CHEMICAL ENGINEERING IN THE FUTURE*

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CHEMICAL ENGINEERING AND its future direction are important and interesting subjects to those of us in the profession. There is much to talk about. In this paper we discuss three aspects of the future of chemical engineering. The first concerns change: What evidence is there that the profession of chemical engineering needs to evolve? And why are these changes taking place?

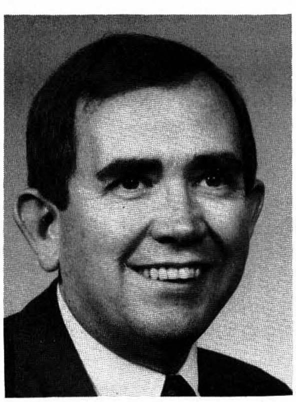
The second part addresses the needs and expectations of industry, or at least that segment of it which is likely to employ chemical engineers: What do we need and expect from our new engineers? What role do we expect chemical engineers to play, and what could that role be if their training were different?

The perspective presented is largely a personal one. Each company, and each division or even each individual within a company, sees things differently. But since each of you know many people from industry, you can judge these opinions in the larger context. Certainly the members of the Septenary Committee on the Future of Chemical Engineering, sponsored by the University of Texas at Austin, represented a wide spectrum of companies employing chemical engineers; yet they were in remarkable agreement about many issues.

The first concerns change: What evidence is there that the profession of chemical engineering needs to evolve? And why are these changes taking place?

The third part suggests possible courses of action. Some would involve only the academic community. Others would require the participation of professional societies such as the ASEE or AIChE; organizations such as the Chemical Research Council that bring together academic, government, and industry representatives; government funding agencies such as the National Science Foundation; textbook publishing houses; or individual firms that employ chemical engineers.

The real issue is cohesive leadership. There are signs that the need for change is recognized, and at least some elements of the matrix are willing to be persuaded to change. Leadership involves setting directions and priorities and providing incentives for movement in the desired direction.



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SIGNS OF CHANGE

The Du Pont Company is a large employer of engineers, especially chemical engineers. Surveys have shown that chemical engineering students think of Du Pont as one of the best places to work. Therefore, changes taking place in Du Pont should be of interest to suppliers of chemical engineering students. Allow me, then, to cite several examples that impact upon the recruitment and careers of chemical engineers.

The Engineering Technology Laboratory, established in 1929 in the Chemical Engineering Group of Du Pont's Central Chemical Department, has been a continuing major influence in the field of chemical engineering research. It was a thrill for me as a chemical

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TABLE 1
Engineers in Du Pont

Final Degrees as of 1/1/86

	BS	MS	PhD	Total	%
Chemical	2911	768	504	4183	45
Mechanical	2066	361	82	2509	27
Electrical	898	127	21	1046	11
Other	1057	353	105	1515	16
Total	6932	1609	712	9253	
Percent	75	17	8		

engineer to lead a research organization founded by Thomas Chilton.

The Chemical Engineering Group grew from two people in 1929 to 37 in 1953. Many employees such as James Carberry, Allan Colburn, Thomas Drew, Robert Marshall, and Robert Pigford have become well-known in the field. The chemical engineering section of the lab has traditionally been a leader in industrial chemical engineering.

Since May 1 of 1986, however, there is no longer a Chemical Engineering Section *per se* in the Engineering Technology Laboratory. The groups have been renamed to reflect a focus on technologies of corporate strategic significance. The new names? Bioengineering. Electronics Materials Engineering. Structural Ceramics. Electronics Ceramics. Polymer Processing and Compounding. Composites and Applied Mechanics. Membranes Engineering.

In the meantime, the tiny Applied Physics Section, founded in 1945, has become the Engineering Physics Laboratory, equal in size to its sister Engineering Technology Laboratory. It is divided into two main sections (Applied Physics, and Electronics and Optics) but within those areas there is a substantial and growing emphasis on materials science. Development of electro-optic devices, characterization of composites, work on optical-disk storage devices, and the modification of materials by microwave radiation are all fields that might have a chemical engineering aspect but are presently the province of solid state physicists and materials scientists.

What's in a name? A lot. Names help focus direction. Names inspire loyalty and *esprit de corps*. If you are looking for signs of change, do not ignore changes in the names of organizations, groups, or functions.

You should find this alarming. A shift of emphasis in industrial research indicates a trend in future jobs in manufacturing and marketing. To industry, it matters little whether applied physicists or chemical engineers are doing the work. If chemical engineers are to be hired, they must receive the training that will make their expected contributions greater than those expected from other disciplines.

Recruitment Trends

Another clear indication of change for the field of chemical engineering can be seen in Du Pont's recruitment trends. Du Pont is a highly diversified company that employs a great many chemical engineers. As shown in Table 1, Du Pont (minus Conoco) employs about 16,000 people with college technical degrees, out of a total exempt force of 22,000. More than 9,000 of these are engineers, of whom 45% are chemical engineers. In all, 25% of the engineers hold advanced degrees, as do 30% of the chemical engineers.

Since [last] May . . . there is no longer a Chemical Engineering Section *per se* in the Engineering Technology Laboratory. The groups have been renamed to reflect a focus on technologies of corporate strategic significance.

During the past ten years, we have hired 2,242 chemical engineers, half of the total number of engineers hired. Although individual years vary a great deal, some trends are clear. Figure 1 shows that the relative percentage of chemical engineers hired has dropped.

