunately, the graduate students are not issued computers, so it is necessary to provide appropriate facilities for them either in the research laboratories or in departmental terminal rooms. Our graduate terminal room contains three Sun workstations, three Z-248 computers with 30M hard drives and expanded memory, one Z-248 with an Opus board, 318M hard drive and expanded memory, and two Z-100 computers, one with color monitor. Except for the Z-100s, these are all linked together with similar facilities in the other engineering departments and with the university mainframe computers by an ethernet. The mainframe computers include an IBM 4341, Gould 9080, VAX 11-780, and an Alliant FX8 mini-supercomputer. The IBM machine is now used largely for administrative purposes and the VAX for undergraduate instruction in computer graphics. Because all faculty offices in the school of engineering are wired into the ethernet, all of the above facilities and their software are directly accessible for use by the faculty from their office. Further, through BITNET, EARN, ARPANET, UUCP, etc., electronic mail transfer to faculty at other universities and to colleagues in industry, both in the U.S. and abroad, is easily accomplished.

The research laboratories scattered throughout the building contain a large variety of equipment and facilities reflecting the research interests of the faculty. Among the major large-scale facilities are an extruder, injection molding machine, blown film line, hot press, Instron universal testing machine, Perkin Elmer differential thermal analyzer and differential scanning calorimeter, Siemens D500 X-ray diffractometer, Plasmatherm PECVD and plasma etching reactors, CO2 and excimer lasers, and commercial scale crystal growth equipment. There are many well-equipped research laboratories associated with individual faculty or groups of faculty but which do not necessarily contain large scale facilities such as identified above. These include the electrochemical engineering laboratory (Chin), chemical metallurgy laboratory (Rasmussen), nucleation laboratory (Rasmussen), crystal growth laboratory (Wilcox), glass processing laboratory (Subramanian, Cole), bubble dynamics laboratory (Subramanian, Cole), chemical kinetics laboratory (McCluskey), holographic interferometry laboratory (Sukanek, Cole), gas treating laboratory (Welland), polymer fabrication and properties laboratory (Campbell, Sukanek, Harris), separation process design laboratory (Taylor), plasma and laser processing laboratory (Babu, Sukanek), heat transfer laboratory (Obot), oil residual characterization laboratory (Baltus), and the multiphase flow laboratory (McLaughlin). This summer, a new materials preparation and ultra-high vacuum surface analysis laboratory will be established by Dr. S. Ted Oyama who will be joining the faculty.

FACULTY RESEARCH

Our faculty's research interests and interactions can be represented schematically as three connected body centered cubic unit cells with each faculty member as a lattice point. Conveniently, there are nineteen faculty members to be placed on the lattice. An arrangement is presented which optimizes cohesive energy by forming the bonds with the strongest individual interaction. It can be observed that the two outer unit cells are centered with the past chairman of the department, Bill Wilcox, and the current chairman of the department, Shankar Subramanian. Each has his influence within the department through a maximum number of immediate interactions within his own area of specialization.

Bill Wilcox's research interest is in materials and materials processing. Specifically, he is interested in the effects of crystal growth on the quality of the re-
sultant crystal or composite eutectic structure. During his tenure as chairman, a number of faculty with interests in materials or materials processing have joined the department. Obviously, as indicated by the lattice connections, the materials and the processing methods are wide ranging and of current commercial and theoretical interest. Rasmussen, Babu, Sukanek and McCluskey, as well as Wilcox, have an interest in electronic materials and on-chip processing. Each of these faculty members have spent at least one summer or sabbatical year with an industrial electronics manufacturer. Campbell, a polymer processing engineer, and Sukanek, a polymer rheologist, combine to work on polymer processing in bulk, injection molding, blown film and spin coating. They are also involved with Rasmussen in work on foaming of polymeric and multicomponent systems. Baltus's interest in hindered diffusion in porous systems and McCluskey's work in kinetics and catalysis complete the left hand unit cell.

Shankar Subramanian did his doctoral dissertation under Bill Gill and joined Clarkson's faculty in 1973. His ascent to the chairmanship of the department in 1986 brings continuity to the research group—originally founded by Gill—interested in transport and transport related problems. McLaughlin, Chin, Nunge, and Cole combine with Subramanian to study turbulence, electrochemical phenomena, fluids, and bubbles. Weiland has worked in slurry rheology and fluid flow in filled systems. Taylor, Weiland and Lucia have interests in mass transfer and separation processes. Cole and Obot are interested in boiling and convective heat transfer. Harris's work on digital control and Ward's work on analog control complete both this unit cell and help to tie together the left and right hand parts of the department, as does the interaction between Cole and Sukanek on optical measurement techniques.

A number of important interactions have not been included in the lattice connections because of inability to place the appropriate parties in nearest neighbor relationship. For example, Cole's interest in nucleation during boiling is not far removed from Rasmussen's interest in nucleation of crystals from the liquid state or solution or his interest in polymeric foams. Wilcox, Subramanian and Cole all study materials processing in low gravity and both Wilcox and Cole enjoy flying NASA's KC-135 aircraft to monitor low-G experiments themselves. Again, McLaughlin and Campbell have an interest in fluid rheology of filled systems under high shear, though our model cannot indicate this collaboration. The newest faculty member, S. Ted Oyama, is included in the matrix where he is expected to interact. His background is in the study of surfaces on solids and processing at surfaces. Oyama will arrive on campus this summer.

The research interests of our faculty are constantly evolving. The future will combine materials and transport phenomena. The obvious evolution continues to materials processing and the establishment of a center for materials processing, CAMP. The building of a physical facility for CAMP which will include our entire department indicates Clarkson's commitment to our research interests. We will move on.

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THE CHEMICAL ENGINEERING GUIDE TO HEAT TRANSFER: Vol. 1, Plant Principles; Vol. 2, Equipment

Reviewed by
Robert Cole
Clarkson University

Each volume consists exclusively of papers originally published in the McGraw-Hill Chemical Engineering magazine. The editors have classified ninety-three articles into two major categories depending upon whether they emphasize plant principles or equipment. These categories are further broken down as

- Heat exchangers
- Design
- Steam
- Shell-and-tube equipment
- Heat recovery
- Cost

for the former, and

- Boilers
- Heating and insulation
- Dryers
- Cooling
- Condensers
- Other equipment

for the latter. In general, the classification has been well done and the articles on heat recovery, for exam-
ple, do emphasize heat recovery. That is not to say, however, that the same articles do not discuss either design or equipment.

Chemical Engineering magazine is noted for its abundance of very practical and clearly written articles. It is, in effect, a “how to” magazine for the practicing chemical engineer. It follows that the same may be said about these two volumes. Articles are found which discuss, for example:

- Choice of construction materials (for heat exchangers)
- Latest TEMA standards
- Trouble shooting shell and tube equipment
- Hairpin, finned bundle, and helical coil heat exchangers
- Energy efficiency and conservation
- Heat recovery networks
- Steam traps and accumulators
- Fog formation
- Selection of industrial dryers
- Microwave drying
- Solar ponds
- Packaged boilers (specify carefully)
- Selecting refrigerants
- Coolers for cryogenic grinding
- Winterizing process plants
- Insulation without economics

The examples above are, of course, just a sampling of the many interesting articles which have been selected by the editors. Thirteen articles include detailed programs for both the TI-59/59 and HP-67/97 programmable calculators. Although many engineers now have their own microcomputers, and portable or laptop versions are available, it is doubtful that they are being carried around to the extent that the personal calculator is or the slide-rule (what?) was. Hence these programs should still be of considerable interest and use.

Although these volumes are certainly not intended as a text for any specific course, they should be part of any collection of reference books available for use with courses in heat transfer, design principles, and plant design. Excellent examples are presented of the practical usage of equations and concepts already familiar to upper level chemical engineering students. Perhaps just as important, the articles are short, interesting, and readable. With the increasing emphasis accreditation has placed upon such topics as safety, economics, practical open-ended type problems, etc., these volumes become of increasing interest and value.

CHE letters

JOURNAL PRICES SKYROCKET

To the Editor:

An article in Science (236, 908, 1987) caught my attention. It was entitled

Libraries Stunned by Journal Price Increase

...research libraries also believe they are being exploited by journal publishers.

It tells of libraries being terribly upset by a 16% annual price increase. That's just peanuts. I wonder whether my fellow academics know what goes on in our field. Let me relate one of our horror stories.

In the 70s CEC was launched with six real bona fide issues/volume and one volume/year. Then things started changing with more and more volumes per year, combining issues, calling one mailing three issues and so on; of course always charging per volume. Finally they dispensed with the fiction of issues. Now each mailing is called a volume, and the number of pages has continually shrunk. The latest volume has just 254 small pages with large print.

CEC published thirteen and one-half volumes in 1987, charging close to $300/volume. That comes to just about $4000/year. In comparison, CES gives you twelve issues/volume, each issue having more in it than a whole volume of CEC.

The following table compares what you get from these two commercial publishers (December 1987 figures):

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<th># pages/vol.</th>
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<td>CES</td>
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Look at that - over eleven times as expensive.

A rogue operation like CES acts as an insidious cancer on our profession, looking healthy at first but then strangling its host - the information disseminating channels of our profession. For example, why shouldn't other publishers say, "If CEC can get away with charging over ten times as much as we do, we're fools if we don't follow suit." And if many of them do, what will this do to our libraries and to the profession's ability to disseminate knowledge?

How does such a situation develop? Simple. You want something (a place to publish your papers), the publisher gives you what you want, and it costs you nothing directly. To get going, the publisher gets a prestigious editorial board, the rest follows. In a way we are all to blame for this situation: the editorial board members for allowing their good names to be associated with these rapacious operations, and we, the consumers, for going along with it.

What can we do about this? More important - do we want to do anything about it? I wonder. Does anyone have ideas?

This spring our library has asked each university department to recommend cutting 15%, in dollar terms, from its journal holdings. I think I know how to do this in chemical engineering by eliminating just 1% of our journals.

Sincerely,

Octave Levenspiel
Oregon State University

EDITOR'S NOTE: CEE welcomes any additional comments from our readers on this subject. CEE has published four issues/volume since its inception while at the same increasing the average size of individual issues. Subscription rates have been raised only twice in the past ten years.
J. C. Friedly of Rochester

GULAM SAMDANI
University of Rochester
Rochester, NY 14627

John C. Friedly is a born gentleman, quite in contrast to M. J. Adler’s “go-getting materialism of the American environment.” He is always a patient, cheerful man who, it seems to those who know him, could not be otherwise even if he tried. Perhaps being aware that this personality trait could very well align his future with the inexorable fate of an endangered species, he learned how to transcend his phylogenetic destiny through ontogenetic inventiveness and his amazing (to others) quickness of mind. In daily interaction with his students and colleagues, he knows just when to be the anecdotal turtle and when the rabbit. And to bring this art to perfection, he never runs out of enthusiasm to test his flexibility against the demands of a situation, be it in the role of a teacher, a colleague, or an administrator. One speculation is that this is a legacy from his days on the championship teams of three different intramural sports, namely, basketball at Carnegie Tech, softball at UC Berkeley and handball at the U. of R. Even to this day, one colleague and long-time handball partner attests to his dexterity in the handball court.

Professor Friedly comes from a proud family in Glen Dale, West Virginia. His father was a banker who taught him the illusory character of money and inculcated in him the passion for the “finer things in life.” Dr. Friedly seems to fit the overachiever’s profile; he was a good student by all measures of competence in high school and college. His four years at Carnegie Institute of Technology (now Carnegie-Mellon) sharpened his skills and interest in mathematics. Without much second thought, he chose to study chemical engineering, perhaps lured by the campus...
reputation of chemical engineering being the “toughest one.” While an undergraduate, somehow he came to know about Charles Wilkes’ research at UC Berkeley and ended up going to Berkeley for his graduate education.

Although he was attracted to UC Berkeley by Dr. Wilkes’ work, he was eventually drawn into Professor E. E. Petersen’s group. He reminisces about his days at Berkeley with such zestful relish that it is hard to understand why he was in such a hurry to finish his PhD dissertation in about four years. Professor Petersen gets high marks for his advising style. “He gave me plenty of independence,” says Dr. Friedly. “But he was always there when I needed him. His approach to research and student advising has had an enduring influence. So much so, that to this day I try to follow his style.” He believes that it is a teacher’s privilege to let a fledgling mind grow at its “free will and free won’t,” and that the teacher should take every opportunity to facilitate that growth through exhortation and the catalyzing action of time-tested experience. For Dr. Friedly, however, the skeptic in him always keeps him on his toes with the caveat, “Am I overdoing my job?” Some, here in the department, have dubbed it as the “Berkeley Style” of research, teaching and advising.

After finishing his graduate education at Berkeley, he wanted to sample the real world as a research scientist at General Electric. It was in the Information Studies Section that he tried out some of his ideas in computerized process control. GE provided him with so much independence in the choice and conduct of research that he was “having a ball” and hardly noticed any difference between industrial and academic research in content or style. However, this research strategy took a turn when the GE management decided to pursue a more practical application-oriented research program, perhaps in anticipation of their withdrawal from the increasingly competitive computer market. At this point, Dr. Friedly chose not to take further stock in industrial research and said goodbye to GE. He applied to several universities for a faculty position and accepted an offer from Johns Hopkins University, hoping that he would be able to start his own program of research. It turned out that the Department of Chemical Engineering there was on top of the University Dean’s list of departments soon to be disbanded because of their high cost of maintenance, overhead or otherwise, and low enrollment. Because of a nominal teaching load and no advising responsibility, he spent most of his time at Johns Hopkins doing research. That was when the idea of putting together his notes and scribbles and writing a book dawned on him. It was going to be a book on process dynamics—a subject he deemed to have a broader point of view and needed a treatment parallel to, but separate from, traditional process control. Although now he cringes at the thought of venturing into such a task (reading endlessly, writing at all hours, and dealing with the publisher) the end, according to him, more than justifies all the pains. For Dr. Friedly, his first brainchild, a lasting gift to generations of students and researchers of process dynamics, was his book Dynamic Behavior of Processes (1972). Surely one can feel the resonance of an inspired mind, with page after page of insightful discussion and ways to attack realistic problems with the approximate mathematical techniques available at that time. He introduced the use of asymptotic analysis as a way of approximating long-time response of certain model systems. His treatment was comprehensive, starting with the strategic steps of mathematical model development and concluding with nontrivial examples of exact and approximate analyses of linear and nonlinear systems. It was indeed a momentous intellectual debut.

Although the idea of the book had its inception in Baltimore, Dr. Friedly moved to the University of Rochester in New York to nourish the idea. At that time, James M. Douglas (the author of two volumes as Process Dynamics and Control) was getting ready to leave Rochester for the University of Massachusetts at Amherst. There was a brief communion of similar minds alive with the idea of writing books on process dynamics, but destined to go their separate ways.

Dr. Friedly’s thesis work at UC Berkeley was on the dynamics of chemically reactive systems. He sees his subsequent interest and research initiative in other areas as a logical continuum; they all grew, like branches from the main trunk of a tree, into the dynamics of distributed and multivariable systems, system stability, optimal process control, dynamics, and control of food processing. He concedes that the area of research one launches into after completion of graduate work is at least half determined by chance. There is always the pull of intellectual inertia to stay
Although he is a member of several professional organizations, he seems to enjoy his association with the AIChE the most. For the Rochester Section of the AIChE, he has served in positions varying from employment coordinator to director of the section.

on the safe and familiar road and the push from circumstantial contingencies. One must develop intellectual flexibility while at graduate school and through exposure to the whole gamut of perspectives necessary for independent scholarly work. Those who practice conservatism at this point in their education are missing out on some of the exquisite thrills of discovery and they end up paying a high price for this error of omission through regret for not making enough errors of commission while at school.

At the University of Rochester, Professor Friedly developed his new interests by teaching both graduate and undergraduate courses on heat transfer while continuing research in heat exchanger stability, heat transfer in food processing, combustion, and solar heater dynamics. He has also been teaching courses on process dynamics, advanced process control, and stability in distributed parameter systems, and he became involved in many other emerging areas along the way. For instance, his interest in environmental pollution abatement led him to learn about solid waste management and groundwater pollution. Interest in chemical process system analysis led him to learn more about computer-aided design, artificial intelligence and, more recently, design and development of expert systems for process control applications. If nothing else, this example gives us some idea of how an active mind makes its forays into unexplored territory and how it values the learning experience in and of itself.

Professor Friedly's approach to teaching is coextensive with his research style. He considers that the success of his method is in direct proportion to the extent that students shy away from "telephone-book memorization." Of course, an engineer ought to know where to look things up, but the challenge is more often with problems that are not in handbooks or other standard references in the library.

