is small. Of the 31 schools whose curricula were examined, only two offered five-year curricula and both of these had multifurcated programs.

The 11 schools having multifurcated programs in chemical engineering had an aggregate of 53 separate options specifically designated (including 11 chemical engineering options). The distribution of these programs by number of options, or multifurcation index, is shown in Table I.

**TABLE I. Multifurcation Levels of Eleven Large Chemical Engineering Schools.**

| Number of Schools | *Multifurcation Index |
|---|---|
| 5 | 2 |
| 2 | 3 |
| 1 | 6 |
| 1 | 7 |
| 1 | 10 |
| 1 | 14 |

* A multifurcation index is defined as the number of alternate routes in a chemical engineering curriculum. For example, a bifurcated curriculum would have a multifurcation index of two.

That multifurcation does exist to an appreciable extent in chemical engineering curricula today can be concluded from the number of curricula involved, the percentage of students graduating annually from such programs, and the magnitude of the multifurcation index. Lumping all programs leading to B.S. Ch.E. degrees into one category for statistical analysis should no longer be attempted, therefore, if the results of a curriculum survey are to be meaningful.

In conclusion, the remarks of Thatcher at the ASEE-A.I.Ch.E. Summer School for chemical engineering teachers at Boulder, Colorado, in 1962 are appropriate:

"There have been significant changes within a relatively stable curricula framework. The lamentable fact is that such changes are all too frequently not reported to groups such as this so that they can be tried elsewhere, perhaps adopted, and, most important, perhaps built upon to achieve even more satisfactory results."

Let us continually analyze our curricula and their courses, in terms of what we are trying to accomplish, how we are going about it, and how effective our efforts are. Let us experiment to identify new and more effective ways of achieving our objectives. And finally, let us report the results of both our analyses and our experiments.

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# Science, Technology, or Both?

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The term "bifurcation" was introduced into discussions of engineering curricula a little over a decade ago through the activities of the ASEE Committee on Evaluation of Engineering Education, known as the Grinter Committee.

About 1951 it became evident that a critical appraisal of engineering education was badly needed. Relatively few major changes had been made for many years. The general form of engineering curricula had become fairly well standardized some 50 years before; and as new programs, such as Chemical Engineering, were formed, they largely followed the traditional pattern. Modifications in response to the changing demands of the profession consisted mainly of updating technical information and introducing new methods of solving problems.

The impact of the war served to de-emphasize curricular programs and to emphasize research and development. Superimposed on this was the need for specialized training courses, and universities became more and more involved in project-oriented research.

As research results and sweeping technological advances were applied to peace-time industry following the war, broad changes were needed in engineering courses of study. Recognizing the urgent need to examine these problems, Dean Hollister of Cornell, then President of ASEE, set up a committee of about 40 under the chairmanship of Dean L. E. Grinter for the evaluation of engineering education. This Committee met for a total of about thirty working days during the three-year period 1952-5 and discussed every aspect of engineering education.

The Committee reasoned that engineering graduates, although needing preparation for a broad spectrum of activity from sales to research, shared certain attributes: proficiency in mathematics and the physical sciences; mastery of those principles that make engineering more science than art (the engineering sciences); need for the understanding achieved through social-humanistic studies; and the key characteristic distinguishing engineer from scientist — the ability to synthesize, to design, to create new products for the needs of an ever-demanding civilization. To provide these attributes in a four-year program was judged to be no easy task; in fact, all the obvious methods of simple improvement (five-year curricula, better preparation of high school graduates, elevated standards of admission to engineering schools) appeared to be inadequate. The Committee made the preliminary recommendation, therefore, of curricular bifurcation to permit stressing either the operational or the research-development aspects of engineering.

There was immediate and widespread opposition to bifurcation on the basis of assumed increased instruction cost and administrative complications. Every department might be required to offer two separate curricula, it was feared. Furthermore the graduates of one of the two curricula might be regarded as second-rate citizens, and this would reflect badly upon the entire engineering profession. As a result of the violent reaction, the concept of bifurcation was not included in the final report.

Although bifurcation was rejected, the need suggesting it was real. Consequently, to meet this need engineering curricula have swung generally to the science side of the spectrum (with considerable opposition by some professional societies out of fear that graduates may have insufficient operating knowhow to enter jobs without additional training by employers).

The question now is whether there exists another solution to the problem — a solution that will enable a student to become knowledgeable in the practice of his job and also in the principles required to keep abreast of developments until he reaches his career peak (about 2000 A.D. for current undergraduates).

In considering a program that will be responsive to the spectrum of engineering activities, it may help to review the processes of invention development. A new idea — nuclear fission or the laser principle, for example — emerges from the inventor's shop or the laboratory, the result of discovery.