Specific figures are listed in Table 2. In the three-year period 1976-79, Du Pont hired 746 chemical engineers, 52% of the total number of engineers hired. Of these, 5% of the chemical engineers had PhD's. In the three-year period 1983-86, seven years later, 373 chemical engineers were hired, 43% of the total. Of

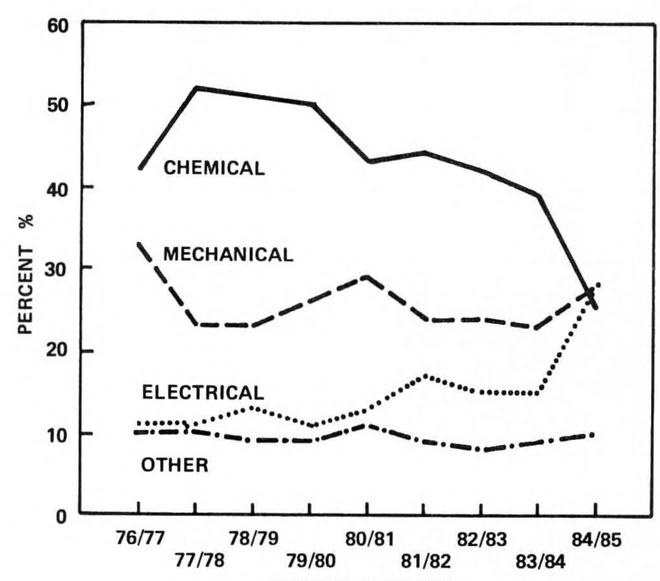


FIGURE 1. Ten-Year history: Du Pont engineering hiring for Bachelors and Masters degrees

these, 21% had the PhD. In this seven-year period, the total number of chemical engineers hired dropped by half, and the percentage of PhD's among them quadrupled. The absolute number of PhD hires in chemical engineering increased by 114 in the face of a 58% decline in BS/MS hires. The trend toward hiring fewer chemical engineers who individually know more seems unmistakable.

Other types of engineers are faring relatively better. Subtracting these figures will show that, although

TABLE 2
Chemical Engineering Recruitment

	CHEMICAL ENGINEERS			ALL ENGINEERS		
	B-M	PhD	Total	B-M	PhD	Total
1976-79	710	36	746	1383	60	1443
1983-86	296	77	373	763	102	865
Change, %	–58	+114	–50	–45	+70	–40

the total number of BS/MS hired dropped 45%, this figure represents a 58% reduction in chemical engineers combined with a 31% reduction in all other types of engineers.

Consider electrical engineers, not shown specifically in Table 2. We employ over 1,000, 11% of our total engineering employment. Comparing the same periods, Du Pont went from 172 hired to 182, a 6% rise in the face of a drop of 40% in the total number of engineers hired. The very small number of PhD's doubled from 4 to 8, but the latter figure would have been higher had we been more successful in recruiting them. One of our problems in recruiting is that, as a chemical company, we are not yet perceived by research-oriented EE's to offer outstanding opportunities for them. We are trying to combat this erroneous perception.

A number of our R&D positions are being filled with applied physicists and materials science and ceramics majors. Again, we are pleased with the quality of these people, but to the field of chemical engineering such hires may represent lost opportunities. Unless something is done to change the trend, the role of chemical engineers in industry will diminish. Also, it seems that the part of industry which hires chemical engineers will gradually move away from having the BS as the terminal degree. This happened with chemistry, biology and mathematics long ago. These trends have major implications for those who teach chemical engineers.

Market Orientation

Everyone pays lip service to market and customer orientation. In fact, since the publication of *In Search of Excellence* [1], not to do so would be heresy. Those who have seen such trends come and go develop a certain degree of cynicism about them. However, we believe that the movement toward better customer orientation, both in Du Pont and the chemical industry in general, is truly significant and has long-term implications for the field of chemical engineering.

We compete in an international market where other countries have equivalent technical skills and infrastructure, plus advantages such as labor cost. Where formerly we might have expected a sustainable cost and hence price advantage through technology alone, now we must focus on providing value to the customer not merely by lower price but in every way that the customer sees value. Examples of change in Du Pont include not only formation of new, customer-oriented entities but also new ways of thinking about existing organizations. Consider the new organization chart for our Biomedical Products Department, shown in Figure 2.

Instead of the traditional triangle with the Group Vice President at the top, here you see the various divisions clustered like flower petals about the health-

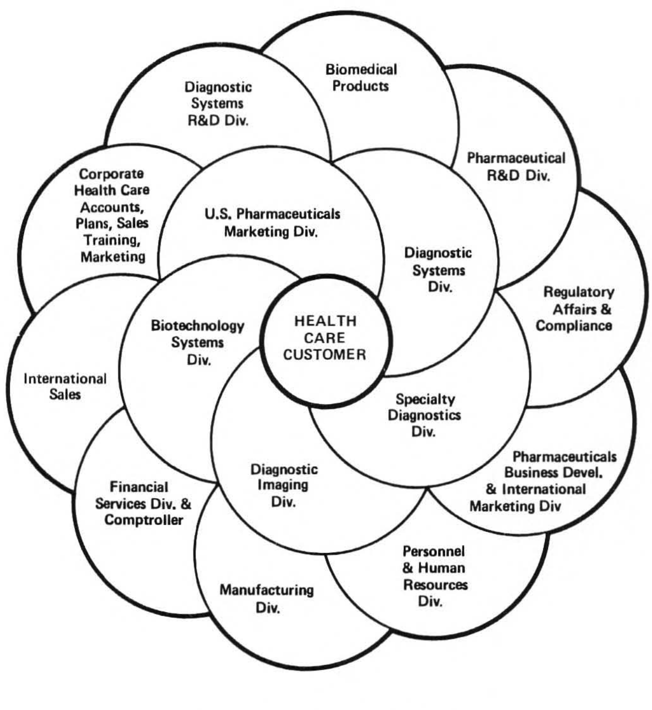


FIGURE 2. Organization chart

care customer. Note also that the names of the divisions—pharmaceuticals, diagnostic imaging, biotechnology systems, specialty diagnostics, etc—differ considerably from such traditional areas as nylon, polyethylene, and industrial chemicals.