Besides his teaching and research activities, Professor Friedly has always enjoyed pitching in whenever there was a call for administrative responsibilities and making things happen in that role. He once headed, in congruence with his innovative research interest, a flexible student-oriented interdepartmental engineering program. Then the certain prospect of heavy administrative chores did not dissuade him from serving as the Associate Dean of Graduate Studies for the College of Engineering and Applied Science. Since 1981 (the beginning of the twilight years for the employment of graduating chemical engineers), he has been at the helm as department chairman and has weathered the storms of criticism from professional accreditation boards, industry, and government for updating and expanding nationwide chemical engineering curricula within the four-year span of undergraduate education. Dr. Friedly seems to subscribe to the ancient Chinese doll's method of encapsulating breadth within multilayered depth. Instead of offering separate courses for small topics of emerging interest, they are assimilated into appropriate ChE courses and treated in the overall context of fundamental principles of chemical engineering. If and when a topic demands a more comprehensive coverage, he is quick to invite experts from local industry and to recruit new faculty members to do the job. For example, the recent surge of interest in biotechnology, materials science in general, and polymer science and technology in particular, called for the addition of two new faculty members. He looks forward to capitalizing as much as possible on the great resources and fine reputation of the university's Institute of Optics and various optics-based concerns such as Bausch & Lomb, Corning, Kodak and Xerox. He believes the department's emphasis on optical (polymeric) materials is only natural for Rochester.
Providing a suitable research atmosphere for the community of scholars and scholars-in-making (i.e., the graduate students and post-doctoral fellows) is also a responsibility of the chairman of the department. Marshalling the available resources for the maintenance of excellence in research and teaching is no small task. Although there is the higher call for efficiency, Dr. Friedly is bent on making allowances for the adventurism of young investigators in pursuing untried avenues of research.

Dr. Friedly's open door policy has a counterpart for a pair of finches who take advantage of his “open window” policy in the spring. When they came in as freshmen to occupy the hanging ivy-plant pot in his office, he was ambivalent about what to teach them; nevertheless they had a bird's-eye-view of the rows of books on his open shelves and perhaps read titles like *Odyssey of a Chemical Engineer* and *Principles of Heat Transfer*. Although there is no way of knowing how much they learned about chemical engineering, they certainly have mastered the techniques on how to incubate newborn nestlings and to hatch and nurture the little ones until they could be on their own. We can only speculate about the extent to which they might have utilized their “textbook knowledge” of heat transfer during the incubation phase. Upon completion of the freshman year, their return as sophomores took everybody by surprise, so much so that their second visit not only made the local news but was also covered in an Audubon society publication in Oregon.

When he finds time to relax, Dr. Friedly likes to listen to classical music. He also likes to unwind by solving English crossword puzzles which, he never fails to point out, are quite different from those in American newspapers. For some time he has been developing this type of less interlocking, yet cryptic on a theme, English crossword puzzle and hopes to publish one some day. He also enjoys travelling with his family. He is particularly fond of the countryside—even today he talks endlessly about a small village near Oxford in England where he stayed during his last sabbatical at the University of Oxford. Another private passion of his is restoring old houses and doing the carpentry work himself. He tries to keep up-to-date on the “vernacular architecture” of the Rochester area and is devoted to maintaining the historical landmark status of his house in Penfield, New York.

The picture of this man would be an utterly truncated one if we failed to mention his professional involvement and active participation in societal affairs. Although he is a member of several professional organizations, he seems to enjoy his association with the AIChE the most. For the Rochester Section of the AIChE, he has served in positions varying from employment coordinator to director of the section. He was once a member of the US-USSR Study Group on Helium Fluid Flow and Heat Transfer Research and recollects the pleasures and frustrations of communicating with the Soviet scientists and engineers through the iron curtain. He is an activist in consumer protection and has been a member of the Consumer Health Protection Committee of the Monroe County Health Department.

When Professor Friedly, a teacher, researcher and administrator ponders the future of our profession, he concludes we have a long way to go. Public perception of engineers in general and chemical engineers in particular needs to be improved. Since we have to depend on government financing for research in academia, the importance of public opinion looms large in who gets what share of the government's budget.

Last but not the least important responsibility of educators in chemical engineering is to write books and monographs. Textbooks and the allied literature indeed go a long way in redefining the boundaries of our profession, and this redefinition influences potential employers and the decision-makers in research-supporting institutions in their expectations of what we as chemical engineers are not only trained to do, but also are capable of doing. This is no puny task. But Dr. Friedly is no naive idealist and says, “Did I say it was going to be easy?” And that is, at least in the author’s opinion, an apt counterpoint to complacency.
CREATIVITY IN ENGINEERING EDUCATION

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Unless man can make new and original adaptations to his environment as rapidly as his science can change the environment, our culture will perish.

Carl R. Rogers

There has been much discussion in recent years on the need for creative engineers in American industry and the associated need for engineering schools to foster creative thinking ability in their students [1-5]. The first problem one encounters when thinking about how these needs might be addressed is that while creativity has been exhaustively studied [6-11], it has never been satisfactorily defined. There is general agreement, however, that creativity (whatever it is) involves the ability to put things (words, concepts, methods, devices) together in novel ways. Moreover, at least some types of creative ability are thought to involve skill at divergent production—generation of many possible solutions to a given problem—as opposed to convergent production, or generation of “the right answer” [7,8].

Academic excellence (at least in engineering) is synonymous with skill at convergent production, since engineering education (unlike engineering practice and life in general) normally involves only problems with single correct answers. On the other hand, both convergent and divergent production are required to solve serious technological problems. The purely convergent thinker is not likely to come up with the innovative solution required when conventional approaches fail, while the purely divergent thinker will generate a great many innovative ideas but may lack both the analytical ability to carry them through to their final form and the evaluative ability to discriminate between good and bad solutions. If we as engineering educators cannot find enough individuals who combine these abilities, at the very least we should be turning out some who excel at one and some who excel at the other. To do this, we must provide instruction and practice in both modes of thinking.

In this respect we are failing abysmally. In the educational experience we provide for our students, from the first grade through the last graduate course, never (well, hardly ever) are words breathed to the following effects:

- Some problems do not have unique solutions.
- Some problems may not have solutions at all.
- Problems in life, unlike problems in school, do not come packaged with the precise amount of information needed to solve them—some are overdefined, and most are underdefined.
- Problems in life, unlike problems in school, are open-ended: there is no single correct solution and any realistic answer invariably begins with, “It depends. . . .”
- The more possible solutions you think of for a problem, the more likely you are to come up with the best solution.
- Sometimes a solution that at first sounds foolish is the best solution.
- To be wrong is not necessarily to fail.

If we are to produce engineers who can solve society’s most pressing technological problems we must somehow convey these messages in our instruction.

Richard M. Felder is a professor of ChE at N.C. State, where he has been since 1969. He received his BChE at City College of C.U.N.Y. and his PhD from Princeton. He has worked at the A.E.R.E., Harwell, and Brookhaven National Laboratory, and has presented courses on chemical engineering principles, reactor design, process optimization, and radioisotope applications to various American and foreign industries and institutions. He is coauthor of the text Elementary Principles of Chemical Processes (Wiley, 1986).
There is general agreement that creativity (whatever it is) involves the ability to put things . . . together in novel ways. Moreover, at least some types of creative ability are thought to involve skill at divergent production—generation of many possible solutions to a given problem—as opposed to convergent production, or generation of "the right answer."

We must provide our students with opportunities to exercise and augment their natural creative abilities and we must create classroom environments that make these exercises effective. The balance of this paper suggests methods for achieving these objectives.

CREATIVITY EXERCISES

The need to be right all the time is the biggest bar there is to new ideas. It is better to have enough ideas for some of them to be wrong than to be always right by having no ideas at all.

Edward de Bono

Every really new idea looks crazy at first.

Abraham H. Maslow

Many techniques have been suggested for exercising creativity and developing problem-solving skills in the classroom. (See, for example, the articles in Lubkin [12], especially that by Woods et al., and Costa [13].) In every course some open-ended and underdefined problems should be assigned, and more information than is needed should be provided for problems with unique solutions. Problems should also be assigned which call for the generation of possible alternative solutions, and when the solutions are evaluated credit should be given for fluency (number of solutions generated), flexibility (variety of approaches adopted), and originality.

If the generation of possible solutions is to be done effectively, it is essential that the critical facility be suspended in the initial stages of the process. The problem-solver must feel free to advance any idea that occurs, regardless of its apparent practicality or lack of it. A number of techniques have been used successfully to facilitate the uncritical generation of ideas. Following are several that have been found particularly effective in industrial settings:

1. Alex F. Osborn's Checklist for New Ideas (cited in Arnold [14]). A series of questions is used to stimulate new ways of thinking about a process, plan, or device.
   - Adapt? (Are there any new ways to use this as is? Other uses if modified?)
   - Modify? (New twist? Change meaning, color, motion, sound, odor, form, shape? Other changes?)

2. Attribute Listing, proposed by Robert Crawford (cited in Arnold [14]). List attributes or specifications of the entity to be improved, and systematically try modifications or variations. Example: a screwdriver—(1) round, steel shank; (2) wooden handle riveted to it; (3) wedge-shaped end for engaging slot in screw; (4) manually operated; (5) torque provided by twisting. Then try changing each one, separately and in combinations, and see what you come up with.

3. Morphological Analysis, proposed by Fritz Zwicky (cited in Arnold [14]). Set up axes for principal attributes of the entity, with entries for each variable. Example: devise a mode of transportation for a specific application. One axis would be the form of conveyance (cart, chair, sling, bed, capsule, . . . ), another is the medium in or on which the transportation occurs (air, water, oil, rollers, rails, . . . ), another is the power source (internal combustion, compressed air, electricity, steam, magnetic fields, cable, belt, atomic power, . . . ). Then try to come up with an example of each possible combination of variables (i.e., every point on the grid formed in the space of the axes).

4. Random stimulation, one of the techniques suggested by Edward de Bono [15] under the general framework of "lateral thinking," in which something arbitrary is selected and an attempt is made to apply it to the problem at hand. Use a dictionary to provide a random word. Pick a book or journal off a shelf, choose any article or chapter, and apply the information to the given problem. Pick the nearest red object.

Making students combine two apparently unrelated concepts in this manner forces them to think about their problem in new ways, which is the object of the exercise. In a recent junior-level class on fluid dynamics and heat transfer [5] students were assigned to think of as many ways as they could to measure the viscosity of a fluid. Extra credit was given for any method that involved the
use of a hamburger. (An instructor who dislikes whimsy could use a more serious sounding noun—it makes no difference.) The results were enjoyable: students measured the settling velocity of a hamburger in the fluid; poured the fluid over the hamburger like ketchup and measured its spreading rate; covered a flat surface with the fluid and skipped the hamburger across it like a stone; offered a hamburger to someone who owned a viscometer; and came up with a number of other ideas that (with some stretching of the imagination) could lead to viable viscosity measurement methods.

5. **Brainstorming,** formally developed by Alex F. Osborn. A problem is posed and a group session is held in which ideas are proposed and recorded but not evaluated critically, and then in a subsequent session the ideas are evaluated and the less promising ones are culled out. The idea generation phase can be completely unstructured or one of the preceding four techniques can be used as the basis of the exercise. Any idea, no matter how far-fetched, is fair game.

Several brainstorming exercises were used recently in the junior fluids/heat transfer course cited previously [5]. One asked students to come up with methods of measuring the velocity of a fluid in a pipe when no conventional flowmeter is available (several students reached the upper limit of 50 distinct solutions); another described a hazardous waste treatment method and called on the students to identify as many potential flaws in the method as possible; a third requested them to think of as many uses as they could for a hot stack gas; and a fourth was the viscosity measurement exercise.

Such exercises serve several useful purposes: they encourage and reward creative thinking; they force students to look at the subjects they are studying from different perspectives, which leads to deeper understanding; they provide excellent points for class discussion; and they are enjoyable to both the students and the instructor. In addition, if they are done in class they are remarkably effective at getting all of the students involved as opposed to the few who are normally willing to ask and answer questions in public. Which technique is used is immaterial: the idea is to introduce novel ways of looking at problems—to force thinking patterns out of their well-worn grooves—and all of these methods achieve this objective.

A word of caution, however. Exercises of these types seem like games when they are first introduced and they can easily be dismissed as trivial or frivolous by faculty colleagues and by the students themselves. Woods and Crowe, for example, report that students introduced to brainstorming in a freshman design course felt the experience was “mickey mouse” and not useful [16]. It should be impressed on the students that whatever these methods may look like, they are used extensively in industry to generate ideas for new products, cost reductions, and solutions to difficult problems.

Once the ideas have been generated and collected, the next phase of the process is to bring back the critical facility and select the solutions that have the greatest promise of working. Here we are on much more familiar ground where the convergent thinking skills that the students are used to exercising can once again be called into play. At the conclusion of the process, however, the students should be reminded that the more innovative of their eventual solutions probably would not have emerged from a conventional approach.

Where in the curriculum should this type of exercise be introduced? One possibility is to present an elective course on problem-solving methods; however, I would argue that this is not a good way to go. For one thing, these classes only reach a fraction of the population that could benefit from them. For another, they convey the impression that creative problem-solving methods are in a separate category from regular engineering analysis: you use them in this course, but for normal engineering problems you go back to business as usual. Instead, the methods should be integrated as thoroughly as possible into the regular curriculum. Open-ended and divergent problems can be assigned to individuals or to small groups as in-class exercises, homework, or take-home quizzes [4, 5]. Assignments to groups of two or three are particularly effective; students tend to enjoy them, competing with one another at coming up with outrageous ideas, and they also discover the synergistic effects of group interactions on the generation of problem solutions.

Training should be provided in asking questions, not just answering them, especially in advanced undergraduate and graduate courses. Several examples of problem-defining exercises have been presented recently [4, 5]. In one instance [4], students in a graduate course in chemical reaction engineering were asked to make up and solve a final examination for the course. They were told that a straightforward “given this, calculate that” examination would earn only a minimum passing grade, and to get more credit they would have to include questions that called for analysis beyond that contained in the text, synthesis
Most of us learn early that being wrong is unacceptable and looking foolish is even worse, and these lessons are reinforced throughout our lives. Unfortunately teachers are frequently the worst offenders in creating these fears.

of material from other subject areas, and subjective evaluation.

The results of this exercise ranged from acceptable to spectacular. Excellent questions were formulated covering every aspect of chemical reaction engineering and incorporating elements from chemistry, biotechnology, a variety of other scientific and engineering disciplines, behavioral psychology, and several topics that defy classification. The students almost unanimously reported finding the exercise instructive and enjoyable and many of them indicated satisfaction at discovering abilities in themselves that they had never valued or even knew they had. The exercise has subsequently been repeated twice with equally good results.

Two factors are necessary for exercises of all types listed above to be effective: preparation and repetition. The class should initially be given some background on what the exercises are supposed to accomplish. What is divergent thinking, for example, and why is it important? What are synthesis and evaluation? What is the point of underdefining homework problems? Illustrative solutions should be presented to give the students an idea of what they are being asked for but not to an extent that the students can use them as detailed models. This preparation can be accomplished with a handout preceding the first problem assignment plus about fifteen minutes of explanation in class.

The need for repetition is critical. Each new type of exercise should be assigned at least twice and ideally three times. In their responses to the first assignment the students will almost invariably miss the point and try to convert the exercise into something they know how to do, or they will avoid it altogether out of fear of getting it wrong. The second time they will begin to take the assignment seriously but will generally do a mediocre job. By the third time most of them will start catching on. At this point it is time to move on to something different.

A useful method to accelerate adaptation to a new approach is to collect representative samples of the responses to the first assignment, reproduce them without attribution, distribute them to the class, and discuss them. The discussion should bring out the strong points of the responses and provide ideas for how they could be improved. When this is done the improvement in responses to subsequent assignments is usually dramatic.

CREATING AN ATMOSPHERE HOSPITABLE TO CREATIVITY

What is then the correct way of teaching people to be, e.g., engineers? It is quite clear that we must teach them to be creative persons, at least in the sense of being able to confront novelty, to improvise. They must not be afraid of change but rather must be able to be comfortable with change and novelty, and if possible (because best of all) even to be able to enjoy novelty and change.

Abraham H. Maslow

Perhaps even more important than providing exercises in creativity is making students feel secure about participating in them. Most of us learn early that being wrong is unacceptable and looking foolish is even worse, and these lessons are reinforced throughout our lives. Unfortunately teachers are frequently the worst offenders in creating these fears, and the child who is humiliated for asking a “stupid” question or coming up with a “ridiculous” idea or offering an “obviously wrong” solution will wait a long time before sticking his or her neck out again. If we are indeed to produce creative engineers, we should be offering classes in which the risk-taking usually needed to solve real problems is encouraged.

No matter how secure we professors are in our knowledge, there is in most of us the fear of finally being caught, of being asked something we think we’re supposed to know but in fact don’t. Many of us consequently have a tendency to discourage questions, although usually not intentionally. Also, since most or all of our teaching is based on the precisely defined, closed-ended problem with one and only one correct solution, we tend to get annoyed when a student produces a correct solution other than the one we had in mind—it confuses the grading terribly. When students come up with unanticipated ideas, our impulse is to prove them wrong—both the ideas and the students.

Eventually, the students get the message. At best they will just stop asking hard questions and offering ideas that might be thought wrong or foolish and will instead concentrate simply on figuring out what we want and then giving it to us. In the worst case—when they find no outlet in the educational system for their creative impulses—they will turn those impulses off, perhaps for the rest of their careers and lives, to their own detriment and society’s loss.

Several things can be done to create a relatively
safe atmosphere for questioning and idea generation:

- Encourage and applaud questioning. Asking a question in class is taking a risk; if we are to encourage risk-taking in our students this is a good place to begin. Even when a question seems “stupid,” try if at all possible to find merit in it, even if it means reinterpreting it or extending it to something that the questioner undoubtedly never dreamed of.

