DEVELOPMENT AND CRITIQUE OF THE CONTEMPORARY SENIOR DESIGN COURSE*

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SENIOR DESIGN COURSES VARY far more from school to school than any others in the chemical engineering curriculum. The particular form of a given course seems to depend mainly on

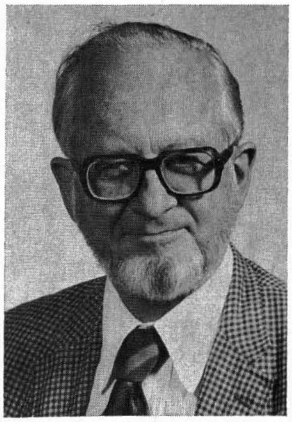
- **the tradition in a department**
- **the goals of the instructor or staff**
- **the degree of faculty participation**
- **the availability of resources**
- **the instructor's experience or background**

In view of the spectrum represented by the design course as offered across the U.S., a careful and orderly consideration of its many aspects has been made as a way to clarify its goals and to point out ways to improve this course.

RATIONALE FOR THE DESIGN COURSE

THERE HAS BEEN A STRONG consensus, almost unanimous, among chemical engineering educators, that a major design exercise represents an essential element of the curriculum. Common justifications for this position are:

- **an integrating experience—a course in which the students draw on and use their wide and varied resources**
- **an opportunity for the creative application of theoretical fundamentals to practical problems**
- **an exposure to the real world of engineering; in particular the handling of open-ended problems**
- **an exercise in organizing and completing a complex project**
- **the introduction and/or use of economics in the decision-making process as a vital and central factor in design.**



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DEVELOPMENT OF THE SENIOR DESIGN PROJECT

THE EVOLUTION OF THIS course can well be traced in terms of the content and emphasis of the design texts used by U.S. schools over the past forty years. It can be considered to have taken place in five stages which overlap to some extent.

1. **Preliminary engineering along with process calculations was emphasized; this preliminary engineering was concerned with items such as simple foundations, and service facilities. See three editions of Vilbrandt [1].**
2. **The engineering calculations become concerned almost exclusively with the process design. And at the same time projects of some complexity were regularly undertaken. Both these trends are demonstrated in Vilbrandt and Dryden [2], and Baasel [3].**
3. **Engineering cost analysis, and sometimes optimization, were formally made a regular part of the project; this is especially emphasized by Peters and**

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Timmerhaus [4, 5]; it is also demonstrated by Baasel [3], Sherwood [6], and Bodman [7].

4. **Rules of process synthesis as elucidated by Rudd et al. [8], and Motard and Westerberg [9] are used. They serve to codify good engineering practice, and both facilitate and optimize the selection of necessary process steps.**
5. **The use of computer programs was introduced for process design and also, in some cases, for engineering cost analysis. Examples of such program are: FLOWTRAN, CHESS, CHEMOS [10].**

For this development the rationale declared above was fully realized by the third stage, i.e., the economic evaluation of preliminary process designs for complex projects (this corresponds to systems engineering), and the ability to solve open-ended problems (this is considered to be the application of the practice of engineering.) The fourth and fifth stages are concerned with sophisticated techniques which, in recent years, have often become the *raison de etre,* and thereby have often served to obscure the basic goals of the design course. The primary goal of the senior design project should not be the teaching of special techniques or even process design *per se.* Rather it is a means to an end: an experience in the practice of engineering. Fortunately the field of chemical engineering provides excellent tasks for realizing the stated general purposes of the design course. In contrast, other engineering disciplines appear to lack manageable vehicles that are as complex; projects are generally restricted to only elements of a system: structures, machines, and devices.

The purposes of a curriculum are best served by recognizing the stated basic goal of a senior design course, and then providing opportunities for students to organize and complete complex, open-ended problems. Sophisticated techniques should be explained to demonstrate helpful, available tools, but facility in their use should not be the primary end.

NATURE OF THE ASSIGNMENTS

CHARACTERISTICS COMMON TO THE preponderance of senior design courses are commented on below:

Subject Matter: Processes amenable to chemical engineering type analysis are usually selected; for example, they include wastewater treatment, flue gas desulfurization, food processing, artificial kidney system, and the processing of nuclear waste. The range of possible problem topics is demonstrated by the AIChE Student Contest Problems, and the Washington University Case Study Series in Design [11], Sherwood [6] and Bodman [7].

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Number of Exercises: These vary from comprehensive projects such as the examples cited above, to two or more graded exercises. Statements of suitable short problems can be found in Peters and Timmerhaus [4, 5].

