EDITOR'S NOTE: The following papers deal with the rapidly developing graduate programs for students with a B.S. outside chemical engineering. The first paper is a general survey paper, the second discusses a specific program, and the third gives a student point of view.

ChE GRADUATE PROGRAMS FOR NON-CHEMICAL ENGINEERS

E. L. CUSSLER
Carnegie-Mellon University
Pittsburgh, Pennsylvania 15213

WHEN TIMES ARE GOOD, college students tend to be interested in education. They study subjects because of inherent interest, without regard for the utility of what is learned. When times are unsettled, college students become much more interested in professional training. They believe that such professional education will facilitate employment. They often choose to study engineering because it provides one of the fastest routes to a professional degree.

Because times are currently unsettled, many students who have majored in chemistry as undergraduates are now interested in graduate study in chemical engineering. Most of these students have studied at private liberal arts colleges or at smaller campuses of state university systems. Those in the liberal arts colleges choose a more personal undergraduate experience. They are often undecided about a career or want additional time to mature. Those at the small state colleges are most commonly there because education is inexpensive. At both types of school, undergraduate engineering is rarely offered.

At the same time, many ChE graduate programs could use more qualified students. This is a consequence of the fact that there are more graduate programs than engineering student demand justifies. Many of these programs, which multiplied rampantly in the 1960's, have admitted huge numbers of foreign students to justify their existence. Independent of the foreign students' quality, many departments would prefer to enroll more North American natives. When departments see the supply of chemists available, the lure is obvious: why not teach ChE to chemists?

This essay explores the ways in which this teaching can be effectively accomplished. It explores what programs exist to do this, how they are operated, and how they can be started. In writing this essay, I have been strongly influenced by our own experiences. Our experiences and information are not exhaustive. Part of the reason is that there seem to be more programs for chemists than there are chemists in the programs, so that judging effectiveness is difficult. Another problem is that many seem reluctant to discuss efforts which have failed. In any case, before I start, I apologize in advance for not mentioning many specific experiences.

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OPEN ADMISSIONS

THE EDUCATION OF chemists as ChE's can be roughly organized into three methods. In the first method, one simply denies any difference. One admits chemists as engineers and has them take the same courses as engineering students. Such flexibility has a long tradition: almost every senior professor can remember a few individuals in the 1930's and 1940's who made such a transition. Moreover, it has the tremendous appeal of

requiring little extra work, either by faculty or by the administration.

What is different now is the number of students involved. During the past few years, I have been surprised to discover that in a significant number of ChE departments, chemists make up the majority of North American graduate students. These departments have bright faculty, strong research support, and reasonable reputations. Since they seem to have operated successfully for at least five years, there may be no problem.

However, I am concerned about this method because I believe it significantly changes the education of the graduates. If more than a third of my graduate class is not trained in chemical engineering, the technical level of the material taught drops. Moreover, because the current trend in many departments is to reduce graduate course requirements, one may certify "engineering" graduates who know very little engineering. I should emphasize that I cannot either support or refute these opinions; I just feel concerned.

UNDERGRADUATE REMEDIAL WORK

THE COMMON ALTERNATIVE to open admissions is a program which requires undergraduate courses as part of the transition. While the number of courses varies considerably (cf. Table I), all include courses in transport phenomena, and most require thermodynamics. After completing these courses, the chemist enters the conventional graduate program. The cost to the university is minor, since no new courses are involved. Such requirements certainly insure a solid engineering education of both breadth and depth, so that graduates can be fully employed as chemical engineers. They are demanding; for example, in the Texas A&M program, only 25-30% of the students originally admitted qualify for graduate study.

The characteristic of this type of program is that it can have trouble attracting students. The chemists whom we want to attract are bright, aggressive, and individualistic. They often are admitted to medical school but cannot afford to go; they always are admitted to graduate school in chemistry with full fellowships. They cannot afford to undertake extensive remedial work at their own expense, which is the common expectation. As a result, many of these programs may attract only a small number of superior applicants.

We have preceded our special summer course with a one-week mathematics review, taught by people connected with our affirmative action program. This has two results: it provides the minority and returning student with the necessary mathematics and it also establishes firm friendships between these two groups.

SPECIAL COURSES

THE THIRD WAY of teaching ChE to chemists is to require special courses giving an accelerated synopsis of the undergraduate engineering curriculum. This is the strategy we have used here, and so is that with which I am most sympathetic. The effective development of this approach here has been facilitated by generous assistance from the Exxon Education Foundation. Such special courses require additional faculty and administrative effort at an approximate cost to date of $10,000/year. However, because of this accelerated synopsis, the quality of other graduate courses need not be compromised. Be-

TABLE I. Typical Remedial Programs

(All of these lead eventually to a masters degree)

University of Buffalo
Two courses in transport phenomena; one in unit operations.