- When you ask students for suggestions, give them time to think of answers, don’t criticize incorrect solutions, and don’t automatically stop asking when you get the answer you’re looking for.

- If you really want student responses, an almost sure way to get them is to divide the class into small groups (3 or 4 in a group) and tell the students to formulate questions or ideas among themselves; then call on a member of each group to write down the things they came up with. Most students feel safe talking, questioning, and floating ideas in a small group of their peers and the relative freedom they feel in this setting frequently carries over to subsequent full-class discussions. This technique is particularly useful for large classes, in which student involvement is almost impossible to get by conventional means.

- Offer leading questions as focal points for brainstorming sessions. The questions can be designed to improve understanding of the course material, such as “Which steps are unclear in this derivation?” “What have I assumed that I didn’t specifically tell you?” “What more would you need to know to really understand how this device functions?” They can also be used to stimulate thought and discussion about applications and extensions of the material. “How could you measure this quantity?” “What possible applications might there be of the result we just proved?” “Think of as many things as you can that could possibly go wrong here and what might be done to correct them (or prevent them).”

- Be on the lookout for solutions, correct and incorrect, that show clear signs of creativity, and take care not to discourage the imaginative impulses that gave rise to them. Reward innovation. Reward ideas drawn from fields other than that of the course in progress.

- When innovative solutions, correct and incorrect, are forthcoming, make them and your positive response to them public so others in the class get the idea.

- Provide case histories of problem solutions, especially creative ones. Show how incomprehensible the process seems when only the final solution is presented; then show the steps, including false starts and blind alleys, that led to that result. In Torrance’s phrase, “Dispel the sense of awe of masterpieces.” [17]

IDENTIFYING THE CREATIVELY GIFTED

The sad fact is that teachers generally do not prefer the more creative students. Furthermore, they do not have much confidence in the future success of the more creative students.

J.P. Guilford

The creatively gifted seem to resist being classified, which is exactly what one would expect of people who think in unique ways. A number of instruments have been devised that are supposed to measure creative potential but no general agreement exists regarding their validity or reliability. However, studies suggest that certain traits are characteristic of creative individuals, including independence, inexhaustible curiosity, tolerance of ambiguity in problem definitions, willingness to take risks, persistence in pursuit of problem solutions, and the patience to allow the solutions to take shape in their own time.

The problem is that these characteristics are difficult for course instructors to spot, since they don’t show up in normal classroom activities. Other characteristics of some creative individuals are more easily recognizable but are unfortunately apt to be viewed in a negative light. Reid [2] speaks of creative students whose course performance is highly erratic—very good grades in some courses, very poor ones in others. Other studies of creative individuals also refer to the possible presence of such personality traits as self-confidence bordering on arrogance, introversion bordering on misanthropy, and indifference bordering on hostility directed at anything that diverts the individual from his or her immediate areas of interest.

The oddball makes us uncomfortable. The student in the next-to-last row, chin in hand, looking bored or apparently sleeping, who suddenly pipes up in the middle of a phrase with the killer question that zeroes in on the flaw in our logic—our unstated assumptions, the exception we never thought of—is not someone we welcome in our classes with gladness in our hearts. Those of us without high degrees of self-confidence don’t particularly want to see him coming, and if there is a way to put him down or shut him up we are tempted to grab it. Failing that, we go to the delay game: “Good question, but we really don’t have time for it now. I’ll get back to you later.” That is often the last anyone hears of it unless our nemesis is pushy enough to come back with it.

Obnoxious behavior may in fact be the negative sign we take it to be. However, it could also be an indicator of the type of thinking ability needed to solve problems that defy conventional solution. There are times when we are in unique positions to encourage or stifle creative individuals in our program, such as when we advise students, assign grades in courses or projects, and evaluate applications for graduate school. On such occasions we might look twice at the individuals who display the traits we have been discussing, hunt for evidence of a creative spark in the erratic or socially unacceptable behavior with which they often confront the world, and attempt to convince them that they have something unique and critically
important to contribute.

It is unfortunate, but true, that many creatively gifted students have never been told they are gifted; they only know that they are different and that their differences are socially unacceptable. It may take nothing more than recognition from a single professor to set them on the path to the productive use of their gifts for the rest of their careers and lives.

REFERENCES


tion, provided the hydraulic conductivity of the frozen zone is factored into the model. Another paper details a numerical study using various models to predict the movement of the freezing line in soil around a buried cold gas pipe. These results are compared to a pilot experiment for one type of soil. It is noted that more work will be necessary to verify the models that have been developed. Another interesting paper provides new experimental information on the influence of various transport mechanisms on the total energy flux that is transmitted through a frost layer.

The plenary paper reviewing heat transfer in low-temperature insulation is a good summary of the recent advances in this field. This paper briefly describes the fundamental aspects of heat transfer in low-temperature insulations, examines the anomalous heat transfer effects at cryogenic temperatures and discusses several insulation types which represent state-of-the-art in this field. A good bibliography supports the review presentation.

Another good study is the one reported on heat transfer in polyurethane foams. In this study the authors experimentally determine the heat flux contributions for each heat transfer mechanism. This permits modeling of the insulation system and optimizing the foam parameters. A paper that complements this last study considers the structural parameters of polyurethane foams and how these affect the thermal conductivity. Taken together, these two papers provide a better understanding of the steps that need to be taken to minimize the thermal conductivity of this widely used insulation material.

Even with a number of excellent papers, the book is over-priced and will only find its way into selected library holdings. Therefore, only a very few readers will have an opportunity to benefit from the dozen or more good papers that were presented at this international meeting.

In Memoriam...


W. Robert Marshall died on January 14, 1988. At the time of his death he was Director of the University-Industry Research program. He was born in Calgary, Alberta, on May 19, 1916. He earned his BS degree in chemical engineering in 1938 from Illinois Institute of Technology, and his PhD from the University of Wisconsin in 1941. In 1947 he joined the faculty at the University of Wisconsin, and he served the University in many capacities until his untimely death in January.

Bob became Associate Dean of the College of Engineering in 1953, and was Dean from 1971 to 1981. His interest in new and innovative research and educational programs was critical to many programs that are strong on the campus today. He chaired the committee that led to the establishment of the Department of Nuclear Engineering and the development of the undergraduate curriculum in NE. He was also instrumental in the development of the Solar Energy Laboratory and the Materials Science Program.

Bob was always an enthusiastic supporter of the American Institute of Chemical Engineers. He presented his first paper there in 1939, while a graduate student of Olaf Hougen. He served as a Director for years, was vice president in 1962, president in 1963, and treasurer from 1976 to 1980. He was particularly influential in establishing the Institute's continuing educational program to make it possible for members of the profession to keep up with new developments in their field.

Bob's accomplishments were recognized in many ways. He was a member of the National Academy of Engineering. He received an honorary doctorate from Illinois Institute of Technology. He was a fellow of the American Academy of Arts and Sciences, and a fellow of the American Institute of Chemical Engineers. He received the Verein Deutscher Ingenieure Gold Medal in 1974. He was an invited speaker at numerous conferences and meetings.

Bob was devoted to bringing the best possible opportunity to the individual. He had great pride in colleagues and students. He was able to convey to staff, students, and colleagues his enthusiasm for their skills and their potential. He gave them opportunities to present their ideas and hopes in a supportive setting. He never assumed any credit for their contributions. His deep concern was for each individual to have the opportunity to realize their hopes and dreams.

Bob is survived by his wife, Dorothy, by three children, and by six grandchildren. He left his colleagues, friends, and family a remarkable legacy of high principles, challenges, and accomplishments on both professional and human levels.
Last fall, the American Institute of Chemical Engineers (AIChE) introduced ChAPTER One (tm) a "full service" magazine geared to the special needs and interests of undergraduate chemical engineering students. Published twice a year, in the fall and spring, ChAPTER One includes technical stories highlighting new directions and opportunities in chemical engineering, as well as regular features on career planning, campus activities, and profiles of outstanding students and young professionals.

The magazine also presents guest editorials, lists of professional contests, scholarships and grants, and reviews of relevant books. "Primary Elements," a people-in-the-news section, spotlights students and faculty who are involved in important and interesting activities, while "Base Notes" offers brief write-ups on noteworthy campus projects.

Future issues of ChAPTER One will present findings of the National Research Council's Committee on Chemical Engineering Frontiers: Research Needs and Opportunities, report on the Student Pugwash Organization, which explores the relationship between science and society, and give tips on preparing resumes and managing stress.

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INSTRUCTION IN SCALEUP

ROBERT L. KABEL
The Pennsylvania State University
University Park, PA 16802

SCALEUP IS THE ultimate synthesis and design experience. The idea from the lab bench must be carried all the way through design, construction, startup, and successful operation of a commercial facility.

There are two kinds of design: design for economic evaluation and design for construction. All design courses taught in chemical engineering curricula are of the first type. Such a design must give a reasonable estimate of the commercial viability of the process under consideration but many details are left unresolved.

On the other hand, if a plant is to be built it must work. This implies that a design for construction must be more rigorous and must be fully supported by a comprehensive experimental base. The development of this experimental base (from the chemist's 3-necked flask, through the pilot plant, to the commercial unit) is traditionally called "scaleup." Modern scaleup, however, attempts to achieve the most efficient blend of theory and experiment. Although scaleup may be the quintessential chemical engineering activity, it has been learned only in the "school of hard knocks."

The need for formal instruction in scaleup was demonstrated several years ago when the Center for Professional Advancement asked Attilio Bisio to organize a course on "Scaleup in the Chemical Process Industries." Bisio invited the author of this paper and other experienced engineers to be lecturers in the course. That short course, for practitioners, was the genesis of a book, Scaleup of Chemical Processes, published in June 1985 [1]. The first scaleup course known to have occurred in an academic setting was offered to Penn State seniors in 1985-6.

The AIChE and ABET are responsible in the modern scaleup... attempts to achieve the most efficient blend of theory and experiment. Although scaleup may be the quintessential chemical engineering activity, it has been learned only in the "school of hard knocks."

Robert L. Kabel received his BS degree from the University of Illinois in 1955 and his PhD from the University of Washington in 1961. From 1961-1963 he served in the U.S. Air Force Space Systems Division, receiving the Commendation Medal for Meritorious Achievement, and since 1963 he has been at The Pennsylvania State University. His primary research areas are catalytic kinetics, reactor dynamics, adsorption, and scaleup. He has received numerous awards for outstanding teaching.

U.S.A. for accreditation of undergraduate programs in chemical and all engineering, respectively. Both AIChE and ABET have recognized weaknesses in the creative and interdisciplinary components of engineering education. Accordingly they have placed an increased emphasis on synthesis and design. Moreover, support is building for the introduction of applied chemistry, emerging technologies, environmental considerations, safety, reliability, aesthetics, ethics, and social impact into our curricula. Wei [2] urged increased attention in the curriculum to "macroscale" topics such as 1) process and product design, 2) safety, health, and the environment, 3) economics, and 4) productivity and world competition. Although such matters can be addressed in isolated courses, scaleup is the natural context for them. It also provides a new perspective for economic considerations.

Scaleup involves the judicious use of all engineering tools in effective synergism. Thus the scaleup course is a capstone course in the same sense as the traditional design course or as the product design course proposed by Wei. There is no overlap, however, as the scaleup course can build upon and/or complement design courses. As this is a new instructional venture, substantial experimentation on how to teach the sense and skills of scaleup is required. Being de-
veloped at this time are a textbook and the whole complement of teaching aids (course outlines, reading materials, examples, exercises, experiments, projects, solution manuals, etc.). Ideas on teaching scaleup follow.

METHODS

Almost by definition, what is taught in the universities is that which is known. In contrast, scaleup implies the reconciliation of the unknown in pursuing a commercial goal. The goals of scaleup instruction are to generate an awareness of scaleup issues, to offer solutions to scaleup problems when possible, and to suggest approaches for resolving issues for which solutions are unavailable.

Eight different instructional modes, appropriate to this task, are listed below, with six categories under the project mode.

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Experimentation, computer simulation, and interaction with practicing engineers are crucial to the injection of realism in such instruction. Coordinating oral reports and laboratory demonstrations with visits by practitioners has proved particularly effective, giving a rich experience for both students and visitors. Companies represented are Chevron, Dow, Envirotrend, Exxon, Kraft, Mixing Equipment Co., Mobil, Monsanto, National Bureau of Standards, Procter & Gamble, Quaker Oats, Quality Chemicals, Shell, Squibb, and Union Carbide. Making the written reports due a week after oral presentation enables the students to exploit their new insights.

Pedagogically, a creative laboratory must be a part of any meaningful scaleup course. The coordinated laboratory incorporates experimental work directly into a capstone course, achieving an integration not found elsewhere in the curriculum. Some material is most effectively presented by lecture and/or recitation. Quizzes and essays are used to promote and evaluate student understanding of the reading material. Student project activities are conducted individually and in teams of two to six members. Computer-Assisted Instruction (CAI) is well suited to open-ended simulation of the practice and outcome of decision-making aspects of scaleup.

TOPICS

In defining the topics of interest in scaleup, it is convenient first to identify several well-understood areas in engineering design (pressure drop, pumps, compressors, heat exchangers, cooling towers, homogeneous reactors, and distillation columns). These are areas in which calculations alone, or in conjunction with very small scale experiments, often suffice in designs for construction. Of course it is not difficult to think of exceptions.

Two areas, multiphase processing and solids handling, absolutely guarantee the need for scaleup studies. Also most design activities require considerable physical, thermodynamic, and transport data. Only when a similar plant exists are sufficient data likely to be available.

Many more specific areas receive considerable attention during scaleup. Thermal complications arise because nonisothermal, and often adiabatic, operation is common at the commercial scale. Fixed bed reactors and gas absorbers are good examples. Mixing is often an important consideration in alleviating thermal effects. It also comes into play in blending, generation of interfacial area, and allowance for nonideal states of flow.

Emerging technologies, such as semiconductor processing, are inherently accompanied by lack of experience and hence result in severe scaleup problems. New separation methods arising from biotechnology, e.g., HPLC and affinity chromatography, are very difficult to scale up.
Most processes derive much of their appeal from special chemical characteristics. Unfortunately, special chemistry also leads to trouble, as in the cases of toxicity, impurity buildup, and corrosion. One simply cannot think of carbon monoxide, chlorine, and phosgene as A, B, and C. Such chemical factors have a major impact on the selection among equipment and processing options.

Safety comes into play in environmental considerations, fire and explosion hazards, and toxic substances. Mathematical modeling has proved to be quite powerful in assessing circumstances which are not readily subject to experiment. Used judiciously, modeling can render unnecessary some experimentation, thereby advancing the date of plant operation and the generation of profits.

Specific

In the spring semester of 1986, twenty-five of the twenty-nine students engaged in one individual and two team projects. Four students did all their project work in teams. A complete listing of the project titles is given in the Appendix. Footnotes indicate integration among projects. A few highlights are noted here.

Examples were drawn from the “Ten Greatest Achievements of Chemical Engineers,” published by the AIChE on the occasion of its diamond anniversary. These are cases of scaleup at its most triumphant.

Chemical engineering being the diverse and pervasive discipline that it is today means that a scaleup must consider problems of international significance, e.g., the constraints of natural resources, safety, and the environment. To illustrate an ethical dilemma, should an American company, operating in an overseas location where environmental regulations are less rigorous, follow the local laws or its practice in the U.S.A.? Ethical issues arise naturally in the consideration of scaleup. There is the fear that the exploitation of recombinant DNA technology could lead to global ecological disaster. On a more personal scale, if a probe identifies a genetic defect in an individual, should the individual be informed?

An unusual manifestation of scaleup principles occurs in biomedical engineering. One project team explored the use of data on dogs to predict the uptake of ozone in the lungs of humans. Many similar physiological scaleup opportunities exist.

Biochemical synthesis also provides interesting technical and economic features. The desired product is produced by precursor cells, so the higher the precursor cell concentration the higher the production rate. Biosyntheses are almost always done batchwise to preclude ill effects of contamination. Nevertheless the autocatalytic nature of the synthesis reaction suggests substantial economic benefit to continuous production using stirred tank reactors. Separation remains the most critical issue in biosynthesis scaleup, but a change in reaction mode could have a positive impact on separation options and efficiency.

Economic considerations are at least as important as technical issues in planning a scaleup program. A Computer-Assisted Instruction (CAI) module has been prepared to simulate the planning process and the impact of the plan on the startup of the plant. The specific process is the separation, primarily by low temperature distillation, of steam-cracked naphtha into hydrogen and light hydrocarbon streams (see Figure 1). The simulation is based upon a CACHE process design case study by Linoff, Grossmann, and Blau [3].

Once you begin to look, you discover scaleup examples everywhere. One recent find involves a vapor phase process using diethyl zinc for the preservation of books at the Library of Congress [4].

EXAMPLES

Equipment

In contrast to the usual predetermination of apparatus and experiments in familiar transport and unit operations laboratory courses, the scaleup laboratory equipment is more an assemblage of components for the performance of experiments appropriate to particular scaleup purposes. Certain items have been found to be particularly useful.

Transparent plastic pipe and containers, column packing, and flow distributors comprise the primary vessels and internals in which the processes to be explored occur. Metering pumps, flow meters and controllers, two- and three-way valves, pressure relief...
Valves, and digital thermometers allow for measurements and control of flow and temperature to, in, and from the vessel of interest. Polymers, acidic and basic aqueous solutions, and gases such as air, oxygen, nitrogen, and carbon dioxide are convenient media for such mock-ups. Spectrophotometers (IR, Visual, UV), pH meters, and continuous sensing transducers for \( \text{CO}_2 \) and \( \text{O}_2 \) enable chemical analyses of the media in use.