Although our Engineering Research organization has no outside customers, we do have a well-defined internal market. Our clients are Du Pont's other departments. We receive about one-third of our funds from the corporation for long-range and discretionary R&D, and must get the other two-thirds by convincing our clients that we can serve them better than someone else can. They are free to go elsewhere.

Table 3 lists some of the ways in which recent trends affect the practice of chemical engineering.

TABLE 3
Recent Trends Affecting ChE's

- **MOVE OF BASIC INDUSTRIES OFF-SHORE**
- **FLEXIBLE MANUFACTURING**
  - **Automation**
  - **Batch Processes**
  - **Small Scale / Small Lots**
  - **Rapid Changes**
- **PRIMARY EMPHASIS ON QUALITY, SERVICE, VALUE-IN-USE RATHER THAN PRODUCTION PROCESS AND TECHNOLOGY**

While this change in emphasis is relatively recent for much of the chemical industry, the focus on customer needs is well-established in the electronics industry, which is now hiring more chemical engineers.

Traditionally, chemical engineers have found positions in the chemical and petroleum industries in jobs emphasizing the scaleup of processes. The six-tenths power factor "proved" that technical work oriented towards ever-increasing scale would be rewarded many times over. After all, half again as much investment would build a plant producing twice as much. Not many people noticed that in some cases the 0.6 factor was becoming 0.7, 0.8 or even higher, and that the effort and expense directed toward keeping huge plants on-line were beginning to outweigh the vaunted advantage of scale. Technical efforts were directed toward ever-increasing reliability to counter the extremely high cost incurred when the unit was shut down for any reason.

Next, problems arising from cyclical swings in the economy were found to be accentuated by the enormous single-line plants whose breakeven rates were 70% of design or higher. During an economic downturn, a producer with two small plants could shut one down, doing relatively well by running the remaining unit efficiently. To the large producer, the laws of economic thermodynamics (you can't win—you can't break even—you can't quit playing) were not so funny, as they found themselves forced by contracts and internal needs to continue playing a losing game.

Also, it seems that the part of industry which hires ChE's will gradually move away from having the BS as the terminal degree. This happened with chemistry, biology and mathematics long ago.

Another blow to the concept of unalloyed benefits from ever-larger scale came with the realization that real value to the customer might lie in small amounts of material tailored to the customer's needs, as opposed to huge amounts tailored to the producer's desires. Considerable technical effort was devoted to "product wheels" or other schemes to make large plants behave more like small ones. The effort to be flexible and maintain high quality while tailoring products to each customer is a dominant theme in process work today.

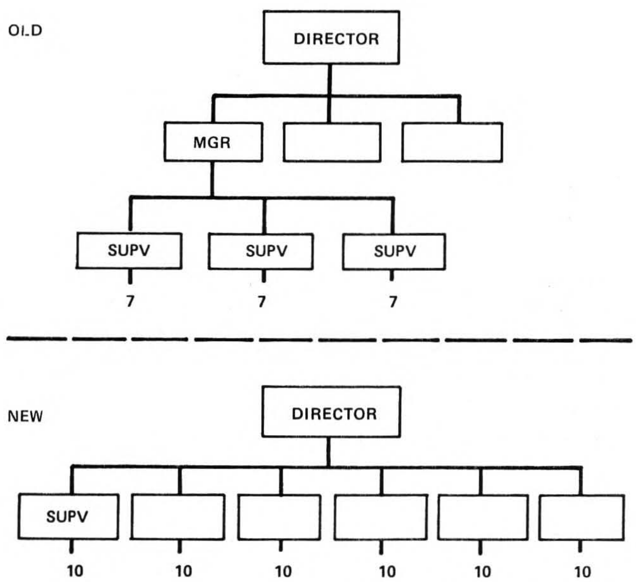
Finally, as mentioned earlier, the United States and Western Europe lost their virtual monopoly on technical capability and the infrastructure needed to support large plants. Developing countries could obtain and operate comparable facilities close to the source of supply. These countries could then price downstream products to support their internal social programs, undercutting our industries, which depended upon scale for their economics. Unfortunately for us, the rules of economics as applied in the United States are not necessarily those of a nation that owns raw materials and abundant unemployed labor but must fuel any real growth with foreign exchange.

The response by industries in the industrialized nations must be to emphasize flexibility, quality, and service rather than scale. The need for technical talent still exists, perhaps more so than in the past, but the emphasis is different. Educational programs should be adapted to produce graduates prepared to function in this new environment.

Organizational Effectiveness

As stated earlier, Du Pont has been hiring fewer engineers lately. Why is that? The need to become more competitive, felt by all American industry and especially in recent years by the chemical and petroleum industries, has resulted in a marked change in organizational structure and attitude. These changes are much more fundamental and significant than indicated by the mere change in numbers; the kind of work and the degree of training and expertise needed are profoundly affected.

In Du Pont, we talk about "organizational effectiveness." In practice, this means doing more with fewer people, cutting out whole layers of supervision, depending more upon nontechnically trained people, and reducing services and administrative support. Figure 3 shows the change in a hypothetical R&D or technical support organization. The total size has been reduced 12%. The number of supervisory or managerial slots, however, has been reduced by 46%. The ratio of total people doing technical work to those supervising or managing it in some capacity has increased from about 5 to about 9.



	OLD	NEW	REDUCTION
SUPERVISORS / MGRS	13	7	46 %
AT BENCH	63	60	5 %
TOTAL	76	67	12 %
RATIO BENCH / MGRS	4.8	8.6	

FIGURE 3. Example of change in a typical technical or R&D organization.

Notice the change in the kind of work that this new structure implies. Only half as many engineers will advance into R&D or technical supervision. The first supervisory opportunity will be at a higher level than before and normally will occur later in one's career. Since there are fewer managerial personnel in the organization, the individuals at the bench will receive less direction. This change in effect upgrades those jobs also, which means that to function effectively those doing technical work will need greater expertise.