University of California, Berkeley
Variable; for example, courses in thermodynamics, transport phenomena, kinetics, and design plus another elective.

Clarkson College
Courses in fluids, thermodynamics, heat and mass transfer, kinetics, control, and design.

University of Delaware
Courses in stoichiometry, thermodynamics, fluid mechanics, heat and mass transfer, kinetics, equilibrium stages, and design; seminar; laboratory.

Rensselaer Polytechnic Institute
Courses in kinetics, design, control, and mass transfer; some prerequisites in previous summer.

Rutgers University
Two courses in transport phenomena; one in design, and in mathematical methods; audit in control.

Texas A&M
Courses in thermodynamics, fluid mechanics, mass transfer, process control, kinetics, design, electrical engineering, and materials; laboratory.

cause of its speed, bright students with chemistry backgrounds quickly qualify for research support on government grants and contracts. Seventy percent of the students entering complete their degrees. The major difference is that the graduates are not conventional ChE's but a new breed, armed with a new mixture of skills. The implications are explored below.

As the above paragraphs describe, the educational innovation in programs for teaching ChE to chemists largely arises from the special courses designed to give a prompt synopsis of ChE (cf. Table II). As a result, these will be discussed in more detail. Although accelerated, the Texas Tech program is most similar to the remedial courses in Table I. It takes a full year, and consists of material taught at the same rate as the undergraduate courses of the same description. The chief difference is that the students in this course are separated from the conventionally trained engineers.

TABLE II. Accelerated Courses for Teaching Chemical Engineering

Carnegie-Mellon University
Eight week summer course covering the following sequentially: stoichiometry, thermodynamics, equilibrium stages, fluid mechanics, heat transfer, mass transfer; senior level design course required during the academic year, and kinetics often taken as an overload.

Texas Tech University
One year course equivalent to stoichiometry, thermodynamics, fluid mechanics, stages, heat and mass transfer, kinetics, economics, mathematics, design.

University of Virginia
Nine week summer program of two parallel courses consisting of 1) mathematics, fluid mechanics, and heat transfer; and 2) heat transfer, mass transfer, and kinetics.

The other two special courses, at Carnegie-Mellon and Virginia, consume about eight weeks of the summer before the masters year. They commonly have three hours of lecture per day, five days a week. They also have at least one problem-solving session every day. These problem sessions can run a long time. I had one at Carnegie-Mellon that started at 3:00 p.m. and continued until midnight. In our program, tutors are available both in the afternoon and in the evening. These tutors are largely graduate students whose backgrounds are in chemistry and who have already successfully completed the masters program. We rarely assign individual tutors to specific students.

The content of these two special courses is obviously a synopsis of undergraduate ChE. The students joke that the freshman year takes one week, the sophomore year two weeks, and the junior and senior years about three weeks apiece. Somewhat to my surprise, the plethora of topics listed can be effectively covered. To test this, we have given the same exams both to undergraduates and to students in the program. The students in the program easily outscored the undergraduates. This is a result of the students' quality, their maturity, and their dedication to making an effective transition.

TROUBLE WITH MATH AND THERMO

THE CHEMISTS HAVE the most trouble in two areas: mathematics and thermodynamics. Mathematics presents a big problem. While most students have studied differential equations, few can apply what they've learned to physical situations. Virginia's program teaches mathematics directly. Ours relies on graduate-level mathematics courses taken in the fall semester.

In contrast, the student's deficiency in thermodynamics is less expected and harder to rectify. While most of the students in the programs in Table II are graduates of ACS-accredited chemistry departments, and these departments do teach a required thermodynamics course, most of the students claim to have had little or no thermodynamics. I think the truth is probably more nearly what one student said, "Sure, I had all this stuff but no one ever acted like it was important."

We have tried to remedy this deficiency in thermodynamics by including material in the summer course. We have not yet been able to teach this material effectively, partly because an extremely abstract subject is being presented at a very rapid rate. After the summer, students do not feel that they understand thermodynamics. They are able to handle our graduate course in thermodynamics in the fall semester, but the experience is trying, demanding, and unpleasant. I know no simple way out of this problem.

The summer courses also contain no reference to engineering design. Our program, and several of the remedial ones, correct this by requiring that students with chemical backgrounds take a senior level design course. Our special students work much harder than our seniors, do better, and thus cause some resentment. I think pushing our seniors this way is healthy.