In addition to the creative use of the generic components described above, it is mandatory to develop experiments in areas such as multiphase systems, solids handling, and the flow and mixing of polymers or slurries. Finally, a plant model kit enables students to build a model of their scaled up “plant,” learning as they do so about process complexity, maintenance, and safety. Such tangible models are important even as we move toward computer-aided design.

**Trickle Bed Experiment**

An earlier pair of students had studied the major issues in scaling up a trickle bed reactor and had identified the liquid-phase residence-time distribution as a significant problem area. A new team (Ted Rauth and Carrie Mehalic) was then assigned to explore this issue experimentally. They assembled a column 10 cm in diameter and 20 cm high, packed with 2.54 cm Berl saddles. The rates of downward flowing water and upward flowing air were varied.

Step-function dye-tracer experiments were performed for flow visualization. Impulse-function HCl-tracer experiments, with liquid-outlet samples analyzed by a pH meter, were used for quantification. The blue dye was observed to collect and remain at the packing junctions. No effect of gas flow rate was detected on liquid linear velocity or on axial dispersion in the liquid.

Rauth and Mehalic calculated the first and second moments of the experimental exit age distribution. From these the mean residence time and axial dispersion coefficients were determined as functions of the liquid flow rate. One comparison which could be made was to data presented by Shah [5]. The results from his Figure 8-4 are combined with the new data on Figure 2. The lack of agreement left the two students discouraged and apologetic.

Jim Oldshue was with us the day they reported their results and said that they did well to get on the same graph. Actually their data were quite reasonable. The data reported by Shah were for 0.635, 0.953, and 1.9 cm Raschig rings compared to the 2.54 cm Berl saddles used by the students. Further, no error bands are given around the lines on Shah's graph. From the Raschig ring data, the Peclet number tends to be lower for larger rings at a given Reynolds number. The data for the larger Berl saddles are below the lines on the graph. Also the slope of the new data is consistent with those of the earlier data.

![FIGURE 2. Axial dispersions in trickle beds.](image)

This project provided a powerful message to the whole class on uncertainly in scaleup.

All multiphase reactor experiments were extended in the spring semester 1987 to include the determination of mass and heat transfer coefficients. This was a real eye-opener for the students who, based on their course experience, took such coefficients as given. In the process they came to understand the importance of coherent mass and energy balances over the apparatus.

**Thermal Effects in Geometric Scaleup**

Patti McAuley and Bruce Wonder performed a modeling study of thermal effects in the batch liquid-phase nitration of toluene. The assignment specified geometric scaleup with reactor height and diameter equal at each scale and with a production scaleup ratio of 100 between bench, pilot and commercial scales. The actual cases chosen had reactor volumes of about 0.2, 20, and 2000 litres, respectively, at the three scales. The exothermic batch reaction was initiated at 35°C. In nonisothermal cases the reactor was cooled by 25°C water entering a jacket at a flow rate proportional to the volume of the reactor. The model com-
prised mass and energy balance equations, a reaction rate correlation from Walas [6], and coefficients and property data from handbooks.

Figure 3 shows a small portion of the computed results. A horizontal line at 35°C would characterize isothermal operation. Isothermal and adiabatic performance are unaffected by change of scale. Thermal effects are seen to change significantly with scale for nonisothermal operation. As the scale increases the exothermic effect becomes more pronounced because the volume (∼L³)-dependent heat generation gains advantage over the heat removal which depends on the surface area (∼L²). McAuley and Wonder also considered the impact of scale on conversion and extended their results to other practical reacting systems and reactor configurations.

This example demonstrates the fallacy of geometric scaleup, which is familiar to experienced chemical engineers but is rarely contemplated by students. The principle comes up repeatedly in many different manifestations.

Safety

It has been pointed out that the scaleup course is a natural place for instruction in safety. In the fall of 1985, we contemplated the recent toxic gas leaks in Bhopal, India, and Institute, West Virginia. Another project involved modeling of factors related to the Texas City NH₄NO₃ explosion of 1947. The appendix shows considerable attention to safety during the spring of 1986. During the laboratory portion of the course, one student (Bruce Wonder) was assigned to serve as “safety engineer” to monitor the experimental work and to report to the class on his observations. He noted the following areas for increased attention.

- The use of safety glasses.
- Physical support of equipment.
- Pressure effects on equipment.
- Organization of the work area.
- The effects of correcting a symptom instead of the source of the problem.

CONCLUSIONS

Instruction in scaleup was initiated in the 1985-86 academic year with students taking the scaleup course instead of the traditional capstone design course. In 1987 students studied scaleup in addition to design. There has been a lot to learn about how to teach this subject. It now seems certain that effective instruction in scaleup is possible.

Benefits from this program should be propagative. The immediate beneficiaries will be the recipients of the instruction, who will then deliver their new skills to large and small industrial employers in familiar and emerging technologies. Sooner than in the past, perhaps, some of them will start their own companies. Special mention should be made of the potential of scaleup courses for students from underdeveloped countries. Training in developing small plants that work safely and well will be of much greater value than experience in designing and costing large, integrated chemical plants and refineries. Such industrial benefits translate directly into public benefits through increasingly effective, more timely, and lower priced products. A broad, but less tangible, public benefit is to be derived from formal training in ethics and safety for practicing engineers.

How to introduce emerging technologies, safety, ethics, economics, applied chemistry, and synthesis into the chemical engineering curriculum has been a vexing problem in the United States and abroad. Departments often encounter difficulty finding faculty willing and able to teach the classic capstone design course. Scaleup offers an alternative capstone course, which integrates the above elements with the central components of the curriculum. Indeed, there is a scaleup issue within every professor’s specialty, making possible broader and richer participation of all faculty in the integrative aspects of their students’ experience.
ACKNOWLEDGEMENTS

Major funding for this work was provided by the Exxon Education Foundation. Additional funding was received from Mobil, Procter & Gamble and the National Science Foundation. The Penn State College of Engineering contributed significantly to the establishment of the scaleup laboratory. Penn State’s Office of Microcomputer Applications has supported the development of the Computer-Assisted Instruction module.

The author wishes to express his great appreciation to industrial and academic colleagues for their encouragement of and contributions to this course development effort. Finally, the students deserve much credit for the creative and enthusiastic acceptance of their roles as experiment subjects.

REFERENCES


APPENDIX

Actual Projects (Spring 1986)

Individual

Introduction to Scaleup
The Manhattan Project: The Ultimate Scaleup
The Manufacture of Polystyrene
Scaleup in Polypropylene Manufacture
Penicillin: A Glorious Story
Scaleup in Underdeveloped Countries
Scaleup Failures

Emerging Technologies
Colloids: A New Look at a “Familiar” Topic
Semiconductors: An Emerging Technology
Scaleup in the Semiconductor Industry
Interferon: History and Scaleup
Human Insulin from Recombinant DNA Technology
Materials Processing in Space
Planning for Emerging Technology

Trouble
Combating Impurities

Corrosion
How Plastics Are Being Developed and Used to Fight Corrosion
Hazardous Wastes
Hazardous Waste Disposal
Material Safety Data Sheets: Origins, Development, Effects
Preproduction Requirements of T.S.C.A.
Carcinogenic Hazards in Direct Coal Liquification
Risk Analysis
Fault Tree Analysis in the Scaleup of Chemical Systems
Safety in the Laboratory

Ethics
The Debate over Recombinant DNA
We also discussed:
Professional Integrity
Whistle Blowing
The Challenger Disaster and Evolving Implications

Team Projects—I

Reactor Options for Biosynthesis Reactions
Thermal Effects
Liquid Phase CSTR
Liquid Phase Batch Reactor
Exothermic Tubular Reactor
Gas Phase Endothermic PFR

Multiphase Reactors—Modeling and Scaleup
Bubble Columns
Slurry Systems
Spouted Beds
Chemical Vapor Deposition
Trickle Beds

Reactor Type Selection
Ethylene Dichloride Production
Fischer-Tropsch Synthesis
Polypropylene Manufacture

Team Projects—II

Biomedical Scaleup
Prediction of Ozone Uptake in Human Lungs from Data on Dogs
Advanced Chemical Reaction Engineering
Tubular Reactor Hot Spot Simulator
Rigorous Analysis of Multiphase Semibatch Reactor

Experimental—Mockups and Mixing
Bubble Column
Slurry Reactor
Spouted Bed
Chemical Vapor Deposition
Trickle Bed
Polymer Flow and Mixing

Comprehensive Design, Planning, and Economic Analysis
Batch vs. CSTR for Biosynthesis
Cryogenic Separation of Light Hydrocarbons

TEAM PROJECTS

1. Projects with the same footnote are closely linked.
2. This project was a scaleup follow-on of earlier work by students in the traditional design course and is also related to the CAI developments of 1987. □
CHEMICAL ENGINEERING AND INSTRUCTIONAL COMPUTING*

Are They in Step?
PART 1

WARREN D. SEIDER
University of Pennsylvania
Philadelphia, PA 19104

During the past five years, a large fraction of our chemical engineering graduates have found jobs in industries that utilize the principles of the transport processes, thermodynamics, and chemical kinetics, but whose primary operations are peripheral to the mainstream curriculum in chemical engineering and to the focus of the traditional chemical industries. These operations include biochemical and biomedical processing, advanced materials processing, solid-state electronics, and risk and hazard management. As a consequence, there have been calls for an enrichment of the chemical engineering curriculum with subject matter relevant to these fields by inclusion of applications in the common core courses and the development of new, specialized, elective courses. See, for example, the Proceedings of the Conference on “Chemical Engineering in a Changing Environment” [1] and the Amundson report [2].

Concurrently, computers comparable in power to the mainframe processors of the mid-1960s (e.g., the IBM 7090) have become inexpensive and highly interactive, and are now an integral part of our homes, offices, and laboratories. The rapid growth of this vast market has stimulated the development of high-quality, general-purpose software to permit data-base management, spreadsheet analysis, display of 2- and 3-dimensional colored graphics, numerical analysis, symbolic manipulation, and word processing. More specifically, in the chemical engineering curriculum, these systems, together with specialized packages for the synthesis and analysis of process flowsheets and control structures, the estimation of costs, etc., have become widely used. Software for illustration of the concepts of transport processes, thermodynamics, and chemical kinetics, as well as those that emphasize biochemical and materials processing, has been slower to develop. In an effort to understand this situation, perhaps it is appropriate to trace the evolution and status of software for instructional purposes and to raise the question: “Chemical Engineering and Instructional Computing—Are They in Step?”

Initial efforts to use digital computation in chemical engineering coursework were unquestionably oriented toward the design course, followed closely by the process dynamics and controls course. With the advent of personal computers in the early 1980s, many more faculty became computer users and, al-

*This manuscript is based on a plenary lecture presented at the ASEE Summer School for Chemical Engineering Faculty in August, 1987.
EDITORIAL NOTE:

The following detachable pages describe some industrial employment opportunities for graduating chemical engineers. Please post the information in a conspicuous place for the benefit of your students, or distribute the pages to students who may be interested. These companies have expressed a definite interest in hiring chemical engineers in the areas described, and we strongly encourage students seeking employment to respond as indicated.

Ray Fahien
Editor
Chemical Engineering Education
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**Employee Relations Department**

1007 Market St., N-13451

Wilmington, DE 19898

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**PhD**

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ENTRY LEVEL OPPORTUNITIES FOR CHEMICAL ENGINEERS

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ADDITIONAL INFORMATION

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BFGoodrich
Department of Human Resources
Moore and Walker Roads
PO Box 134
Avon Lake, OH 44012

ENTRY LEVEL OPPORTUNITIES FOR CHEMICAL ENGINEERS

BS/MS

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PhD

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<td>Polymer materials, polymerization, processing</td>
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● ENTRY LEVEL OPPORTUNITIES FOR CHEMICAL ENGINEERS ●

BS/MS

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● ADDITIONAL INFORMATION ●

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BS/MS

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● ENTRY LEVEL OPPORTUNITIES FOR CHEMICAL ENGINEERS ●

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though there is some evidence of computer-oriented problems in courses other than design and control (i.e., in courses on transport processes, thermodynamics, chemical kinetics, etc.), the level of utilization lags far behind that in the design and control courses.

This article is being published in two parts. Part 1 focuses on the design and control courses, whereas Part 2 (to be published in the next issue of CEE) concentrates on courses other than design and control.

**DESIGN COURSE**

One of the most significant developments in the field of process design has been the rapid evolution (in less than three decades) and widespread utilization of computing systems for the evaluation of alternative flow sheets. In the 1960s, many systems such as PACER [3] and CHESS [4] were introduced to perform material and energy balances and estimate equipment sizes and costs. Then, in 1973, the CACHE Corporation began facilitating the use of Monsanto's FLOWTRAN system over a communications network by many chemical engineering departments [5]. These first and second generation systems contained a library of subroutines to simulate the more conventional processing units, such as flash vessels, distillation towers, absorbers and strippers, liquid-liquid extractors, heat exchangers, compressors and turbines. For the most part, phase equilibrium was assumed in the separations, overall heat transfer coefficients were specified for the heat exchangers, and isentropic efficiencies characterized the compressors and turbines. Simple reactor models permitted the specification of the fractional conversions of key species or the extents of key reactions. All of the models were evaluated in the steady-state and the systems placed emphasis on the convergence of the recycle and control loops that typically arise through design specifications.

To permit generality in the modeling of streams with arbitrary mixtures of chemicals over broad ranges of temperature and pressure, physical property data banks were developed. In FLOWTRAN, the INF program implemented one of the first information systems to store and retrieve the physical constants for large numbers of chemical species in public and private files on random access disks. These systems permitted the engineer to select the data records and methods for estimating thermophysical properties such as the vapor pressure, density, enthalpy, and entropy of chemical mixtures. These facilities for selecting from amongst many subroutines and data were, in many respects, the precursors of today's expert systems.

By 1985, with the advent of individual minicomputers for departments and engineering schools, FLOWTRAN had been installed in about 100 departments of chemical engineering. Concurrently, other commercial packages were widely installed, primarily PROCESS (Simulation Sciences) [6], DESIGN II (ChemShare) [7], and ASPEN PLUS (Aspen Tech) [8]. These are large systems, which are executed in batch mode and which require computing power greatly in excess of that provided by personal computers such as the IBM PC.

Each of these systems introduced special features, only a few of which can be mentioned here. ASPEN PLUS was the first to simulate solids-handling equipment, including cyclone separators, flash dryers, and crushers, with several models that account for heat and mass transfer between phases. Its reactor models implement nth-order kinetic expressions for CSTR and PFTR configurations. DESIGN II utilizes a stand-alone package, CHEMTRAN, for the estimation of thermophysical properties. Its data base contains the physical constants \( T_c, P_c, T_{NBP} \ldots \) for nearly 1000 chemicals. Probably the most important characteristic as far as use by undergraduates in their design projects is concerned, is the ability of this package to estimate the physical constants for organic molecules using group- and bond-contribution methods. At the University of Pennsylvania, with a separate design project for each group of three seniors, unusual chemicals are often encountered. It is difficult to locate physical property constants for some of these chemicals, and CHEMTRAN enables the students to begin their design calculations while they continue their search for data. In addition to the physical constants for some of these chemicals, CHEMTRAN estimates activity coefficients using the UNIFAC group-contribution method. Hence, it can estimate the properties of nonideal mixtures of organic molecules even when no physical property data are available.

In the past five years, these systems have been augmented to permit the optimization of process flow sheets subject to equality and inequality constraints specified by the engineer. For example, Biegler [5] added the successive quadratic programming algorithm, QPSOL, to FLOWTRAN. His interface,
SCOPT, and the QPSOL algorithm are distributed by the CACHE Corporation.

Also, during this period, with the availability of PCs, COADE prepared a microcomputer version of CHESS called MICROCHESS and recently upgraded it to CHEMCAD [9], a highly interactive package which displays process flowsheets as illustrated in Figure 1. A similar package is HYSIM [10] by Hyprotech, Ltd. These packages are finding widespread usage in the chemical engineering curriculum. Two other packages that run on an IBM PC with an IBM 370 board are ChemShare's DESIGN II and ASPEN/SP-PC [11], but these are not being used by any academic departments, to my knowledge.

**FIGURE 1. CHEMCAD [9] flowsheet for design of a gas plant.**

It is noteworthy that stand-alone, microcomputer packages are becoming useful for the undergraduate design courses. One, in particular, is the CHEMCOST [12] program by COADE. CHEMCOST provides up-to-date estimates for the capital cost of the individual process units in a chemical plant.

Software systems for the synthesis of process flowsheets have been less successful than those for analysis, with the exception of software for the synthesis of networks of heat exchangers. Union Carbide's ADVENT system [30] provides excellent color graphics displays of the process flow sheets and the heat integration diagrams that result from the implementation of Linhoff's Temperature Interval Method [13]. Although the ADVENT System is not available to universities, the Linhoff March Co. recently began distributing, through the CACHE Corporation, a less complete system, TARGET II [31], that runs on the IBM PC. TARGET II determines the minimum requirements for hot and cold utilities, but does not match the hot and cold streams to synthesize a network of heat exchangers. A more complete system, called HENS [14], has been prepared for the AT&T 6300 microcomputer. HENS enables the student to position heat exchangers on a heat integration diagram interactively. To my knowledge, however, it is not being widely used. Other packages, with automated facilities to design the networks of heat exchangers, but not implemented on microcomputers with highly-interactive graphics, are HEXITRAN (Simulation Sciences) [15], RESHEX [16], and MAGNETS [17].