Young people ought not to study a field that they do not want to practice and do not enjoy. This advice might sound... ridiculous, but many engineering students view the field as a stepping-stone into management.

Similar changes in manufacturing have resulted in fewer supervisory jobs for engineers, a higher barrier to entry into management, and a longer time spent doing technical work before having an opportunity to try management.

This change in the culture of a company—trying to eliminate all nonessential work and focus on the real business needs—has even greater effects on the staff functions than on line organizations. Most staff jobs are filled by technical people. The result of all this change is more reliance upon the individual and a consequent premium on knowledge and experience. Since training people on the job is much more risky and less affordable now than before, rotational moves are less frequent. When vacancies created by transfer or other reasons are filled, there are no excess people to carry the new person while he learns the new job. Demands upon the replacement to produce quickly are therefore very great.

This development will gradually force a search for more knowledge in the people we hire, manifesting itself in a premium for the master's degree and an increased number of experienced hires. Both trends represent breaks in our tradition. It will also place a greater premium on continuing education of the voluntary, after-hours sort.

Young people ought not to study a field that they do not want to practice and do not enjoy. This advice might sound so apparent as to be ridiculous, but in fact many engineering students view the field as a stepping-stone into management. In the past, it was often possible to move into supervisory jobs within a year or two, and never really learn the practice of engineering at the bench or in the plant. In the future the norm, even for managers, will be to practice engineering for several years before the first supervisory opportunity arises, and so they should be well prepared and motivated to do so. After all, the main criterion for promotion is nearly always to be outstanding at the job one has.

This, then, completes the first part of this paper. Chemical engineers in the future will need to know more and different things than they did in the past and be able to operate more independently at the start of their careers. The typical career path in the chemical industry will be different.

The possibility of employment in other industries and in even greater numbers exists, but only if the graduate fits their needs. Let us turn now to what those needs might be.

INDUSTRY NEEDS

We have considered the ramifications of industry's renewed commitment to providing value to the customer—value as the user sees it, not as the producer might see it. Many commercial blunders and even disasters can be traced back to the sincere but naive belief that the customer would have to be crazy not to want the producer's wonderful product. Producers spent their energy trying to change the customer's perception of value rather than to satisfy his desires.

The academic community has products, too—an array of them. Probably most of all you enjoy producing and marketing your premium products—the fruits of your own research and the PhD's you have personally trained. However, your fixed costs are largely covered by the lower end of your product line—the BS and MS recipients—and you ignore their salability at your peril.

Continuing this analogy, consider what your customers are saying and how their message is being conveyed; only about half the graduates in many chemical engineering schools are getting jobs in the field. If this situation continues, many of your businesses will fold, the smaller and weaker ones first. The problem is more than one of economic cycles. It would not be a good idea to dig in and wait this one out, because there are long-term changes in American industry that will require engineers to have different training in the future than most of them get now. To enjoy a continued expanding demand for your products, you must try two approaches—first, to get your existing customers to buy more, and second, to develop new customers. The approach to either is the same; try to analyze value as they see it, develop a product that provides that value, and then convince potential customers that your product will fill their needs better than any other.

There are potential customers outside the traditional chemical and petroleum industries. Our engineering research organization works with a number of industrial segments involving such diverse technologies as packaging of food products, composites for aerospace and automotive applications, artificial ligaments and diagnostic devices for the health services industry, optical disks, opto-electronic devices and ceramics for the electronics industry, and many others. Opportunities for chemical engineers in those fields are as great as those in the traditional industries hiring chemical engineers. And the general educational requirements are also similar. Therefore, let us consider what industry in general expects from the engineers they hire. We are potentially your customers, but we'll seek value where we find it—from chemical engineers or others.

The first point shown in Table 4 is essential. In the discussions held by the Septenary Committee in Austin, the unanimous opinion held by representatives of the electronics, chemical, and petroleum industries represented on that panel was this: Chemical engineers are uniquely trained to apply fundamentals to complex, unstructured problems of the kind industry faces. When those problems involve molecular change or the separation of chemical species, the present curriculum provides a great deal of additional knowledge that may be brought to bear. We want to enhance those capabilities, not lose them. The assertion that "chemical engineers can do anything" has some evidence to support it, and that reputation is invaluable to those wanting to broaden the employment spectrum of chemical engineers.

TABLE 4
What Industry Expects from ChE Grads

- **Maintain traditional strengths such as ability to deal with complex, real-world problems.**
- **Be able to function productively without extensive additional training.**
- **Be technically oriented.**
- **Have the tools, motivation and ability to continue to learn.**
- **Be able to communicate effectively.**

Special Knowledge

Unfortunately, they cannot do anything well without some specialized knowledge. The traditional curriculum provided that knowledge for the traditional customer. If you wish to broaden your customer base, a way of providing the special tools needed to serve those customers must be devised, which brings up the subject of curriculum.

In a discussion of the undergraduate curriculum, the first question that comes to mind is: "So what? What difference does it make whether a few courses are added or subtracted from the curriculum, or the teaching methods and texts are changed a little? Can't that difference be erased during the first year or so on the job?"

Of course it can—at a price. Many options are available. For example, the new hire can be sent back to school for a master's degree or for supplementary

Continued on page 50.

ChE IN THE FUTURE

Continued from page 17.

training. Or one can establish an internal school, like MacDonalds' Burger Tech. The company can offer short courses, either taught by employees or conducted by outside firms or local universities. Even courses for degree credit can be arranged, locally or by television. All of these things are being done—it is a big business.