Level of project execution: The conception and level of most projects corresponds to what is termed a preliminary process design. This requires

- **A definition of the process as expressed by a process flow diagram, e.g., Baasel [3, p. 262], Vilbrandt and Dryden [2, p. 65], Sherwood [6, p. 9]**
- **Mass and energy balances. The results can be effectively presented on flow diagrams, e.g., Vilbrandt and Dryden [2, pp. 65, 67]**
- **Sizing of major pieces of equipment for the battery-limits process**
- **An engineering cost analysis**
- **Sometimes, a process control scheme**

The sizing of lines (piping) is not usually included, also, ancillary facilities are specified for the scope, but not designed or sized. The capital cost for the battery-limits plant is usually estimated by a factor times the sum of the delivered cost of the major equipment items.

Format of Completed Report: The design is presented in a report that includes appropriate background, a description of the process, the completed preliminary process design, an engineering cost analysis, comments, conclusions, and in an appendix examples of the calculations. A form is outlined in Peters and Timmerhaus [4, 5], and specified in the instructions for many of the current AIChE Student Contest Problems.

From school to school reports are fairly consistent with respect to format, the range of subject matter, and emphasis on project innovation. The variation occurs in the number and kinds of assigned exercises. Some departments work only one major problem, others consider several shorter exercises, but graded in difficulty; most schools assign at least two projects—often the last is the AIChE Student Contest Problem, to be solved either by a group or by individual students.

EXECUTION OF DESIGN COURSE

ESSENTIAL REQUISITES ARE AN awareness of the goal, appropriate projects, and students who are both adequately prepared and genuinely interested; but the quality of the course depends on its execution. This calls for a sound plan, effective management, and sufficient resources—mainly faculty. Successful execution is assured by following these three basic ground rules:

- **The students should work in groups, at least for the more complex problems. A three-person group is widely held as ideal and two persons are considered satisfactory; with four or five person groups it is commonly observed that one or two persons tend to participate less, if at all.**
- **The progress of the design effort, particularly in the more advanced or final problem, needs to be monitored, reviewed, and discussed in scheduled sessions with the instructor. However, it is desirable that the instructor also be available for a few posted hours each week for impromptu queries. If the counsel is always available, the groups may tend to "lay back" and lose initiative. Because of this kind of interaction, this course is unique—it assumes the character of an internship.**
- **The projects, particularly the major one, should compel the student to "stretch"; that is, to require knowledge and information beyond that drawn from past resources. It should demand that the student learn and gain facility in subject matter on his own, with guidance or tutorials from the instructor only as a last resort.**

If assignments are made, designs undertaken, and reported without the benefit of these three practices, the exercise . . . most often degenerates to a fantasy of "busy work."

The orchestration of this conventional wisdom requires a considerable investment of faculty time. If assignments are made, designs undertaken, and reported without the benefit of these three practices, the exercise (although impressive in terms of the bulk of paper generated) most often degenerates to a fantasy of "busy work." Students can be misled regarding the efficacy of such unguided or undemanding efforts.

Effort of the Teaching Staff: The intelligent use of adequate and competent staff is essential. Assistance from capable persons in industry can be valuable. However, their efforts should be well coordinated. Industry persons are of use as lecturers, but they are of greater value for the combination of advising and grading reports of a few groups. For this they must be on hand at scheduled times (preferably once a week). Experienced teachers agree that graduate students serving as course assistants can contribute little guidance to students, in particular because they lack the background of practice and because of limited experience in their field. By far the most important factor is the effort and competence of the faculty.

Obviously, course instructors should have some process experience—in design, operation, or development. This requirement can be obviated by faculty with an interest in design, and by the use of solved exercises such as the Washington University Case Series in Design [11]. Sufficient staff time and energy is more essential; the intensity of effort is higher than that ordinarily demanded by lecture courses. Also, because fresh problems are assigned each year, the demands correspond to that for a new course preparation. In addition, the conferences with student groups (both scheduled and impromptu) add up to one to two hours per group each week. Because of these considerations, and to retain freshness in the face of tedium generated by too much exertion in this one course, it is fairly well held that one faculty member cannot effectively handle more than about twenty students, or five or six groups. Fair and Smith [11] state: "The manpower commitment . . . to support a really effective, professional process-design course, . . . requires at least twice as much time to teach as an ordinary lecture course." Accordingly, chairmen often have a problem adequately staffing this course. Some faculty avoid making their contribution because the exhausting labor is offset with correspondingly little credit, and it bears no connection to their scholarly activities.