**PROCESS CONTROL**

In process control, mainframe packages have never achieved the popularity of the comprehensive packages developed for the analysis of the flow sheet in process design. One such package, ACS [18], developed to run on the IBM 4341, performs the dynamic simulation of processes with alternate control structures (e.g., PID, lag/lead, ratio, cascade, ...). It has been used in the control courses of approximately fifteen chemical engineering departments.

In the area of digital control, more emphasis has been placed on real-time interaction, initially with minicomputers and more recently with microcomputers. Many control laboratories have been created using microcomputers, as exemplified at Washington University [19].

Traditionally, procedures for the design of process control systems have involved the analysis of linearized systems in the Laplace and frequency domains. With the recent generation of microcomputers, system designers have added highly interactive graphical interfaces that display Bodé and Nyquist plots, Root-Locus diagrams, responses in the time domain, etc. One such package, CC (Systems Technology Corp.) [20], runs on the IBM PC and is used at many universities. It includes facilities to convert between the state-space and the Laplace and Z-domains, and to implement optimal control algorithms. A more complete package, CONSYD [21], is available for VAX computers, but provides a lesser quality of graphical interaction. Yet, another package, PROCOSP [22], provides better interactive graphs on the IBM PC with a mouse. PROCOSP focuses on the design of PID controllers that satisfy the engineer's specifications for the overshoot ratio and settling time.

Of course, many chemical processes are highly nonlinear. Hence, software systems that permit both the steady-state and dynamic simulation of alternate control structures can be very helpful. For the analysis of process flowsheets, probably the SPEED-UP system [23] has received the most publicity in recent years. This package has been used successfully in industry and is expected to be distributed by the CACHE Corp. to the universities in the near future. SPEED-UP has not been installed on PCs and, consequently, can be expected to have limited facilities for graphical interaction.
A more specialized package is UC ONLINE [24] for the simulation of distillation towers with alternate multiloop PID feedback control schemes. UC ONLINE runs on the IBM PC with interactive graphics. For example, the distillation tower and control structure displayed in Figure 2a were simulated after a step-change in $x_{sp}$, with the response plotted in Figure 2b. UC ONLINE has been distributed to several university departments.

Before long, it can be expected that packages for the bifurcation analysis of nonlinear systems, both steady-state and dynamic, will be used routinely for studying their performance and stability [25]. Programs for bifurcation analysis, such as AUTO [26], should become widely used.

EXPERT SYSTEMS

The current flurry of activity to develop logic-based systems has been confined principally to the design and control areas. One such expert system was created by Shinskey [27] to design multiloop control systems for distillation towers. It was written in BASICA to be run on an IBM PC. Given specifications for a tower, controlled and manipulated variables, Shinskey's system calculates relative gains and selects the control structure by threading through decision trees with approximately 1000 rules, before drawing the PID. Other expert systems are being developed to detect faults in chemical plants [28] and to estimate thermophysical properties by selecting an appropriate combination of estimation methods [29].

It is especially noteworthy that, as of this writing, there is no evidence of the use of expert systems in chemical engineering coursework. A Task Force of the CACHE Corporation is working to prepare monographs that show how to apply the principles of artificial intelligence in building expert systems.

PARTIAL SUMMARY

Having traced the evolution of instructional computing in the design and control courses, it seems reasonable to conclude that the computing tools for undergraduate instruction are, for the most part, in step with design and control practice in chemical engineering. In some cases, the computing systems used by undergraduate students are less elaborate than those available to industrial practitioners. In other cases, the tools are those that have evolved in university research and are more advanced than those used in industry.

The successes in the design and control areas have, for less well-understood reasons, not been paralleled in the courses that focus on the transport processes, thermodynamics, and chemical kinetics. This has led the Curriculum Task Force of the CACHE Corporation to seek answers to two questions:

- Can microcomputers stimulate the use of “open-ended,” design-oriented problems in these courses?
- Can high-resolution displays permit students to better learn the principles through visualization of streamlines in fluid flows, visualization of PVT surfaces, etc.?

These questions, together with one other:

- Can computers enable undergraduate students to analyze and possibly design less conventional processes
involve, for example, crystallization of chips, deposition of thin films, natural convection in solar cells, etc.? will be addressed in Part 2 of this paper, to be published in the fall 1988 issue of CEE.

REFERENCES

This handbook meets the dictionary definition of a handbook, though the print is a little small for long-time, continuous reading. The handbook also meets rather well requirements 1 and 2 of the personal definition. Equipment and operating costs are generally not covered, so presumably were outside the definition or scope of the work.

Of the thirty-six authors, twenty-two are from academia and fourteen are from industry or research institutes—a reasonable balance. Of the twenty-two chapters, four are devoted to “general principles,” and eighteen discuss specific separation processes and their applications.

If I were facing the problem of selecting a separation process to be used for an unfamiliar industrial application, I would go through the following steps:

1. Select a process.
2. Collect necessary properties and data for design.
3. Size the separation equipment and estimate costs.

In Chapters 4 and 22 there is some discussion of the applicability of given processes to various types of separations. In some discussions of the individual processes there is indication of the range of applicability of the process. Unfortunately, in several there is no indication of the type of separation for which the process should be considered. Is the process equally applicable to mixtures of gases and liquids, and liquids and solids? Will the process work equally well with feed concentrations of 0.1% and 90%? Are the process elements subject to contamination by trace components, including “dirt”? These and similar questions sometimes are not addressed. The uninformed engineer needs this type of information.

All the treatments deal quite well with the sizing of equipment. Efficiency of operation is addressed in most cases. The requisite component properties and other data required for design are indicated, if not explicitly, by example.

There is a natural tendency of the authors to dwell at length on things known and particularly on those that can be satisfactorily dealt with from currently known and accepted theory. There is much less discussion and presentation of information that is not known. In the treatment of Phase Segregation (separations not involving equilibrium considerations or phase changes) there is an excellent and extensive discussion of separation of particles of a given size, in a number of different environments. There is, however, no discussion of the most perplexing and difficult problem: how to determine the size distribution in the stream which must be segregated into two or more distinct phases. This subject cannot be easily presented in a simple equation, but there is certainly some satisfaction for the inexperienced reader in learning that he is not the only person unable to make this size distribution determination.

In the discussion on distillation there is no treatment of a common approach to the determination of the products that can be achieved—using a batch or continuous laboratory column, performing the distillation of the feed mixture, varying operating conditions until the desired products are achieved. The problem then becomes how to perform the same separation in full-scale equipment. This, also, is not easily quantified, but it is a technique that is used rather often, and therefore it is worth mentioning.

Presenting a detailed critique of twenty-two different subjects in any field is all but impossible for a single individual, and separation processes is no exception. The areas with which this reviewer is most familiar are treated suitably in scope and in depth.

The book represents a valuable compilation of information and material. In all probability, it will prove more valuable to the student or recent graduate than to the experienced engineer, though the theory of some of the newer separation processes is well covered. The handbook represents a compilation of a number of significant pieces of effort by experts in the given processes in collecting and presenting information of value. For that reason alone it represents a valuable contribution to the literature on separation.

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**ChE books received**


*Dynamics of Proteins and Nucleic Acids,* by J.A. McCammon and S.C. Harvey. Cambridge University Press, 32 East 57th St., New York, NY 10022 (1987); 234 pages, $39.50

*Handbook of Multiphase Systems,* by Gad Hetsroni. Hemisphere Publishing Corp., 1025 Vermont Ave. NW, Washington, DC 20005 (1982); $64.50

*Corrosion Mechanisms,* edited by Florian Mansfeld. Marcel Dekker Inc., 270 Madison Ave., New York, NY 10016 (1987); 472 pages, $89.75
THE OPERATIONS AND PROCESS LABORATORY
A Unique Summer Course at Wisconsin

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THE "OPERATIONS AND PROCESS LABORATORY" has a long tradition at the University of Wisconsin. Since its inception in the 1916-17 academic year, the course has accommodated the evolution of chemical engineering by retaining some of the basic operations and philosophy while at the same time allowing students to explore the newer technologies. In those early years when chemical engineering was consolidating at Wisconsin, the course was named "Chemical Manufacture," and its contents, according to the University Catalog, were described as follows [1]:

Laboratory practice supplementary to chemical machinery courses, tests of chemical machinery, manufacture and recovery of products, special problems.

Today it is a five credit course, and the College of Engineering Bulletin (1986) describes it as follows:

Experiments in unit operations, and supervised individual assignments selected from areas such as: fluid dynamics, analogic methods, reaction kinetics, plastics technology, and use of computers in data processing and simulation.

The course is offered in the summer and is taught in five-week sessions, with two sessions usually being offered. The course meets for a full eight hours each day, five days a week. The enrollment in each session is typically 35-45 students.

The Chemical Engineering Curriculum shows the course as being taken at the end of the junior year; however, approximately one-half of the students postpone it until the end of the fourth year of coursework. The prerequisites for the course are Transport Phenomena, Transport Phenomena Laboratory, Chemical Engineering Thermodynamics, and Fluid Flow and Heat Transfer Operations. While not formal prerequisites, Mass Transfer Operations and Chemical Kinetics and Reactor Design have been taken by a majority of the students when they enroll in the summer course.

THE COURSE PROGRAM

In the early years of the course the pattern of laboratory work was, to some extent, based on the interests and ability of the student. Typical projects consisted, for example, of setting up a distillation column or saponifying tallow to produce soap. After a library search, most of the work was left to the stu-

Glenn Sather received his PhD in chemical engineering from the University of Minnesota in 1959. He has been a member of the department of chemical engineering at the University of Wisconsin since 1959, and is presently Associate Chairman for Undergraduate Studies and Director of the Summer Sessions. He held a NSF Science Faculty Fellowship at Imperial College of Science and Technology, London (1966-67) and was a Dupont Year-in-Industry Professor (1973-74). His teaching interests in addition to the Operations and Process Laboratory are in material and energy balances and in thermodynamics.

José Coca received his PhD in 1968 from the University of Salamanca in Spain. He spent two years (1968-70) as a post-doctoral fellow at the University of Wisconsin. As a visiting professor he has taught the Operations and Process Laboratory on several occasions. He joined the department of chemical engineering at the University of Oviedo in 1972 and is currently the chairman of the department. His research interests are in the area of separations processes: Liquid-liquid extraction, chromatographic separations and chromatographic reactors.
dent’s ingenuity, and as a consequence, even the most talented students rarely were able to complete more than three experiments in the course.

After being discontinued during World War II, the laboratory was reinstated in 1948. At that time, Professor Olaf A. Hougen became chairman and several new experiments in process operations were set up. Some of these experimental units are still in operation today, though most of them have been remodeled or replaced with more modern counterparts.

At the present time the operation of several large units constitutes the core of the formal experiments and offers the students (in groups of six or eight) the opportunity to verify the principles in the areas of fluid flow (test of a centrifugal pump), heat transmission (heat transfer from condensing steam to oil), and mass transfer (distillation, extraction, and air-water contact). Schematic diagrams and photographs of these units, together with a brief description of the main purpose of each experiment, are shown in Figures 1-5. (See next page.)

The experiments are introduced by a lecture which consists of a review of the principles underlying the experiment and specific instructions on the operation of the equipment. Information on the formal experiments is also supplied in handouts which provide detailed descriptions of the experiments, mode of operation, etc.

In addition to the formal experiments, which every student is required to perform, a second series of informal experiments (usually four in number) is assigned by the instructors. These experiments are conducted by two-member groups and usually require a literature survey and a considerable experimental effort in constructing simple but reliable apparatus. The type of experiment depends on the instructor’s interests and occasionally are related to present or future research projects. When possible, student interests are also considered in assigning these experiments. A few examples of informal experiments which have been used are the following:

- Sedimentation of particles in the presence of coagulants or floculants. Scale-up of a settling tank.
- Flow characteristics of a CaCO₃-water slurry.
- Hydrodynamic characteristics of a spouted-bed and an airlift reactor.
- Evaporative cooling of water droplets.
- Mass transfer with single drops and coalescence of drops.
- Dissolution rate of limestone into an acid solution.
- Residence time distribution in a stirred tank and in a packed bed.
- Hydrolysis of methyl acetate catalyzed by an ion exchange resin.
- Hydrolysis of amyl acetate in a batch reactor.

Another aspect of this course is that it serves as a good preparation for the profession. [It] is a comprehensive learning experience, and at the end of the course the students are expected to have acquired a fair amount of expertise with a variety of equipment.

- Oxidation of sulphites with oxygen in a batch reactor. Catalytic effect of metal ions.
- Analysis of the dynamic behavior of a water heating system.
- Plant/model correlation for a first order system by pulse testing.

Tutorial work is particularly intensive in this course because of the nature of the experiments and the time which instructors spend with small groups of students. Students keep in contact with the instructors through meetings in the laboratory or in a summer sessions office. All students are required to submit individual reports on the formal and informal experiments, usually within one week of the completion of the experiment. Report writing is an important part of the course, and requirements are rather stringent in this regard. A report which does not meet the standards may be returned to the student for rewriting. Students are occasionally asked to present an oral summary of their report to the class.

At the end of the course the students take a final examination based on each of the formal experiments. It includes questions which cover the fundamental chemical engineering principles that are involved in each of the formal experiments, equipment operation, and some specific calculations. The final examination accounts for ten to twenty percent of the course grade.

THE COURSE GOALS

The general purpose of the course is contained in the college bulletin description; however, some specific aspects deserve special mention. In order to understand the goals of the Operations and Process Laboratory, it has to be considered in the context of the other chemical engineering laboratory courses taken by undergraduate students at the University of Wisconsin. Two additional laboratories are required of all students: Transport phenomena laboratory and process control laboratory.

The Transport Phenomena laboratory is offered before the Operations and Process laboratory, while most of the students take the Process Control laboratory later. Both of the laboratories have a four-hour laboratory session each week for one semester. The
FIGURE 1. Centrifugal Pump. (a) Performance of the impact tube and the venturi meters, (b) computation of shaft power and hydraulic power, (c) total head developed by the pump, and (d) relationship between pump speed and its capacity.

FIGURE 2. Heat Exchanger. (a) Determination of heat transfer coefficients for the oil side, steam side and overall, (b) estimation of the liquid side heat transfer coefficient using the Dittus-Boelter, Sieder-Tate and Colburn correlations, and (c) statistical analysis of data.

FIGURE 3. Liquid-liquid extraction in a rotating disc contactor using the system, kerosene-propionic acid-water. (a) Number of transfer units as a function of flow rates, rotor speed and height of the phase boundary, and (b) factorial design analysis to determine the important variables and their interaction in the process.

FIGURE 4. Distillation of ethanol-water mixture. (a) Performance of a 28 valve-tray, 8 inch O.D. column at total and finite reflux conditions, (b) tray efficiencies and overall column efficiency, (c) heat transfer coefficients for the reboiler and condensers, and (d) material and energy balance calculations.

FIGURE 5. Air-water contacting in a spray tower. (a) Humidification, water cooling and dehumidification operations, and (b) effect of air and water rates on heat and mass transfer coefficients.
proportion of student-faculty contact hours in laboratory compared to lecture courses is shown in the sector diagram of Figure 6.

The Operations and Process laboratory is a good complement to the chemical engineering education of the UW students because of several special features:

- It gives the students the opportunity to operate pilot-plant scale equipment.
- There is a challenge to work on modern chemical engineering problems of interdisciplinary nature through the assignment of informal experiments.
- Although the main emphasis of the course is on unit operations, the informal experiments give the students an opportunity to deal with chemical reactors and some less-traditional chemical engineering problems.
- It gives the students a chance to work as a team, and to obtain by this type of cooperative activity, a sense of chemical engineering practice.

Another aspect of this course is that it serves as a good preparation for the profession. Some schools in Europe and in the United States have industrial practice as a substitute for laboratory courses. In spite of the importance of industrial experience, it has its disadvantages. It is usually limited to one piece of equipment, within a certain process, and obviously the operating variables cannot be altered at the student’s will. The laboratory course at Wisconsin is a comprehensive learning experience, and at the end of the course the students are expected to have acquired a fair amount of expertise with a variety of equipment.

Despite budget limitations improvements are being made in the course. A new eight-inch valve-tray distillation column was recently installed and was fully utilized in the 1987 summer sessions. A shell-and-tube heat exchanger experiment is being constructed to replace the present double-pipe steam to oil heat transfer experiment, and a membrane separation experiment is in the planning stage. While improvements will continue to be made, it is expected that the general operation of the course will remain the same. The best proof that the laboratory achieves its goals is the positive feedback which the department receives from graduates who have been in industry for five to ten years.

PERFORMANCE AND REMEMBRANCE

Two awards are given to students at the end of the course. While their main purpose is to recognize ingenuity and performance, they also honor two faculty members who were particularly active in the course: Professors O. L. Kowalke and R. A. Grieger-Block.