In order to exploit the idea, additional engineering research must often be performed to provide reliable engineering information. These activities phase into development and then into design. Design involves the selection of suitable materials and components, their optimum arrangement, and a thorough economic analysis. Next comes production, followed by sales and (inevitably) by servicing. The process is then repeated to improve the product.

The preceding steps, each requiring clear decision making and informed thinking, represent the range of engineering function, but one man seldom participates in all. Rather the engineering graduate tends to gravitate to one of three overlapping categories of specialization: (1) research and development; (2) development, design, testing, and possibly production; and (3) production, sales, and servicing. Should we train a student for all three categories, for one of them, or for two?

We observe, indeed, that currently there is a pattern of preparation for each category. Production and servicing are increasingly manned by graduates of Technical Institutes. The principal design, testing, and production aspects are usually supplied by BS engineers; and, traditionally, research and development are the primary outlet for men with advanced degrees. Experience teaches us, however, that what is in the graduate program now may be in the undergraduate a few years later.

We may approach this from another direction by considering what the engineer of 30 years from now may be doing. Such extrapolation of current activities is regarded as a primary sin by many engineers. However, for too long engineers have ridden facing backward as civilization has hurtled forward; experts in what has happened, they have not looked ahead to avoid such acute problems as atmospheric pollution and transportation.

In my opinion we may expect the following changes:

1. The systems with which engineers deal will become increasingly complex, as evidenced by today's communications systems and space vehicles.
2. Entirely new dimensions of research will evolve as more is learned about materials, energy, and the functioning of the human mind.
3. The mechanics of design will move rapidly toward automation, in response to the increased complexity of systems and the wealth of materials available for construction. Optimization offers additional possibilities. Design is becoming a programmed science rather than an art.
4. New methods of information communica-

tion will be evolved so that tools, techniques, and data available in one location can be transmitted instantly to the designer or analyst who needs them.

5. Advances in production techniques will permit factories to become completely automated.
6. Boundaries between the various engineering disciplines will erode. Interdisciplinary thinking will prevail over the narrow viewpoint of professional specialization. Boundaries between the physical sciences will break down. The trends of interdisciplinary cooperation between the engineering sciences and the biological sciences will extend to the other sciences as well.
7. Engineers will emerge as the planners and coordinators of the efforts of technological specialists in much the same way that project engineers today coordinate the efforts of engineering specialists.
8. We shall graduate engineers for two types of careers:
   (a) That of high-level planning and coordination, bringing to products and systems not only the basic physical and economic considerations but also far reaching environment and sociological implications.
   (b) That of special understanding of the nature of things and the provision of detailed information necessary for complete planning.

   This leads us to the conclusion that we must not force all engineering students into the same mold, but must have educational flexibility. Some students will have the aptitude for broad training, whereas others will be more qualified to delve into individual areas of technical specialization. However, such specialization will be of a different character from that now envisioned as the ideal for the engineering Ph.D. For example, with the ready availability of information on a scale only dimly envisioned today, generalization of knowledge may in itself become an area of specialization.
9. Much of what engineers today are doing will be done by graduates of technical institutes; much will be performed by machines.
10. A final item can be predicted with certainty — 30 years from now engineering educators will still be discussing how to improve their programs to prepare engineering graduates for the years ahead.

# A Two-Option Curriculum In Chemical Engineering

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The field of chemical engineering has become so broad and diversified that a two-option plan for undergraduates was introduced at Iowa State University in the fall of 1961. The first class given full advantage of the bifurcated curriculum graduated in 1963. A description of the program and a discusion of some of the early results follow.

**General Character of the Options**

The two options are those of Design and Production (D & P) and of Research and Development (R & D). The first is for students who are interested in the design, construction, operation, and management of manufacturing plants in the chemical process industries. The second is for students who are interested in basic or applied research and development and/or graduate training. While the D & P Option is the more traditional in nature, the R & D Option involves more mathematics, science, and engineering fundamentals. Both lead to a B.S. degree in four years for qualified students.

This system makes the curriculum flexible and yet insures every student certain basic subjects essential for all chemical engineers. Limited substitutions are allowed for even greater flexibility in some cases. The abler student can take advantage of special Honors and Undergraduate Research Participation Programs to secure a more tailor-made curriculum.

Students are allowed a free choice of options. Both options are considered equally important and challenging. It is felt that a student should have the opportunity to base his election entirely on his personal interests and goals. Of course, the R & D Option would not be recommended to anyone displaying weakness in mathematics.

**Time for Decision**

Most undergraduate engineering curricula at Iowa State University are designed for completion in four academic years of three quarters each. The first year is a preprofessional program which must be completed with at least an average grade point of 2.0 (4.0 maximum)