But should this be necessary? A technical degree is supposed to certify competence to practice in the field and provide the necessary background for the recipient to function in a useful capacity while extending the knowledge into specialized areas on-the-job. No business would flourish by selling a product that the buyer had to modify extensively before being able to use it, even though sophisticated buyers often do add proprietary touches.

It is inefficient and costly for industry to try to substitute for the university. Including overhead and support personnel such as technicians, it costs about $200,000 per year to support a technical person in an industrial R&D organization. The lost-opportunity cost when these people either take instruction or provide it is even higher. We should expect a return of nearly $600,000 per year to result from their contributions. The net present value is even higher—one year of R&D work by a knowledgeable person working on new products or major product and process improvements is worth about $2 million. Looked at that way—and we do—it costs over $2 million per man-year for a research professional to do nonproductive work.

Let me hasten to add that we do believe in the value of continuing education to sharpen skills and enhance breadth of knowledge. We are willing to pay for an appropriate amount of it. We have no desire, though, to pay for remedial education, just as you do not want to teach students to read or count.

Hence the last three items in Table 4. Engineers should be taught to use fundamentals to solve problems and to be mentally prepared and motivated to use them. They should be prepared to reason effectively and draw logical conclusions using a quantitative approach. They should then be able to communicate well enough to explain their conclusions and reasoning effectively and to convince management or customers to act in accordance with the recommendations. And, of course, engineers should be willing and eager to learn.

ACTION ITEMS

Assuming that our goal is to expand the marketability of chemical engineers, we must ask several questions: What might be done to provide this kind of product? What kind of changes are possible, and who will make them? *Why* should they make them?

Table 5 lists six areas in which changes might be made. Each will be discussed in turn.

TABLE 5
Possible Actions

- CURRICULUM CHANGES
- STRUCTURED OPTIONS
- IMPROVED USE OF NEW TECHNOLOGY
- FORWARD-LOOKING TEXTBOOKS
- MORE EMPHASIS ON ADVANCED DEGREES
- CONTINUING EDUCATION

Curriculum

Howard Rase, in preparing the report of the Septenary Committee [2,3], devoted considerable space to recommendations on the curriculum. Some of them are listed in Table 6. We urge you to read that report if you have not already done so. The last four issues in the table deal with providing room in the curriculum without sacrificing the most important subjects or lengthening the undergraduate program.

Minor changes, where two or three courses are altered or eliminated in favor of others, will have little if any effect. If the product is to be a chemical engineer able to function in industry and adapt to a continually changing environment, that engineer must have not only a broad knowledge of scientific principles and techniques, but also some specialized knowledge about the particular technology in which he will be employed—biology, electronics, materials, chemical separations, statistics, and computer programming, to name a few.

The term "learning curve" has become such a cliché in the context of pricing strategy, project management and the like, that sometimes we forget its original use as a description of an individual's learning process. Acquiring and using new knowledge depends upon a host of connections among bits of information and also upon attitudes and concepts derived from experience. In four or five years of training, it is impossible to provide every student with every knowledge segment that will be useful. So what can be done?

First, eliminate duplication. Start with high school prerequisites. If you require calculus or chemistry, then expect the student to know it. If it has to be made up, since not all high schools are equally proficient and not all high school students are as studious as one might wish, then by all means teach remedial courses—but don't give credit toward the degree for them.

The next element of duplication that should be eliminated is the repetition between different departments of the university. Reinforcement is certainly needed for many subjects, but teaching thermodynamics in both chemistry and chemical engineering is really unnecessary. The remedy may require the faculties of different departments or colleges to work together to offer sections of, say, physical or organic chemistry that are slanted toward chemical engineers. I realize that this area is a problem in most universities, but it should be addressed.

The second point is to use computers more effectively—and I do not mean requiring more programming! A survey of our own engineers who have graduated within the last five years or so indicates that in many cases they feel they got too much of that. The real need, they think, is to integrate the computer into the course to such a degree that the added capability is channelled toward improving their judgment. All of the tedious hand calculations and shortcut techniques that used to play such a major role in chemical engineering courses should be abandoned. Instead students should learn to use problem-solving software to try cases and to clarify the fundamentals. This approach will require major investments in time, equipment, text writing, problem construction, and nearly every other phase of teaching. Not only would it make better engineers, but it could also allow some time to be cut from the curriculum to make room for other subjects.

TABLE 6
Recommended Curriculum Changes*

- **Prepare for continual change with a broad range of fundamental knowledge.**
- **Provide some flexibility for a limited degree of specialization**
- **Provide room by**
  - **Eliminating duplication**
  - **Using computers more effectively**
  - **Combining courses**
- **Switch some organic chemistry to biochemistry and change physics to emphasize the solid state.**
- **Require modern biology, materials science, modern electronics, economics.**
- **Use specialized liberal arts courses.**

*From report of the Septenary Committee on the future of Chemical Engineering

The third and fourth points are different aspects of the same idea. By judicious selection of problems, experiments, and special requirements, a single course can cover several objectives. For example, oral presentations of results and review by English teachers of written reports can be part of laboratory or unit operations courses. History could cover the history of science, government might discuss the need for a national science policy and the workings of government-sponsored research, language can feature original scientific papers, and philosophy can cover the development of scientific reasoning and thought.

The second possible action, then, is the use of structured options. Many schools do this already, to a limited extent.

There is some disagreement about how much of the curriculum should be devoted to distributional courses and the kind that should be required. Our survey revealed a divided opinion. The general consensus seemed to be that the cafeteria style involving electives from several categories was not effective, and that it would be better to provide some focus. I know that Rice University is considering a "coherent minor" for all students, in which the liberal arts students must minor in a scientific discipline and all science and engineering students must select a liberal arts minor in which courses from several departments are structured to reinforce each other. This idea could be carried one step further and the courses themselves restructured, rather than using a menu selected from existing offerings.