The Kowalke-Harr Award is given to the pair of students who show the most outstanding performance as a team. Professor O. L. Kowalke was chairman of the department from 1914 to 1940, during which period he helped develop and improve the summer laboratory. Mr. R. E. Harr, an alumnus and benefactor of the department, took this course as a student.

The Grieger-Block Award is given to the pair of students who exhibit the most creativity and resourcefulness in conducting experiments. Professor R. A. Grieger-Block was a faculty member from 1970 until his untimely death in 1980. He was known for his innovative approach to experimentation in the laboratory.

It has been a practice to take a group picture of the students and staff in each session. The department has pictures of all classes since 1948.

THE COURSE FACULTY

Six staff members are usually involved in each of the sessions. The staff consists mainly of professors with one or two graduate students. Numerous visiting professors and lecturers have taught the course. In addition to the United States, these visitors have come from Denmark, F.R. Germany, India, Israel, Nigeria, Norway, Latin America and Spain. One or two UW professors are involved in each of the sessions to assure consistency.

The international participation has been challenging in many respects. It provides opportunities to compare chemical engineering curricula, to discuss research projects, and to expose students to other languages and cultures.

REFERENCES

CHEMICAL ENGINEERING EDUCATION IN JAPAN AND THE UNITED STATES

A Perspective*

PART 1

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RECENTLY, CONCERN AND interest in the United States about Japanese technological and managerial “excellence” has been very high, as evidenced by numerous books and articles [1]. It is plausible that Japan’s success in commercial technological development is intimately related to the Japanese educational system [2]. Hence, it is of interest to compare the university training of scientific personnel in each country, to see how strengths are nurtured. As one who has experienced an undergraduate education in Japan (Tokyo Institute of Technology, 1976-1980) and a graduate education in the United States (University of Wisconsin, 1980-1986) in chemical engineering, I will attempt to distill my personal experiences and observations into such a comparison. In addition to curriculum content at the institutions I attended [3] I will focus on some of the broader societal and cultural factors determining the educational environment. Finally, I will discuss some advantages and disadvantages that each educational system appears to possess and attempt to infer where opportunity for learning from each might exist.

THE ENTRANCE EXAMS

No discussion of undergraduate education in Japan would be complete without mention of the entrance examination system. In Japan both the private schools as well as the prestigious national universities have their own entrance exams, and, in addition, there is currently a standard screening exam for all of the national universities. In Japan, it is widely recognized that career opportunities in most major companies are largely determined by the university to which the person gains admittance. For this reason, the competition to pass the entrance exams for prestigious universities such as Tokyo University, Kyoto University, Tokyo Institute of Technology or Waseda (the last a private school) is intense, with applicant ratios as high as five to one. Competition also begins early, as students endeavor to gain admittance to high schools which have good records of producing entrants to the prestigious universities. Many students essentially sacrifice their high school leisure time, attending preparatory schools (Juku) at which supplementary homework is given after their regular school day and on weekends. The level of the entrance exams varies widely, but for a prestigious university may be considered to be at roughly the college sophomore level in the U.S. in areas such as mathematics, physics, chemistry, and written language. While many of the

*The views expressed herein are the author's and not those of Exxon Corporation.

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exam problems are extremely complex, there is a tendency on the part of the students to study problem types by rote, using commercially available booklets of previously given exam problems. Students who fail their exams for a prestigious university on their first attempt often spend an additional year in preparatory school as *ronin* (wandering samurai) to get another chance to take the exams. This activity is generally supported monetarily by their parents.

**UNDERGRADUATE EDUCATION**

The highly competitive entrance exam system guarantees that the prestigious universities get the cream of the high school crop, at least in terms of motivation and stamina. In addition, the almost uniformly high quality of precollege education in Japan (the product of a highly standardized curriculum) means that the entering class possesses a significant head start in scientific knowledge over matriculating U.S. students. For this reason, no classes are offered in algebra or trigonometry, for example, in major Japanese universities (calculus is taken in high school). Nor is there a need for courses to develop written skills in the students’ own language. However, from the foregoing description of the gruelling exam procedure, which looms over the students’ entire high school experience, it is not surprising that undergraduate college is regarded in Japan as a time for rest and play by society as a whole [2]. This leads to a totally different attitude towards classes and coursework in the U.S. and Japan, which partially nullifies the starting advantage held by Japanese students. In contrast to U.S. practice, Japanese students generally receive very little homework, and what there is tends to be composed of rote problems, often similar to textbook examples. There is extensive plagiarism of homework solutions by perhaps one third of the class, so that differentiating grades on the basis of homework is almost meaningless. Class cutting is common, especially in the non-major courses, as is lack of attention (talking, etc.) to a degree that would be considered intolerable by American professors. While exams are more formal, students are rarely failed in courses. Indeed, for mediocre exams, points are sometimes added on for the purpose of allowing students to make the grade (the colloquial expression for this is *geta-kakase*—“putting on the clogs”). While in the U.S. this situation would be considered to reflect on the credibility of the institution, this is not the case in the Japanese cultural context, which does not place a high premium on individual achievement. It is important to remember that in Japan, seniority generally counts at least as much as performance in career advancement, and decision-making is collective rather than on the initiative of individuals. Since the basic “weeding out” process is the entrance examination, a person’s performance in college is less important than the college attended in Japan. Furthermore, because Japanese companies expect that their employees will remain with them for the duration of their lives, they provide extensive formal and informal training for employees newly hired from college. The formal training stresses company unity rather than technical aspects, which are picked up later through mentor-pupil relationships similar to those which occur in graduate school. For example, in some companies, new employees are grouped in rural locations for programs of daily calisthenics and sports, as well as seminars and indoctrination. Typically, technical graduates then go through an apprenticeship period of several months, during which they are rotated through such diverse assignments as shift work or retail sales. By contrast, most U.S. firms emphasize “on-the-job training,” with the assumption that sufficient mastery of basic skills in the relevant technical field has been attained. Despite this, in the United States, geographical, educational, and political factors necessitate that even good universities (especially state schools) accept large numbers of relatively poor students, who are eventually weeded out. In this process, students are deluged with homework, lab reports, and exams, and grading is generally rigorous, with high standards and at least some analytical thinking ability expected. Thus, the situation in the U.S. is just the reverse of that in Japan—a mediocre performance at a good school is not especially helpful for employment.

Another likely important factor in the difference in motivation between Japanese and U.S. undergraduates is the degree to which each group is self-supporting. Unlike the U.S., where it is the norm for
university students to live away from home, in Japan, whether a student lives at home or not is generally determined by how far he must commute to attend school. Many students commute from as far as two hours distance, spending a significant fraction of that time standing in packed trains. Even when Japanese students do not live at home, it is common for their parents to pay all educational expenses, plus a fairly liberal allowance. Japanese university students often work as private tutors, earning as much as twenty dollars an hour (the pay frequently determined by the prestige of the student’s university!). This money would normally be regarded as pocket-money, rather than as a contribution to educational expenses. These customs are, of course, linked to the still prevalent tradition of living with and supporting one’s parents after the father’s retirement. When this is contrasted to the situation of a typical American student, who works for long hours at a university co-op or fast-food restaurant to support his or her basic needs, one can easily see why the degree of seriousness towards undergraduate coursework is quite different.

While the American student likewise regards undergraduate college as a time for play, it is also recognized as a time for personal and career development. Certainly, in both countries, the best students are highly motivated and conscientious. The contrast is that in Japan the top students study mostly on their own initiative. American students... are force-fed material and expected to become competent in it or fail, dependent on their innate ability.

...in both countries the best students are highly motivated. ... The contrast is that in Japan the top students study mostly on their own initiative. American students... are force-fed material and expected to become competent in it or fail, dependent on their innate ability.

It is interesting to examine undergraduate curricula for chemical engineers in Japan and the U.S. In Japan, as in the U.S., the undergraduate degree (Bachelor of Engineering) requires four years of study. At Tokyo Institute of Technology, the school operates on a two-term system, the first term from April to September (with a two-month summer vacation) and the second from October to March (with a winter break). At Tokyo, the freshman year consists of basic courses in the natural sciences (including lab courses), social sciences, humanities, and languages. It is worth stressing that Japanese students in all engineering fields are required to take language courses, even though they arrive at the university with six years of English study completed. At Tokyo Institute of Technology, there is a de facto requirement for four English courses, as well as three courses in another language (German, French, or Russian). In addition, the first year includes an overview of areas in the major field presented by different faculty members. At Wisconsin, as at other institutions, the first year mix is much narrower, consisting of natural science “catch-up” courses (calculus, general chemistry, and freshman English) with only three elective credits available.

In the sophomore year, the student at each institution begins to take a significant number of courses in the major area. Table 1 contrasts the required courses in the major field for the Bachelor of Science Degree in Chemical Engineering at the University of Wisconsin with the Bachelor of Engineering Degree at Tokyo Institute of Technology, as of 1987 [3]. It is evident from this list that there is considerable overlap in the...
“core” courses which constitute the degree. Indeed, the differences between the curricula of the departments are probably due more to departmental culture than national emphasis, e.g., the requiring of transport phenomena-related courses at Wisconsin. However, the overall flavor and certainly the content of the courses at Wisconsin is more mathematical and analytical, whereas the accent at Tokyo tends towards the chemical and empirical. The U.S. curriculum relies heavily upon the chemistry department for chemistry instruction, which is not the case at Tokyo. In fact, it is usual for Japanese departments to provide almost all their own instruction, with ties between departments (even those as closely related as chemistry and chemical engineering) being almost non-existent. Although the same number of lab courses appears in the table, Tokyo Institute of Technology has a de facto requirement for additional freshman labs in chemistry and physics. Furthermore, the Japanese lab courses involve at least ten hours per week of actual lab work (three days per week). Thus, the Japanese student’s exposure to lab work, prior to the senior year, is already higher than that of the average U.S. undergraduate (Wisconsin requires more lab work than many U.S. schools). One should also note the presence of courses intended to familiarize the student with the scientific literature. This type of instruction, coupled with the extensive training in foreign languages, ensures that the Japanese graduate can make full use of the U.S. technical literature, whereas the converse is certainly not true. Although Wisconsin is a rarity in offering a course in technical Japanese [5], there is no foreign language requirement for graduation, and many U.S. Bachelors graduate without taking a single language course. In addition to the courses listed in the table, the graduate at Tokyo must take several other departmental courses in areas of interest as a graduation requirement. These include titles such as Catalyst Chemistry, Separations Science, Environmental Chemical Engineering and Theory of Instrumental Analysis. Typically these courses are overviews, requiring even less assigned work than the “core” courses. At Tokyo Institute of Technology, course requirements are basically completed by the end of the junior year, which is feasible due to the relatively low workloads (the usual course load is eight to ten per semester). While the number of courses required for graduation is around sixty-five at Tokyo (approximately half in the major field), compared to about forty at Wisconsin, the Japanese engineering undergraduate enjoys a surprising amount of freedom in shaping his or her education. By contrast, American students are very constrained in their ability to broaden their background by the pressures of the required courses in and outside of the department, which constitute around 75% of the credits required for graduation. Examination of the curricula for the University of Minnesota and the University of California at Berkeley revealed similar trends.
THE SENIOR YEAR

Although the first three years of the Japanese undergraduate experience are relatively undemanding by U.S. standards, this changes completely in the senior year, which is devoted almost entirely to the student’s undergraduate Thesis Project. At the beginning of this year, the student joins one of the department’s research laboratories and begins to work full time as a junior researcher, receiving training and guidance from the senior members of the lab. Usually, there is a mentor-pupil relationship with a specific graduate student or research associate, and the undergraduate is expected to do data-gathering and follow-up work under this person’s supervision, rather than work on something completely original. Nevertheless, after a year of work, most students produce a fairly good quality thesis, and the student gives a defense to the assembled faculty. The most important consequence of this training is that the student is directly exposed to research practice and the scientific method. This gives the average Bachelor’s graduate a healthy respect both for graduate school and for research as a career. Another significant benefit is that the student generally acquires hands-on experience with several analytical and experimental techniques as well as with building equipment. In addition, from a more Japanese viewpoint, the student becomes conditioned to a rigorous work schedule, similar to that in Japanese companies. Typical hours of work are 9:30 AM to 9:30 PM, the maximum feasible in view of the long commuting times (students in lodgings close by often work later). The whole lab also works on Saturdays, until at least late afternoon*. While the Chemical Engineering Department at UW offers elective credits for working on undergraduate research projects, there is no stated or unstated requirement to participate in research. Relatively few students choose to elect research credits, especially since the junior and senior years consist of very rigorous and time-consuming major courses. Interestingly, a recent article suggests that participation of undergraduates in research is encouraged more at certain liberal arts colleges, which produce a significant number of publications coauthored by undergraduates, than at the major research universities [6]. On the other hand, motivated U.S. students can and do acquire significant practical experience through summer jobs and co-op programs. This is rarely the case in Japan, where companies feel no incentive whatsoever to train short-term employees.

THE SOCIETAL VIEW

To digress for a moment, an important benefit of receiving an engineering or scientific training in Japan is its social status. The Japanese public sees engineering and technology as having conferred great economic benefits to society, and the cynical negativism towards technology that is common in the U.S. and Western Europe is almost nonexistent. While respect for teachers is a trait of Japanese society as a whole, professors in the sciences and engineering enjoy particular respect, perhaps symbolized by their frequent portrayal as heroes in children’s TV cartoons. Consistent with this, the relationship between professors, engineers, and social activists (e.g., environmentalists) is rather less adversarial and more easygoing in Japan. Despite close ties between industry and universities, professors are generally not viewed as partisan in environmental issues, but rather as mediators. The general respect for the scientific professions rubs off onto industrial professionals, graduate students, and even undergraduates of prestigious universities. Interestingly, this is true despite two major “technological” events that have left a profound impression on the psyche of both Japanese scientific personnel and the public at large: the dropping of the atomic bomb and the tragic Minamata pollution case. These events are generally blamed on military personnel and greedy businessmen, respectively, with scientific and technical personnel escaping relatively unscathed. In fact, in the university, it is recognized that environmental problems are the responsibility of engineers to solve, rather than problems to be avoided or covered up. Thus, while there is little formal training in environmental or safety issues, such issues (e.g., Minamata) are frequently and openly mentioned by professors in Japan. This is in sharp contrast to the U.S., where engineering is generally not perceived ideologically, even by its practitioners. Classes in the U.S. are usu-

*Needless to say, these statements are based on my own experience in Prof. Nobuo Ishikawa’s fine laboratory. However, my interactions with graduates from other universities suggest that my experience was typical for undergraduates in technical fields.
ally devoid of commentary on sociotechnical issues, being wholly composed of the technical nitty-gritty. It is ironic that U.S. companies are forced by regulatory agencies and the public to be very attentive to such issues.

One area in which Japanese technical education is sorely lacking is the presence of women. At Tokyo Institute of Technology in 1976, for example, out of approximately 120 matriculating students in applied chemistry fields there were no women; in some years since then there have been two or three. This is not due to formal restrictions, which are unnecessary, since at the present time women do not enjoy career opportunities in technical or managerial roles comparable with males in Japanese firms. Naturally, this and other social pressures (e.g., prejudice against married women working outside the home) strongly discourage women from pursuing technical careers. The highly ingrained cultural factors barring the participation of women in the professional work force in Japan are not likely to diminish rapidly, despite recent legislation directing equal pay for equal work for men and women by the Japanese government. The same is true for the members of Japan's small minority groups (people of Korean descent, Ainu and inhabitants of former “outcast” villages), i.e., while there are no formal restrictions on their participation in university education, their career opportunities are severely limited.

The United States is far ahead of Japan in bringing women into the scientific and technical mainstream. Thus, women have increased their share of doctorates in science and engineering fields from under 10% in 1970 to more than 25% in 1985 [7]. Although women continue to be underrepresented in engineering, earning 6% of the doctoral degrees, the percentage of women bachelors graduates in engineering is higher (around 30% at Wisconsin in 1986), so that continued improvement in women's representation in the profession may be anticipated. On the other hand, the situation for minorities in the U.S. has improved less rapidly, and must be viewed as a fundamental fairness issue [8]. Recent statistics show, for example, that blacks constitute only 2.6% of graduating scientists and engineers at the bachelors level, and only 1.1% of PhD's [7]. Unfortunately, the highly politicized debate on the status of American education in 1986 gave relatively little attention to the issue of minority participation. Although to rectify the current situation much needs to be done by society as a whole, universities should not waver in their efforts to draw and retain more women and minority students into science and engineering programs [8]. If one takes into account the fact that the U.S. actually graduates fewer engineers per capita than either Japan, our major trading competitor, or the Soviet Union, our main ideological competitor [9], it is clear that enhanced participation by these groups is not only requisite, but also that it need not cause “reverse discrimination” issues.

EDITOR'S NOTE: This comparison of U.S. and Japanese chemical engineering education will continue in the next issue of Chemical Engineering Education with Dr. Floyd's discussion of graduate education in both countries.

ACKNOWLEDGEMENTS

The author is deeply indebted to Prof. Yoshiharu Doi of Tokyo Institute of Technology and Ms. Brenda Phyles of American Association for the Advancement of Science for providing some of the materials referenced, and to Prof. R. B. Bird of the University of Wisconsin for motivation and guidance in writing this article. In addition to them, many valuable comments were provided by Tetsuya Morioka of Tomen Sekiyu Kagaku, K. K. and J. J. O'Malley, D. J. Lohse, and N. P. Cheremisinoff of Exxon Chemical.