We've had two other problems with our special

summer course which deserve mention. The first is that we have not been able to find an effective text. The reason is that ChE is almost completely taught in a sequential fashion. Everyone who studies sophomore thermodynamics intends to take the junior-level transport phenomena courses and the senior-level kinetics courses. This means that there is no single text providing an abbreviated overview of essentials of ChE in relatively simple terms. As a consequence, we have had to write a text, which we would be glad to make available to others with similar problems. We plan to revise and publish this text soon.

The second problem we have had concerns retaining minority students in the program. Both they and students who have been out of college three or more years find the mathematics required to be extremely difficult. As a result, we have preceded our special summer course with a one-week mathematics review, taught by people connected with our Affirmative Action Program. This has two results: it provides the minority and the returning student with the necessary mathematics and it also establishes firm friendships between these two groups. When the rest of the class convenes, the black students do not isolate themselves as frequently occurs in undergraduate classes.

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I should emphasize that special summer courses are not substitutes for undergraduate training in ChE. It merely facilitates the student's ability to catch up throughout the regular academic year. Students whose backgrounds are in chemistry do less well relative to their classmates during the fall's courses. By spring, this difference disappears. In other words, the special summer course does not substitute for undergraduate training, but does allow students with different backgrounds to become competitive.

STUDENT RECRUITMENT

WHILE GRADUATE PROGRAMS which teach ChE to non-chemical engineers are multiplying rapidly, these programs often do not have large enrollment. In some cases, the faculty time spent planning them may exceed the student time in them. As a result, it is appropriate to ask where the students in this program will come from.

Most of the larger programs have found that the best source of students is the small liberal arts colleges located close to the university. These small colleges commonly do not offer undergraduate engineering programs. Moreover, because they are close by, the universities' reputations are exaggerated. The students recruited from these colleges have already rejected graduate training in chemistry. Considerable competition comes from schools offering a masters in business administration.

A second effective source has come from general mailings to chemistry departments, again largely at small colleges. We have been particularly successful with the minor campuses of major universities like those of New York and Ohio. We also receive good applications from high school teachers and from employees of local industries. Advertisements in ACS student newsletters and announcements in publications like *Chemical and Engineering News* and *Business Week* have not been effective.

One neglected aspect of these programs is their potential for social action. Specifically, they provide an opportunity to bring additional women and minority studients into engineering. We have been very successful recruiting female teachers from local high schools. They are eagerly recruited by industry because their maturity and perspective makes them excellent candidates for middle management positions. We have been much less effective in recruiting blacks. Part of our trouble is that qualified blacks in chemistry choose medical school. Moreover, chemistry programs in predominantly black colleges sometimes have less stringent requirements in mathematics than those existing elsewhere. Nevertheless, we are convinced that we can effectively recruit minority students in the long term.

Once applications from qualified students come in, one must decide on how to admit them. Applicants commonly fall into two sharp categories. The first category are chemists with very weak undergraduate records. They are grasping at straws, desperate for any opportunity which promises a better chance of employment. The second category are students who are very good; they have decided to go on to graduate school and

are carefully weighing options.

The best predictor of student performance is the quantitative aptitude part of the Graduate Record Examination (GRE). We require scores of at least 700 and preferably 750 to insure satisfactory performance. GRE aptitude scores are also useful in making a decision if the quantitative aptitude score is marginal. GRE advanced chemistry scores are less reliable, and reflect more the quality of the undergraduate institution than the quality of the student. Grade point seems the hardest to interpret. Basically, we have discovered that an entering chemist needs a (3.4/4.0) overall grade point to be effective. This is higher than that needed by entering ChE students.

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WHAT DO GRADUATES REPRESENT?

NONE OF THE PROGRAMS outlined above can produce students who are identical with those trained completely in ChE. This can be especially true when large numbers of students are trained under the open admission strategy described above. This strategy is so wide and leads to such variation that generalizations seem meaningless. On the other hand, if sufficient remedial courses are required, the student should certainly become more and more similar to those trained completely in ChE.

The most intriguing question is, to what category do the students who graduate from programs built around rapid special courses belong? To answer this question, we contacted graduates of the special programs who are employed in industry. These graduates had more job offers at slightly higher salaries than conventionally trained masters engineers. Their reactions to the positions they accepted, and their supervisors' reactions to them are shown in Table III.