Structured Options

Even though some room in the curriculum may be provided by the measures discussed, it will probably be too little to provide the range of abilities needed. The second possible action, then, is the use of structured options. Many schools do this already, to a limited extent. The idea is to offer, say, three courses designed to provide some additional expertise in an area such as bioengineering, materials science, polymer science, separations, applied mathematics, electronics, or chemistry. Completing such an option, which might require a slight increase in total hours for that student, should be recognized by designating it on the diploma. Such an action would be intended to increase the marketability of students by increasing their ability to function effectively during their first job, and to make it easier for them to extend their education in these areas after leaving school. This additional qualification may or may not command a premium price, but it should make it easier for the graduates to get jobs.

Improved Use of New Technology

In 1959, I studied chemical process design under the late Bob Perry. Our university had an IBM 650, a marvelous machine with 2,000 words of storage on a rotating drum that used punched cards as input.

The compiler required three passes with cards to produce a machine language program. There was no applications software available at all—if you wanted to solve a bubble-point calculation, then first you had to write a program to do it. Even then, though, the enormous possibilities to aid process design were evident. We used that computer, hands on at night, to improve our understanding of process design. Each time we wrote a program, we would think, "Never again will I have to do that iteration. Never again will I do a tedious, approximate graphical solution to this problem because now an exact solution is no more trouble." It was relatively easy to try different configurations of equipment, as in multiple-column separation systems.

Now it is possible to do "what-if" calculations on whole processes and to even get theoretical, *a priori* estimates of the best possible separation schemes involving all known separation methods. Expert systems programs can be constructed to help guide the novice engineer through the reasoning process that was once the province of experienced consultants. Complex problems in structural analysis, heat transfer, and fluid flow are routinely solved numerically.

In the past 20 years, the evolution in computer technology has done far more than make repetitive calculations faster and more accurate. One can now do things *differently*, not just faster. Talks with new employees and others seem to indicate that the universities are far from exploiting this capability. It is now possible to concentrate on improving the students' judgment, assuming that calculations can and should be made to the accuracy and degree of complexity warranted by the problem and available data. The student can be taught to consider what other data might be needed, assess the cost and time needed to obtain them, and evaluate the probable outcome of experiments. Experimental design and economic analysis can become a routine part of all evaluations, because complicated statistical inference or discounted cash flow analyses become relatively easy to do.

Computers are now a ubiquitous tool. Electronic communication is becoming routine. Word processing, spreadsheet programs, relational data bases, desktop publishing, and computer-aided design are now ordinary tools, just as the slide rule was in the 1950's. The university must teach the student to use these tools effectively—not just to manipulate them but to understand how they can contribute to technical productivity in all ways.

Any hardware that is made commonly available, such as terminal facilities, must be available in sufficient quantity and be well maintained. At many schools the inconvenience to the students of inadequate ways to access required computer equipment is staggering. You know about the kind of graffiti that is started by one student, then added to by another. At one university, the first student posted a sign on the computer-room door with Dante's words marking the gate to hell [4]:

> **Beyond me lies the way into the woeful city.**
> **Beyond me lies the way into eternal woe.**
> **Beyond me lies the way among the lost people.**

to which another student had added, "And beyond *that* lies a three-day wait for a terminal!"

To integrate computer technology into the undergraduate curriculum will require a major commitment of funds and time by the university, the faculty, and the students. But it must be done. Not only should adequate common facilities be provided, but every student should be required to have a relatively powerful personal computer that will run engineering software. All will also need standard commercial software for word processing and the like. These tools will be an inevitable part of the cost of an engineering education.

Forward-Looking Textbooks

Another major point by the Septenary Committee was that texts will have to be rewritten and courses completely revised to implement the first three potential action areas listed in Table 5.

After reading the report, Professor Byron Bird wrote each of the committee members [5], expressing his endorsement of the report and particularly of the recommendation that new textbooks be written. He enclosed a copy of his 1983 article in *Chemical Engineering Education* on the subject [6], and added the following comment:

> **. . . Ch.E. has suffered in the past decade or so because of a noticeable lack of exciting, sparkling, and responsible modern textbooks. Our professors are too busy getting money for research grants and accounting for it, and the sad result is that our most prominent and brilliant researchers and teachers are being actively discouraged from taking time out (for) text-book writing!!**

He went on to make several points about the role of textbooks in a changing chemical engineering field:

- **In a very real sense, good books *bring about* change.**
- **The very boundaries of what we mean by chemical engineering are *determined* to a significant extent by its textbooks.**
- **The field of chemical engineering will inevitably be known and measured by its journals and books.**

Professor Bird's article suggested that "book-writing" ought to be included as a third principal activity of a university teacher, in addition to teaching and research, since it is concerned directly with the production, organization and dissemination of new knowledge. How the writing of forward-looking texts might be encouraged will be discussed later.

More Emphasis on Advanced Degrees

The first four possible actions in Table 5 relate to the undergraduate curriculum and to teaching methods and tools. The last two are concerned with education beyond that.

References to "terminal" masters degrees are often made with a sneer. Why should there be some sort of stigma attached to wanting more than an undergraduate education, but less than a PhD? If we did not all believe that technical knowledge and excellence translate into better job performance, we would not be here. We should encourage students to learn more, even beyond the undergraduate level, before entering industry. I would much rather hire an MS degree holder than a BS, because the percentage of technical courses taken is far higher. Much of the undergraduate program is devoted to humanities and other broadening courses, as it should be, but graduate work is almost exclusively technical.

It is surprising that this trend is not already apparent. Part of the reason it is not may be that many of those responsible for hiring in industry do not realize the impact of curriculum changes during the past 20 years. They have a mental image of those 145-hour BS requirements with virtually no electives common then, rather than the 128-hour programs heavily laced with electives and distributive requirements common now. Also, as enrollments decline, the tendency at some schools is to lighten the workload to keep as many students as possible in the program. These same people who remember the 145-hour curricula also remember being torqued to the breaking point because chemical engineering was *the* premier, prestigious subject to take—those who wanted the label had to be ready to pay the price. Today, the electrical engineering schools are employing the same Draconian measures to reduce enrollment to the dedicated core.