REFERENCES

1. A particularly controversial example was the book Japan As Number One, by Prof. E. F. Vogel. A concise summary of Prof. Vogel's views can be found in Foreign Affairs, 64 (4), 752 (Spring 1986). Also see Theory Z, by Prof. William Ouchi (Addison-Wesley, 1981), Kaisha: The Japanese Corporation, by J. Abegglen and G. Stalk, Jr. (Basic Books, 1985).
3. Tokyo Institute of Technology, Undergraduate and Graduate Studies Bulletins, 1987; University of Wisconsin, College of Engineering Bulletin, Graduate School (Natural Sciences and Engineering) Bulletin, 1987. In addition to these materials, Bulletins from the University of Minnesota and University of California at Berkeley were examined to see how representative Wisconsin is of U.S. practice.
4. 1986 Enrollment Survey in Chemical Engineering Progress, 83 (6), 90 (June, 1987).
CALCULATION OF PRE-EXPOSENTIAL TERM IN KINETIC RATE EXPRESSION

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Kanpur-208 016, India

The rate of a chemical reaction is commonly expressed as

$$ R = k(T)f(c) $$

(1)

where $k(T)$ is the rate constant and $f(c)$ represents the effect of the concentration of all the relevant chemical species on the reaction rate. The effect of temperature on the rate constant is given by

$$ k(t) = AT^m \exp\left[-\frac{E}{R_g T}\right] $$

(2)

where

- $m = \frac{1}{2}$ from the kinetic theory of gases
- $m = 1$ from statistical mechanics
- $m = 0$ from the Arrhenius relation

In the case of vapor phase reactions, it is customary and convenient to use partial pressures rather than the concentrations. For ideal gases, the molar concentration of an $i^{th}$ species is related to its partial pressure by

$$ C_i = \frac{p_i}{R_g T} $$

(3)

Substituting Eqs. (2) and (3) in Eq. (1)

$$ R = A(T) \exp\left[-\frac{E}{R_g T}\right] f(p) $$

(4)

where the pre-exponent is now a function of temperature. However, it is generally assumed that the effect of temperature in $A(T)$ is dwarfed by that in the exponential term, and hence the reaction rate can simply be expressed as

$$ R = A' \exp\left[-\frac{E'}{R_g T}\right] f(p) $$

(5)

where the pre-exponent $A'$, just like $A$ in Eq. (2), is treated to be constant. It was in fact shown by Smith [1] that, for a simple first order reaction, the use of Eq. (5) instead of Eq. (4) would lead to insignificant error.

However, the validity of the above assumption depends on the values of the activation energy, the reaction order and the temperature range. The purpose of this article is to show that significant errors may result, under certain conditions, if Eq. (5) is used instead of Eq. (4) in the estimation of kinetic parameters from the experimental data to be used in the reactor design.

PROBLEM STATEMENT

Let us consider an $n^{th}$ order reaction such that

$$ f(C) = C_i^n $$

(6)

Substituting Eq. (6) in Eqs. (4) and (5), respectively,

$$ R = k(T)P_i^n; \quad k(T) = \frac{A}{R_g T} \exp\left[-\frac{E}{R_g T}\right] $$

(7)
and

$$R = k'(T) p_0^a$$

$$k'(T) = A' \exp \left[ - \frac{E'}{R_g T} \right]$$

(8)

By nondimensionalising the temperature with a reference temperature $T_0$, the rate constants in Eqs. (7) and (8) can be rewritten as

$$k(t) = k_0 t^{m-n} \exp \left[ - e \left( \frac{1}{t} - 1 \right) \right]$$

(9)

and

$$k'(t) = k'_0 \exp \left[ - e' \left( \frac{1}{t} - 1 \right) \right]$$

(10)

where

$$t = \frac{T}{T_0}; \quad e = \frac{E}{R_g T_0}; \quad e' = \frac{E'}{R_g T_0}$$

$$k_0 = \frac{A}{R_g} T_0^{m-n} \exp[-e]$$

and

$$k'_0 = A' \exp[-e']$$

Typically, using the experimental isothermal rate versus partial pressure data, the rate constants at different temperatures are calculated. In turn, these rate constant versus temperature data are used for the estimation of the activation energy and the pre-exponential constant. Obviously, the value of the activation energy (and so the pre-exponential constant) will be different depending on whether Eq. (9) or Eq. (10) is used. Also, one can expect the difference between the "real" and "apparent" activation energies, i.e. $(e - e')$, to increase with the reaction order. Moreover, this difference should be expected to vary with the temperature range. It can also be seen that the difference between $e$ and $e'$ will not depend on the value of $e$. These points will be illustrated next.

PARAMETRIC ESTIMATION

As an easier alternative to obtaining the best fitting values of $e$ and $e'$ for a given set of rate constant versus temperature data, we adopt the following procedure. First, specific values are assigned to $n$ (1 to 3) and $e$ (5 to 30). $k_0$ is conveniently taken to be unity and $m$ to be zero. Then, using Eq. (9), $k$ versus $t$ data are generated at several discrete points over a temperature range of $1.0 \leq t \leq 2.0$. Finally, using the expression in Eq. (10), the best fitting values of $k'_0$ and $e'$ for the above data are computed by standard numerical techniques.

DISCUSSION

As seen from the results summarized in Table 1, the difference between $e$ and $e'$ increases with the

<table>
<thead>
<tr>
<th>Reaction order, n</th>
<th>Activation energy (dimensionless)</th>
<th>% error in activation energy</th>
<th>Range of % error in rate constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.0 3.60</td>
<td>-28.0%</td>
<td>-2.2 to +4.2%</td>
</tr>
<tr>
<td></td>
<td>10.0 8.60</td>
<td>-14.0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20.0 18.60</td>
<td>-7.0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30.0 28.60</td>
<td>-4.7%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5.0 2.20</td>
<td>-56.0%</td>
<td>-4.4 to +8.6%</td>
</tr>
<tr>
<td></td>
<td>10.0 7.20</td>
<td>-28.0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20.0 17.20</td>
<td>-14.0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30.0 27.20</td>
<td>-9.3%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5.0 0.80</td>
<td>-84.0%</td>
<td>-6.5 to 13.1%</td>
</tr>
<tr>
<td></td>
<td>10.0 5.80</td>
<td>-42.0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20.0 13.80</td>
<td>-21.0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30.0 25.80</td>
<td>-14.0%</td>
<td></td>
</tr>
</tbody>
</table>

FIGURE 1. Real and apparent rate constants versus temperature.
value of \( n \); however, this difference remains unchanged with the variation of the \( e \) value. Consequently, the percentage error in the apparent activation energy is the highest for the highest reaction order and the lowest (real) activation energy. Another kind of error also appears as a result of forcing an approximate function \( k'(t) \) to represent the “real” \( k \) vs. \( t \) data. As shown in Figure 1, when \( k' \) is plotted against \( t \) (using, of course, the computed values of \( k_w \) and \( e' \)), this curve does not conform accurately with the real \( k \) vs. \( t \) curve. The deviation of \( k' \) from \( k \) increases, as shown in Table 1, with the reaction order. This deviation is also a function of the temperature range. For example, the deviation of \( k' \) from \( k \) will be within \( \pm 2\% \) for \( 1.0 \leq t \leq 1.25 \) as against \( \pm 13\% \) for \( 1.0 \leq t \leq 2.0 \) for a third order reaction.

If the value of \( m \) is taken to be unity instead of zero in Eq. (9), the errors will be reduced by one order. Also, the errors shown in Table 1 are likely to be somewhat smaller if instead the values of \( e \) and \( e' \) are computed using the actual experimental data, which are generally error-ridden.

Finally, let us see what happens when \( k'(t) \) instead of the real \( k(t) \) is used in the reactor design equations. As an illustration, two consecutive exothermic reactions are assumed to be taking place in an ideal nonadiabatic plug flow reactor. The design equations and specifications along with the results are shown in Table 2. It is seen that the use of Eq. (10) instead of Eq. (9) in the design equations leads to significant errors in the prediction of the reactor performance. It should, however, be noted that the conditions in the example are chosen so as to magnify the possible errors.

**REFERENCE**


**NOMENCLATURE**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>( A )</td>
<td>Pre-exponential factor of the rate constant</td>
</tr>
<tr>
<td>( a_1 )</td>
<td>reactor parameters in Eqs. (11)-(13)</td>
</tr>
<tr>
<td>( C )</td>
<td>molar concentration</td>
</tr>
<tr>
<td>( E )</td>
<td>activation energy</td>
</tr>
<tr>
<td>( e )</td>
<td>dimensionless activation energy</td>
</tr>
<tr>
<td>( f )</td>
<td>concentration (partial pressure) dependence function</td>
</tr>
<tr>
<td>( k )</td>
<td>reaction rate constant</td>
</tr>
<tr>
<td>( m )</td>
<td>a constant in Eq.(2)</td>
</tr>
<tr>
<td>( n, n_1, n_2 )</td>
<td>reaction order</td>
</tr>
<tr>
<td>( p )</td>
<td>partial pressure</td>
</tr>
<tr>
<td>( R )</td>
<td>reaction rate</td>
</tr>
<tr>
<td>( R_g )</td>
<td>gas constant</td>
</tr>
<tr>
<td>( T )</td>
<td>temperature</td>
</tr>
<tr>
<td>( t )</td>
<td>dimensionless temperature</td>
</tr>
<tr>
<td>( x )</td>
<td>fractional conversion of the reactant</td>
</tr>
<tr>
<td>( z )</td>
<td>dimensionless length coordinate</td>
</tr>
</tbody>
</table>

**Subscripts**

- \( i \) = \( i^{th} \) chemical species
- \( o \) = at the reference temperature
- \( w \) = at the reactor wall

<table>
<thead>
<tr>
<th>Superscripts</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( ' )</td>
<td>partial pressure based values</td>
</tr>
</tbody>
</table>

---

**TABLE 2**

Reactor Specifications and Performance

| Mass Balance: | \[
\frac{dx}{dz} = a_1 \exp\left[ -e_1 \left(1 - \frac{1}{t}\right) \right]\left(1 - \frac{x}{n_1}\right) + a_2 \exp\left[ -e_2 \left(1 - \frac{1}{t}\right) \right]\left(1 - \frac{x}{n_2}\right) \tag{11}
\]
| Heat Balance: | \[
\frac{dk}{dz} = a_3 \frac{dx}{dz} - a_4 \left(t - t_w\right) \tag{13}
\]

**Specifications:**

- \( n_1 = 3; \quad n_2 = 2; \quad e_1 = 10.0; \)
- \( e_2 = 20.0; \quad e_1' = 5.80; \quad e_2' = 17.20; \)
- \( a_1 = 0.0600; \quad a_2 = 0.0400; \quad a_3 = 1.1000; \)
- \( a_4 = 0.0500; \quad a_1' = 0.0689; \quad a_2' = 0.0434; \)
- \( t_w = 0.8; \quad \text{Inlet conditions: } x = 0, \quad t = 1.0 \)

**Results:**

<table>
<thead>
<tr>
<th>Using Eqs. (11) and (13)</th>
<th>Exit Conversion, x</th>
<th>Exit Temperature, t</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.6</td>
<td>1.289</td>
<td></td>
</tr>
<tr>
<td>Using Eqs. (12) and (13)</td>
<td>34.9</td>
<td>1.368</td>
</tr>
</tbody>
</table>
FLUIDISED BED COMBUSTION
Ed., M. Radovanovic
Hemisphere Publishing Corp., 79 Madison Ave.,
New York, NY 10016; 307 pages, $79.95 (1986)
Reviewed by
A. W. Nienow
University of Birmingham (England)

This book arises from a course (one of many) given at the International Centre for Heat and Mass Transfer, Dubrovnik, Yugoslavia. It was organized by the departments of mechanical and of chemical engineering at the Twente University of Technology (Holland). Each chapter is by a faculty member from Twente except for one by Professor H. Masson, University of Brussels, and one by F. Verhoeff, Stork Boilers.

The book is clearly the product of a course. For example, the introduction (Chapter 1) begins with a "welcome to the Summer Course and to Dubrovnik." It also gives details of the departments and the faculty. However, though a little strange, the chapter is short, and from then on the book clearly arises from a good course (as one might expect) from a premier Dutch technical university.

Chapter 2 deals with the mechanical details of fluidised bed combustors in some detail and also gives typical process parameters. Bed level control, fly ash recycle, start-up, and limestone addition are examples of the detailed considerations that are included. This is an excellent chapter.

Chapter 3, entitled "Solids Handling," covers hopper design in detail; feeds for bulk solid handling; covered coal storage and coal spreaders.

With Chapter 4 the book moves into fundamentals of chemical engineering aspects with fluidisation. This is done remarkably well within some forty pages. Next comes "Combustion in Fluidised Beds," starting with basic coal combustion chemistry and including single carbon particle combustion fundamentals. Chapter 6 is entitled "Fuel Circulation and Segregation in F.B.C." This chapter also deals with fluidisation fundamentals, with the addition of segregation. It is an interesting chapter but indicates the difficulty of relating the well-known problems that may arise when handling beds of dissimilar materials, inevitable in F.B.C., to the question of whether such problems will arise in practice. Chapter 6 is not as well referenced as the others.

Chapter 7 deals with heat transfer and is a little thin. Chapter 8 with limestone addition and flue gas sampling in great detail (thirty pages), and Chapter 9 is a small but interesting one on thermodynamic cycles. The book ends with a chapter by a manufacturer on the design of a large industrial F.B.C. which is a very useful finale.

The format is remarkably uniform, even though it as clearly produced from camera-ready sheets, and it is also very legible. In places, the English is a little quaint. Overall, it will make a valuable addition to the field, especially for practicing engineers and, of course, for other advanced courses.

MATRICES FOR ENGINEERS
by Allan D. Kraus
Hemisphere Publishing Corp., Washington, D.C.,
310 pages, $49.00 (1987)
Reviewed by
John F. Mahoney
University of Florida

For more than twenty years our department (industrial engineering) has taught a matrix methods course which is required of all of our undergraduates. We eschewed similar courses presented by the mathematics department on the grounds that we wished our students to have a working knowledge of matrix methods while not being burdened by too many proofs. We have considered and adopted many books. No book was without some perceived faults. One book would use obscure notation, another would dwell too extensively on the concept of vector spaces, and virtually all would devote too much emphasis to proofs. The matter of proofs is particularly disturbing. Many theorems are accepted as true since intuitively they seem to be correct. Yet upon carefully following the proofs offered by some books, gaps in logic occasionally emerge. Some books ask for proofs in the problems at the end of chapters which can only be worked easily if material presented in a later chapter is invoked.

Initially I was delighted to encounter the subject book since it appeared to address most of the objections raised to other texts. It is short enough to be covered in a three-semester credit course. The Table of Contents lists nine chapters: Preliminary Concepts; Determinants; Matrix Inversion, Partitioning of Matrices, Simultaneous Equations; Orthogonality and Coordinate Transformations; The Eigenvalue Problem, Matrix Polynomials and the Calculus of Matrices; and Examples. This is only slightly more extensive than our intended coverage. I was further encouraged Continued on page 160.
SIMULATION EXERCISES
FOR AN UNDERGRADUATE
DIGITAL PROCESS CONTROL COURSE

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Atlanta, GA 30332

In seeking to develop a set of homework exercises for a senior level course in digital process control, the authors have devised an alternative to the classical approach of short homework problems assigned at the end of each lecture segment. Instead, we have tried to provide longer-term exercises which complement the lecture material while allowing for more creativity and independence on the part of the student. The concept is to define a control problem, have the students analyze its dynamics, and then have them digitally simulate both the open-loop process and its closed-loop dynamics under various control schemes. Digital simulation has some advantages as a learning tool. It forces the students to understand the process in order to write the code to simulate it, and it requires an understanding of how each control scheme is actually implemented in quasi-real time. In addition, since digital simulation is, by its nature, digital, the concept of discrete control is emphasized.

These exercises were designed as the primary homework set for a two quarter-hour senior-level course in digital process control. The students have already taken a three quarter-hour course in classical control theory, and a one quarter-hour laboratory in system dynamics and analog and digital control. The exercises are meant to supplement lectures from Deshpande and Ash [1] or Stephanopoulos [2]. Extensive use is made of Program CC (a control design package for the personal computer available from Systems Technology, Inc., of Hawthorne, California [3]), but only as an analysis tool to aid in implementation via digital simulation. Simulations are run on a VAX 11/780 and may make use of numerical integration routines from the IMSL Library [4]. Students work in groups of two or three members of their own choosing. Although it is not explicitly stated in the problem statements below, students are expected to plot and discuss all results. Due to space limitations, only the Problem Statements are included here. Full solutions, documentation of the simulation program, and the Program CC results may be obtained from the authors.

We feel that these exercises give the students experience in implementation, allow them to compare various algorithms on a single process, and stimulate initiative and creativity.

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Problem Statement

Consider an example from Ray [5] consisting of a system of two continuous stirred tank reactors in series as shown in Figure 1. The irreversible reaction $A \rightarrow B$ is carried out isothermally in the two-stage reactor system. The composition of the product streams, $c_1$ and $c_2$, must be controlled. However, there is a substantial analysis delay. The manipulated variables are the feed compositions to the two reactors, $c_{1f}$ and $c_{2f}$, and the process disturbance is the concentration of an additional feed stream, $c_d$. The flowrates to the system are constant, and only the compositions vary. An additional delay arises due to the transportation lag in the recycle stream.