One conclusion is that those trained in chemistry have a more pragmatic attitude than those trained in engineering. For example, these students complain that the masters courses are too theoretical, while students with an engineering background feel the same courses are excessively applied. Apparently, those who move from chemistry into engineering make a mature and conscientious decision that their future lies in an industrial environment. They are very sensitive to industrial demands and respond accordingly. On the other hand, those trained in engineering go to graduate school in part because they are anxious to learn more of the intellectual basis of their discipline. This basis is more strongly represented in universities than in industry.

TABLE III.

Job Performance of Graduates

FROM THE GRADUATE

1. **How do you view yourself professionally?**
   A mixture of a chemical engineer and a chemist.
2. **To what professional organization(s) do you belong?**
   Most belong to both the American Institute of Chemical Engineers and the American Chemical Society.
3. **Does your job provide adequate professional challenge?**
   Yes—both chemical engineering and chemistry required.
4. **Did the program provide you with the professional training you expected?**
   Yes—worked effectively.
5. **In your job, do you see any professional advantages or disadvantages of your training compared with a traditionally trained chemist or chemical engineer?**
   Advantages over chemist; often translator between chemists and engineers.
6. **Do you have any other comments, suggestions or observations about the program?**
   Many courses were too theoretical; Masters thesis takes too long.

FROM THE SUPERVISOR

1. **How do you regard the professional training the graduate has?**
   Pleased so far.
2. **Do you see any advantages of this type of program over traditional majors?**
   A range of answers—from disadvantages to advantages to ignorance of program.
3. **How would you rate the graduates initiative, flexibility, maturity?**
   Much better than average on all points.
4. **Do these graduates require more supervision?**
   Most require an average amount of supervision. Those who require more do so because they are more productive.
5. **Do you have any other comments, suggestions or observations?**

Positive comments with good advice: e.g., "students should choose positions with a mixture of chemical engineering, chemistry;" "student quality more important than education;" "should use these people to replace chemistry Ph.D.'s."

A second conclusion which can be drawn from Table III concerns the students' effectiveness. This effectiveness is largely inherent in the students themselves. If they are bright, smart and aggressive before entering a program, they remain so afterward. As a result, their performance has more to do with their own character and ability than with any educational gloss. These students apparently perform a mixture of tasks. Certainly industrial jobs require a continuum of skills: they are not balkanized between science and engineering as are the university departments. However, industry recruits within the departmental structure and recruiters seek not specific individuals but people with specific types of certification. The students are being hired as engineers, but are working as hybrids.

AT YOUR UNIVERSITY.....

AS THE ABOVE paragraphs show, there is now extensive experience on how to start a graduate program for teaching ChE to non-chemical engineers. If you decide to develop such a program at your university, you should do three things. First, decide on a strategy. If you plan to use open admissions, be sure you assemble sensible arguments defending the quality of your program. If you decide to require a significant number of remedial courses, think about how you plan to attract and retain smart students. If you decide to use special summer courses, you must discover a source of money to pay the additional cost.

The second thing you need to develop is a scheme for recruiting students. Any program which has an enrollment of less than about half a dozen will inevitably attract administrative criticism in hard times. You must decide whether to recruit locally or nationally. You should decide whether you are more attractive as ChE department or as a university. Moreover, the mailing list that you use to attract students should take advantage of undergraduate chemistry newsletters and local ACS meetings. Advertisements in *Chemical Engineering Education* won't help because chemists don't know this journal exists.

The third thing you should do is to talk to others with experience. Most, if not all, of the departments mentioned in this article are willing to send to any who are interested detailed material, including hour-by-hour course outlines, and copies of lecture notes. It would be foolish not to take advantage of the experience of others.

Finally, I wish you good luck. I find rigidly structured departments a real discouragement to free thought. I look forward to the time when it is easier for students to move back and forth between disciplines to develop unique skills which will make them professionally more interesting, interested and effective. □

EXPERIENCE AT ONE UNIVERSITY

R. M. BETHEA, H. R. HEICHELHEIM, A. J. GULLY
Texas Tech University
Lubbock, Texas 79409

AT THE HEART of our accelerated expansion program lies the premise that the holder of any baccalaureate degree has demonstrated intellectual maturity, and, with sufficient motivation, should be able to undertake almost any study of his choice. If such study were to be at the graduate level, he would have to have the background information to follow the advanced study, and, equally important, he would have to have enough "skill" in the discipline to compete at the graduate level with holders of the bachelor's degree in that major. With the foregoing in mind, we examined the course content of each departmental undergraduate course required for the B.S. Ch.E. to determine what topics a person entering our graduate courses would need as an absolute minimum. We also examined our undergraduate requirements in science and mathematics in the same light.

The chemical engineering component of our