Whether you accept this reasoning or not, you may agree that the natural process in a buyer's market is to be more and more demanding of the quality of the product. I believe that the natural result of this process will be to move toward the MS as the typical final degree in chemical engineering, rather than the BS. There may not be so much of a price premium paid, but the MS recipients will have first call on the available jobs. Remember the earlier point that engineers in the future will do more technical work for a longer period of time than may have been the case in the past.

In the present academic system, where most graduate students are paid, the MS candidate can represent a drain out of proportion to his contribution. This problem causes some schools to discourage MS candidates. However, with a good program there is no reason to have to pay students to attend. Consider, for example, the better business schools. People fight for the privilege of re-entering school at an average age of 25 or 26, to pay $20,000 in tuition and spend two years getting a master's degree. Why? Because the buyers are willing to pay for a premium product. The press is full of articles about how MBA's from the big schools are not as good as they think they are; nevertheless, the firms hiring them are willing to pay a premium of perhaps $10,000 per year for that differential. The number of them getting jobs is also virtually 100%.

Continuing Education

Continual change and the need to adapt are synonymous with continuing, lifelong education (Table 5). A professor once told me that one of the goals of the formal educational process is to prepare students and motivate them to continue their education themselves, without the need for spoon-feeding. That is a laudable goal, but most people either continue to need spoon feeding or retrogress to that stage after a few years of using only a subset of their hard-won skills.

One aspect of emerging technology will have a dramatic effect on continuing education. Videotape combined with teleconferencing and electronic mail is making it possible to extend the classroom over the entire country. Several regional efforts have been successful, such as Stanford University's programs in electronics and electrical engineering. Others are planned. At least one national capability exists, the National Technological University (NTU).

The NTU has leased microwave channels and has become an advanced degree-granting institution. They do no instruction themselves, but rather contract with universities to do it. Although many of the offerings are short courses, it is possible to enroll in a masters degree program in electrical engineering, computer engineering, or manufacturing systems engineering. The students may participate in actual classroom instruction, in real time, by videoconferencing or telephone, or in delayed time by videotape relay. They actually enroll in the university giving the instruction. The professor receives additional compensation through consulting fees, and the university receives a negotiated tuition.

For the student, the courses are expensive (perhaps $1,000 per course) and the company must pay a hefty one-time subscription fee, and set up a microwave receiver, provide a "classroom," and fur-

After reading the report, Professor Byron Bird wrote each of the committee members, expressing his endorsement of the report and particularly the recommendation that new textbooks be written.

nish proctors for examinations. In many cases, however, this arrangement is much cheaper than in-house instruction, and almost infinite variety is possible. It also potentially can provide continuity even though the student may be transferred to a distant or remote location. Because the programs can be recorded, people who travel extensively in their jobs can make up lost work. These latter two issues are major problems to the continuing education of engineers in industry.

This kind of capability has the potential for great change in the way instruction is provided, at any degree level. For example, honors students in high school might begin university courses without the social penalty of leaving their age group. Undergraduates could take complex interdisciplinary programs involving selected courses not available locally. Perhaps most important of all, it could revitalize emphasis on teaching instead of research.

Think about it. You have surely heard comedians on television bemoaning the departure of the Catskill circuit . . . and musicians, the virtual disappearance of the community band. These sources of entertainment fell victim to the ready availability in every home of outstanding entertainment, so that amateur efforts in comparison seemed paltry and inadequate. Now, who do you think will get the extra pay and prestige for national televised instruction? Once people see how much easier it is to learn from truly outstanding, well-prepared teachers who emerge to prominence as teachers rather than researchers, some schools that continue to neglect teaching may find themselves on the educational Catskill circuit.

Another example is instruction in the military. Years ago in the Artillery and Guided Missile School at Fort Sill, Oklahoma, I was amazed to see the amount of technical information that could be imparted to a relatively unsophisticated audience within a few weeks. The secret was preparation. Every lecture was planned, rehearsed, and revised, and no effort was spared to design and prepare audio-visual and mechanical aids to instruction. There is little incentive for this approach in many universities, but there will be when national video participative instruction becomes widely available.

The best defense being a good attack, we should examine this new technology to see how it can be used to advantage in the production of chemical engineers who will be in wide demand in many industries.

LEADERSHIP

The real issue for the chemical engineering profession is leadership—who should provide it? A year or so ago I attended a week-long course in Washington sponsored by the Brookings Institute on "Understanding Federal Government Operations." It featured presentations by many officials, both elected and appointed, from all branches of government. A repeated theme was that the congress views itself as a reactive body. Its members do not believe that their job is to lead, or to anticipate change, but rather to sense the desires of the populace and react—a spiritless point of view, I thought. Doesn't possession of great knowledge and power carry with it an obligation to lead?

There seems to be a reluctance on the part of the academic community to lead change in the profession of chemical engineering, as well as a reactionary force to resist change. There are no doubt many contributing factors. For example, some of the better schools still find themselves to be in a seller's market; their graduates are easily placed, partly because they can still impose high selectivity on incoming talent. They also have the financial flexibility to enter any new field with additional faculty and facilities, so that change occurs through a comfortable growth process without the necessity for major sacrifices. In a shrinking field, though, those options are not open to most.

As an example of reactionary influences, consider one of the barriers that Professor Bird cited concerning writing texts. Neither young professors on the tenure track nor active researchers needing a continuing series of research publications believe that they can afford to take the time to write books.