A. For the reactor system above, write the material balances for $c_1$ and $c_2$ around the reactor train. Note that

$$F_{p2} = F_1 + F_d - F_{p1} + F_2$$

B. Cast the equations from (A) in deviation variables. Use the definitions below. (Subscript $s$ denotes steady state value.)

$$\theta_1 = \frac{V_1}{F_1 + R + F_d} \quad \theta_2 = \frac{V_2}{F_{p2} + R}$$

$$\lambda_R = \frac{R}{F_1 + R + F_d} \quad \mu = \frac{F_{p2} - F_2 + R}{F_{p2} + R}$$

$$\lambda_d = \frac{F_d}{F_1 + R + F_d} \quad Da_1 = k_1 \theta \quad Da_2 = k_2 \theta_2$$

$$U_1 = c_{1f} - c_{1f_s} \quad U_2 = c_{2f} - c_{2f_s}$$

C. Show that the results of (B) can be expressed in matrix form as

$$\frac{dx}{dt} = A_0 x(t) + A_1 x(t-\alpha) + BU(t) + Ld$$

where

$$A_0 = \begin{bmatrix} -\frac{1 + Da_1}{\theta_1} & 0 \\ \frac{\mu}{\theta_2} - \frac{1 + Da_2}{\theta_2} & 0 \end{bmatrix} \quad A_1 = \begin{bmatrix} 0 & \lambda_R \\ 0 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{1 - \lambda_d - \lambda}{\theta_1} & 0 \\ 0 & \frac{1 - \mu}{\theta_2} \end{bmatrix} \quad L = \begin{bmatrix} \lambda_d \\ \theta_1 \\ 0 \end{bmatrix}$$

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \quad U = \begin{bmatrix} U_1 \\ U_2 \end{bmatrix}$$

D. Assume there are pure delays of $\tau_1$ and $\tau_2$ on the measurements of $x_1$ and $x_2$ respectively. Thus
\[ Y_m(t) = x_1(t - \tau_1) \quad Y_m(s) = e^{-\frac{s}{\tau_1}}x_1(s) \]

\[ Y_m(t) = x_2(t - \tau_2) \quad Y_m(s) = e^{-\frac{s}{\tau_2}}x_2(s) \]

or

\[ Y_m(s) = H(s)x(s) \]

\[ H = \begin{bmatrix} e^{-\frac{s}{\tau_1}} & 0 \\ 0 & e^{-\frac{s}{\tau_2}} \end{bmatrix} \quad Y_m = \begin{bmatrix} Y_m_1 \\ Y_m_2 \end{bmatrix} \]

E. Take the Laplace transform of the result from (B) to obtain

\[ Y_m(s) = H(s)G(s)U(s) + H(s)G_d(s)d(s) \]

i.e., find

\[ G(s) \text{ and } G_d(s) \]

F. Into the result of (E), insert the operating parameters given in (G). Let \( \lambda_R = 0 \).

G. This reactor system will form the basis for the following problems. If we wish to deal with an SISO system, we will set \( \lambda_R = 0 \) and focus on the first reactor. If we wish to deal with a MIMO system, we will set \( \lambda_R = 0.5 \) and deal with the coupled reactors. Base case parameters will be as follows:

\[ x_1(0) = x_2(0) = U_1(0) = U_2(0) = 0 \]

(System is initially at steady state.)

\[ \theta_1 = 1; \quad \theta_2 = 1 \]
\[ Da_1 = 1; \quad Da_2 = 1 \]
\[ \lambda_R = 0 \quad \text{or} \quad 0.5 \]
\[ \lambda_d = 0.1 \quad (\text{where appropriate}) \]
\[ \mu = 0.5; \quad \alpha = 0.5 \]
\[ T = 0.1 \text{ min} \quad \text{or} \quad 0.01 \text{ min} \]
\[ \tau_1 = \tau_2 = 0.5 \]

**PROBLEM 2**

*Open-Loop Simulation*

**Problem Statement**

A. Digitally simulate the system of two reactors in series as analyzed in Problem 1. Simulate the open-loop response of both reactors to a 0.1 step change in \( d \) at time = 1 minute. Do this for both values of \( \lambda_R \) (0 and 0.5). Use a sampling period of 0.1.

B. Use Program CC to produce the open-loop simulation above for no recycle. Use the s-domain transfer functions developed in Problem 1.

C. Use Program CC to produce the open-loop simulation above for no recycle. Do this simulation in the z-domain with sampling period = 0.1 min.

**PROBLEM 3**

*PID Control*

**Problem Statement**

A. Using the FORTRAN simulator developed in Problem 2, digitally simulate the closed-loop response of Reactor 1 to a 0.1 step change in the disturbance (\( d \)). Use the velocity form of the PID algorithm. Assume zero recycle. Do the simulation for sampling times (\( T \)) of 0.1 and 0.01. Use the Ziegler Nichols method to tune the controller, either by constructing a Bode plot (with Program CC), or by finding the ultimate gain and period on-line by the loop tuning method. Include in your program a calculation of the integral squared error associated with the above disturbance.

B. Use Program CC (in the z domain) to repeat the simulation in (A) for the case of \( T = 0.01 \) only.

**PROBLEM 4**

*Dahlin Algorithm*

**Problem Statement**

A. Design a Dahlin control algorithm for the system which has been studied in Problems 2 and 3. The design should be based on a first order plus dead-time response to a step change in set point. This should be an SISO controller which manipulates the feed concentration to Reactor 1 in order to control the concentration in Reactor 1 (as before). Use \( T = 0.01 \). There is no recycle.

B. Using the FORTRAN simulator you developed previously, simulate the response of the Dahlin algorithm you derived in (A) to a 0.1 step change in \( d \). Plot the concentrations in both reactors, even though only the concentration in Reactor 1 is being controlled.
PROBLEM 5
Analytical Predictor

Problem Statement

A. Design an Analytical Predictor time delay compensator control algorithm for the system which has been studied in Problems 2-4. This should be a SISO controller which manipulates the feed concentration to Reactor 1 in order to control the concentration in Reactor 1 (as before). Use T = 0.01. There is no recycle.

B. Using the FORTRAN simulator you developed previously, simulate the response of the Analytical Predictor algorithm you derived in (A) to a 0.1 step change in d.

PROBLEM 6
Noninteracting Control

Problem Statement

A. Consider the reactor system in Problem 1. Let $\lambda_R$ equal 0.5. Calculate the Relative Gain Array. Discuss the loop pairings.

B. Simulate the system with both reactors under PI control. These should be two SISO loops. Sampling time should be 0.01. Include the delay in the recycle loop. Tune each controller separately. The loop not being tuned should be open. Simulate the response of the system (both loops closed) to a step change of 0.1 in the set point of Loop 1 (Reactor 1). Repeat for a step change of 0.1 in the set point of Loop 2. Simulate the response of both loops to a step change of 0.1 in the disturbance.

C. Design and implement a steady-state decoupler for this system. Repeat the simulations above. (Use PI controllers with only slight integral action.) Do the loops interact more or less than in (B)? Why?

SUMMARY

Integral-squared error results for the various problems are summarized in Table 1. In summary, the PID results indicate that a smaller sampling period produces a better response. This is consistent with digital control theory. Deadtime compensation inherent in the Dahlin and Analytical Predictor algorithms improves the controlled behavior of the system. The predictive capacity of the Analytical Predictor also appears to upgrade the response slightly. It is imperative to note however that the quality of the response generated by each method is highly dependent upon the tuning parameters employed. Thus the above observations should not be taken as conclusive.

In the multivariable case (Problem 6), no clear advantages result upon decoupling; however several undesirable response characteristics are produced by the steady state decoupler. This is probably due to the fact that interactions are inherently small for this system. Hence, a steady state decoupler would not be recommended, but a dynamic decoupler might be a reasonable option for future expansion of the simulation.

ACKNOWLEDGMENTS

This material is based upon work supported under a National Science Foundation Graduate Fellowship.

REFERENCES

4. IMSL Library, IMSL, Houston, TX (1988).
BIOTECHNOLOGY is an area which will continue to be incorporated into the chemical engineering curriculum to an increasing extent in the near future. Many departments currently include an undergraduate course on biochemical engineering. Beyond this, many faculties are wrestling with the problem of increasing the biotechnological component of the curriculum. The reasons for this have been documented in many articles appearing in the last two to three years. As an example, there has been speculation that as many as 25% of all practicing chemical engineers may become involved in various aspects of biotechnology within the next decade [1]. The AIChE is also aware of these kinds of projections [2]. Chemical engineering is an evolving discipline; there is nothing static about it, and this should also be true of the curriculum. Failure to recognize the evolutionary aspects of the discipline could lead to a serious crisis in the profession [3].

There are two extreme approaches that could be used to incorporate biotechnological topics into the curriculum. One extreme is to do it exclusively within the confines of the chemical engineering department (or, less radically, within the confines of engineering in general). The other extreme is to “farm it out” to other departments. There are weaknesses with both approaches. Engineers have one vital role in technology: the role of “technology transfer.” That is, they have an important function in translating the bench-scale ideas of the researcher (in many cases, a chemist) to an industrial-scale process. Therefore, they should know something about the entire spectrum of technical activity. In regards to the chemical engineer in a biotechnological environment, this means that he or she should be able to function both as a biologist and as an engineer. Any curriculum should try to accomplish this by drawing upon the knowledge of both engineering and chemistry departments as well as the life sciences.

USF’s PROGRAM

The undergraduate program developed at the University of South Florida is illustrated in Table 1. The “applied microbiology” option is one of several options or areas of concentration which students can select upon admission to the department (typically at the end of the sophomore year). The program features a strong chemical engineering core along with a series of courses in life science. There is one required biochemical engineering class within chemical engineering which would normally be taken in the senior year. Students may take an additional elective course within engineering in areas such as fermentation which would count towards the degree. While most chemical engineers would take a course in physical chemistry as an advanced chemistry elective, this program requires biochemistry in its place. Finally, students have the option of taking a course in the biomaterials area in place of the normal introductory materials class which is offered by civil engineering on this campus. The total program requires 146 semester hours, which is slightly more than the 136 hour requirement of other engineering departments on this campus.

It should be mentioned that the chemical engineering curriculum in general has been recently over-

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CHEMICAL ENGINEERING EDUCATION
there has been speculation that as many as 25% of all practicing chemical engineers may become involved in various aspects of biotechnology within the next decade. Failure to recognize the evolutionary aspects of the discipline could lead to a serious crisis in the profession.

hauled. For example, there were four required courses offered in previous years: “Transport Processes I” (momentum transport), “Transport Processes II” (heat transfer), “Mass Transfer,” and “Separation Processes.” They were each assigned 3 semester hours, for a total of 12 semester hours. We currently offer two courses in their place, titled simply “Transport Processes I & II,” which address the unit operations aspects of momentum, heat, and mass transport. This freed up hours which could be devoted elsewhere. The general theme has been to make existing courses more reflective of chemical engineering as it is practiced today (and into the future), and to create more free elective hours where previously there had been few.

**DISCUSSION**

One of the goals of the program was to enable students to select from three possible career paths upon completion of the undergraduate degree: continued education within engineering, continued education within some branch of life science, or entrance into the industrial sector. The first path is possible since a strong chemical engineering foundation is provided, and the second path is possible because a sequence of classes is taken within the life science area. The engineering course in bioprocesses helps to put an engineering perspective on the biological knowledge base. Since engineering programs are practical and applied, students are always in a position to enter industry.

The program is described as “applied microbiology” rather than “biotechnology” because topics involving molecular biology (particularly genetic engineering) are not covered in depth. These topics are normally treated in graduate level courses. However, students coming out of this program could easily pursue advanced training in this area.

This is a rigorous program. Certainly it is more challenging than the “normal” chemical engineering program. Our experience is that better-than-average students are attracted to such a program. One note of caution must be mentioned to others thinking about such a program: it is important to get students into such a program early from an advising viewpoint in order to keep the residence time comparable to that of other engineering students. It is also important to have full support of the appropriate areas of the life sciences. In many cases, the interaction between the two groups has led to positive things both inside and outside the classroom.

**REFERENCES**


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**TABLE 1**

Program for the Option in Applied Microbiology

<table>
<thead>
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<th>Sem. hrs</th>
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A. GENERAL DISTRIBUTION

Approved liberal arts courses 25

B. MATHEMATICS AND PHYSICS

Engineering Calculus (3 semesters); Engineering Physics (2 semesters, including labs); Differential Equations, Statistics, System Dynamics, and Computer Programming (1 course) 29

C. CHEMISTRY

General Chemistry (2 semesters, including labs); Organic Chemistry (2 semesters); Organic Chemistry Laboratory (1 semester); Biochemistry (1 semester) 20

D. ENGINEERING SCIENCE

Statics, Thermodynamics I, Introduction to Electrical Systems I, and an approved course in the materials science area 12

E. CHEMICAL ENGINEERING


F. BIOLOGY

Fundamentals of Biology (with lab); Introduction to Microbiology; Cell Biology (with lab); and 2 of the following 3 courses: Applied Microbiology (with lab), Bacteriology (with lab), or Microbial Physiology (with lab) 19

TOTAL: 146
by a statement from the Preface: “The approach here is to provide the necessary material in a direct manner, in most cases without rigorous proofs and derivations, because it is believed that the proof is often formidable and tends to obstruct, rather than aid, the learning process.”

After reading the first chapter, my enthusiasm for the book started to wane. The author seems to imply that there are as many equations as there are unknowns in a collection of linear equations. He also states that, “if \( m = n \) the matrix is square of order \( n \times n \) (or of \( n \) or of \( nth \) order).” I do not know what the “order” of a matrix is, and I never find out, although I am warned not to confuse it with the “dimension” of a matrix, which is also left undefined. The dot product \( A \cdot B \) is covered on page 9, but I am told that \( A \) and \( B \) must be column vectors in spite of the accompanying formula implying that \( A \) must be a row vector. Later, on page 18, the dot is included in one equation and then omitted in the same context in the next equation. This seems to imply poor typesetting and editing.

Chapter Two contains examples of imprecision and poor editing. Take, for example, the statement of Rule Six on page 33: “If the elements of any row (column) of a determinant are multiplied by a constant and then added to or subtracted from the corresponding elements of another row (column), the value of the determinant is unchanged.” Strict application of this rule will not leave the determinant unchanged. The numerical example which follows Rule Six indicates what the author really meant. The reader may come away with the notion that a determinant is an array of numbers, rather than one of many invariants which may be extracted from a square matrix. Chapters Three and Seven refer to “symmetrical” matrices. The Index does not list such a term.

Chapter Six contains some elements of the vector algebra that is found in vector analysis courses. Normally it is unwise to mix “vector analysis algebra” with matrix methods since the former is restricted to three dimensions owing to the inclusion of the cross product. Since chemical engineers encounter the cross product in transport phenomena, this may represent an important innovation. But, alas, we find the equation

\[
x \cdot j = j \cdot k = k \cdot i = 1
\]

which leaves this part of the book seriously flawed.

Our students frequently experience difficulty with eigenvalues. Chapter Seven will not help them. Equation (7.6) gives one definition of the characteristic polynomial, while Equation (7.8a) gives a conflicting definition. Equation (7.8b) contradicts the equation which follows it. Two pages later, still another form of the characteristic polynomial is given. These multiple and conflicting definitions seem to be pedagogically unsound.

While the aim of the book is well directed, it cannot be regarded as a serious contender for adoption. It simply contains too many examples of imprecision and typographical errors. It certainly could not be recommended for self-study either.

The book should not have been printed in its present form without greater care being taken to clean up its rough spots.
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

TITLE. Use specific and informative titles. They should be as brief as possible, consistent with the need for defining the subject area covered by the paper.

AUTHORSHIP. Be consistent in authorship designation. Use first name, second initial, and surname. Give complete mailing address of place where work was conducted. If current address is different, include it in the footnote on title page.

TEXT. Consult recent issues for general style. Assume your reader is not a novice in the field. Include only as much history as is needed to provide background for the particular material covered in your paper. Sectionalize the article and insert brief appropriate headings.

TABLES. Avoid tables and graphs which involve duplication or superfluous data. If you can use a graph, do not include a table. If the reader needs the table, omit the graph. Substitute a few typical results for lengthy tables when practical. Avoid computer printouts.

NOMENCLATURE. Follow nomenclature style of CHEMICAL ABSTRACTS; avoid trivial names. If trade names are used, define at point of first use. Trade names should carry an initial capital only, with no accompanying footnote. Use consistent units of measurement and give dimensions for all terms. Write all equations and formulas clearly, and number important equations consecutively.

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

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

COPY REQUIREMENTS. Send two legible copies of manuscript, typed (double-spaced) on 8½ X 11 inch paper. Clear duplicated copies are acceptable. Submit original drawings (or sharp prints) of graphs and diagrams, and clear glossy prints of photographs. Prepare original drawings on tracing paper or high quality paper; use black India ink and a lettering set. 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 may 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. If drawings are mailed under separate cover, identify by name of author and title of manuscript. State in cover letter if drawings or photographs are to be returned. Authors should include brief biographical sketches and recent photographs with the manuscript.
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