Each school will have to address most of the foregoing issues, taking into account its own financial and personnel resources, state regulations, and the like. The ASEE and AIChE have a stake in the outcome and should consider how some degree of national coordination might be achieved. There is one important issue, though, that might benefit from active involvement of industry and government, as well as the academic community, and that is to encourage the preparation of outstanding textbooks.

Providing Forward-Looking Textbooks

As a student of Jack Powers at the University of Oklahoma in 1959, I was one of the first undergraduate guinea pigs for the "Notes on Transport Phenomena." That volume was John Wiley and Sons' preliminary edition of Bird, Stewart and Lightfoot's famous book that accomplished for that period of time all of the things for the field of chemical engineering that Professor Bird urges others to do today. The field of chemical engineering underwent a dramatic change between 1955 and 1965, and their book was a powerful force for that change.

Bird cited two other quotes:

> **The true University . . . is a collection of books.**
> ***—Carlyle***

> **There must be more books, for engineering data and interpretation of results are fundamental needs.**
> ***—Chilton***

But Bird's point about textbooks "determining the boundaries of the field" may mean either to expand or to circumscribe them. Unfortunately, because of the pressures disfavoring time spent in pursuit of writing books, many are far from revolutionary. As Robert Burton said in the early 17th century, "they lard their lean books with the fat of others' works" [7].

Some of the disincentives to writing texts are that the task

- **Is time consuming.**
- **Distracts from portions of the job considered critical to professional success—research and funding.**
- **Is not financially rewarding.**

These items would have to be addressed just to generate more books. But what is needed is not merely more books, but novel and different ones, written with a coherent goal to allow compaction of the curriculum through sharper focus—books that will use the new tools of today to impart information needed for tomorrow.

The Septenary Committee recommended that the content of every course in the chemical engineering curriculum be examined and changed where necessary to meet a number of criteria and urged that textbooks be rewritten in major ways. But how can incentives be furnished, and who will provide the needed focus over several years?

Leadership to change the field through improved texts is not likely to emerge spontaneously from the academic community, nor to spring from present market forces acting upon prospective authors. The remaining possibilities would seem to be government, industry, publishers, and professional societies. How might all six groups combine their efforts toward improving the supply of well-prepared chemical engineers, capable of contributing to the needs of government and industry in a way that rewards the authors and their employers appropriately to the degree of effort and accomplishment involved.

Once people see how much easier it is to learn from truly outstanding, well-prepared teachers who emerge to prominence as teachers rather than researchers, some schools that continue to neglect teaching may find themselves on the educational Catskill circuit.

Let us suppose that the goal is to persuade young, active research professors, already tenured, to devote the effort and time needed to write really good textbooks in chemical engineering. Furthermore, we want these books to incorporate examples in the newest technologies and to build computer applications into their core. If possible, we should like to encourage co-authorship, preferably by those representing more than one academic discipline or by a blend of perspectives from industry and academia.

As stated in the first item of Table 7, leadership should be provided by the societies, whose stake is in the preservation and enhancement of the profession. The Chemical Engineering Division of the ASEE, the AIChE, and the Chemical Research Council are examples of organizations whose fortunes rise and fall with that of the profession itself. There are, of course, other possibilities. For example, the "National Electrical Engineering Department Heads Association," which I am told has received NSF funding, meets annually to discuss issues important to that group.

Let us assume for a moment that some society would take on the role of setting goals, defining requirements for a series of texts that would achieve these goals, and reviewing the competing proposals that would be submitted if suitable incentives were provided. The society could establish a prize, say $100,000, split one-third upon selection of the winning prospectus and two-thirds upon acceptance of the final text by the society's reviewing committee and a publisher.

TABLE 7
Leadership

- **PROFESSIONAL SOCIETIES SHOULD LEAD**
- **SUPPORT SHOULD EMERGE FROM**
  - **— Government**
  - **— Industry**
  - **— Universities**
  - **— Publishers**
  - **— Authors**
- **FUNCTIONS OF LEADERSHIP**
  - **— Establish Goals**
  - **— Focus Activities**
  - **— Communicate**
  - **— Remove Obstacles**
  - **— Provide Incentives**

Financial support could come from both government and industry, and the universities could contribute faculty-release time for course preparation and text review as well as sabbatical leaves. A number of universities might agree to help evaluate draft texts and use the new texts for at least a trial period.

The next essential element is the publisher, who might agree to establish a series for these books and provide a standard set of rewards for the authors, over and above the initial prize.

The final element is the author. Another Robert Burton remark [8], is that philosophers advise you to spurn glory, yet they will put their names to their books. Prestige is a powerful motivating force, but this plan would allow the author to gain not only in reputation as an author and prizewinner but also to minimize the financial penalty.

Who would gain? Everybody. These thoughts have been discussed with a number of people in industry and academia. Most agree that money spent on stimulating the writing of really good textbooks would do more than an equivalent amount of money spent directly in support of research.

SUMMARY

When the future of chemical engineering is the subject, there is indeed much to talk about. First, some of the signs of change facing the chemical engineering profession were described and the underlying reasons for them were proposed.

Next, you were urged, as members of the academic community, to adopt a market-oriented attitude in addressing the needs of your traditional customers, the industries who have long employed chemical engineers. But also you were encouraged to include the electronics, food, health-care, aerospace, and other industries whose need for chemical engineers might be expected to grow in an increasingly technological society oriented toward high-value-in-use specialty products.

We then reviewed six areas of action to address the needs of industry by expanding the capabilities and improving the training of chemical engineers.

Finally, the problem of leadership was raised and the need for cooperative action in several areas was stressed. A way was suggested by which your society or other professional groups might enlist the aid of industry and government, as well as focus and coordinate your own efforts, to define goals and stimulate the creation of outstanding texts. Cohesive leadership must form the cornerstone of any effort directed toward stimulating evolution in the field of chemical engineering.

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