The staffing problem for the design course has become acute with the upsurge in enrollments. Departments are faced with fifty or more seniors instead of the twenty which could be handled by a single faculty member. This has generally meant fewer and larger groups, less advising, and less demanding projects; each of these factors reduces the benefits to students.

Help from Industry: There are two kinds of significant assistance from industry. One is by individuals to a particular school. As mentioned above, this takes the form of lecturing, advising, and grading. If well coordinated with the overall schedule, it can prove significant. Students respond well to lectures and pointers from practi-

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tioners, who are working "on the line." And their help in advising and grading can be invaluable.

The other form of assistance comes from industrial support of several, well-established, regular programs. Examples are:

- **The preparation and then the evaluation of the AIChE Student Contest Problem.**
- **The preparation and publication of the Washington University Case Series in Design (11)**
- **The preparation of material for the FLOWTRAN program (10).**

These provide a treasury of teaching materials.

Competent assistance from industry should be used whenever it is available, provided that it can be well coordinated with the scheduled program. Such help is much more valuable when it is offered periodically, e.g., once a week, and where the service includes advising several groups of students, and grading design reports.

It must be recognized that the manpower requirement from the regular staff is considerable, and that it varies somewhat with the number of students taking the design course. For a "meaty" course with a reasonable size class (say twenty students), it is considered to take about twice as much effort as teaching a regular lecture course.

THE STUDENTS: PRIOR TRAINING AND ATTITUDE

IT IS COMMONLY ASSUMED that students entering their fourth year in chemical engineering in accredited programs possess the requisite background and motivation to undertake a substantial design project. This implies some proficiency with process calculations. Unfortunately, this appears to be less true today than it was a decade or two ago. The two main reasons seem to be:

1. **Courses intended to develop ability in essential process calculation, e.g., mass and energy balances, often lack the required intensity of effort. The result is that on the average students have less grasp of the fundamentals, and are not sufficiently facile with the elementary computations.**
2. **Currently, many curricula emphasize analysis, sophisticated techniques, and also more credit hours for electives at the expense of a sound understanding of, and facility with, fundamental engineering subject areas.**

Then there is the matter of the attitude of the students. Although the engineering schools are again enjoying large enrollments, with the current "career oriented" attitude there seems to be less will on the part of students (in fact around the world) to expend the intense effort demanded to experience a professional-level education. And in engineering, a design course appears to be critical in this regard. Further, in today's educational milieu, students seem (to some extent) to determine the pace of their education.

The trend in curricula toward too much specialization by courses (too many electives) can be held in check by accreditation standards and visits. However, the vitiation of fundamental courses by inordinate detraction to subsidiary topics and special techniques can proceed undetected.

There seems to be little that the teaching profession can do to obviate the deleterious effects on declining student commitment and interest where it occurs.

THE FUTURE

THIS REVIEW RAISES SEVERAL questions. Is the design course as taught along these established lines in a malaise? Note that it now attempts to include the features most recently published by ECPD [12], namely:

a. "development of student creativity,
b. use of open-ended problems,
c. formation of design problem statements and specifications,
d. consideration of alternative solutions,
e. feasibility considerations, and
f. detailed system descriptions."

However, some change may elicit favorable response and fuller commitment of students. The ECPD document [12], which expresses the desire for design contributions in the curriculum "to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact" may provide some stimuli. Instructors at some schools have already been taking such suggestions to heart.

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CRITIQUE OF DESIGN COURSE

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On the other hand, should chemical engineers boldly strike out and endeavor to develop new forms for "the creative application of fundamentals to practical problems?" Or would another kind of course provide a better synthesis experience for our times? Do we see a candidate in a course based on the text "The Structure of the Chemical Process Industries," by Wei, *et al.* [13]? As stated in its preface, this book has the worthy purpose of making one understand "how chemical technology is mobilized to benefit society, and how chemical engineers can contribute effectively to it."

The design course may be in a rut. If so, changes for just the sake of change (a common motivation for curriculum redesign) should be avoided unless the contending schemes are superior to traditional programs. New directions are encouraged by the 1979 definition of the design experience in education [12] The book by Wei, Russell, and Swartzlander suggests a new kind of capstone experience. ☐

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APPENDIX

For running in still air at velocity v, the drag force of the wind is:

$$F_{wind} = C_d \rho_a v^2 A \qquad (1)$$

Assuming a cylindrical form of radius r and height H for the body, the projected area is:

$$A = 2rH \qquad (2)$$

and the volume is:

$$V = \pi r^2 H = \frac{M}{\rho_b} \qquad (3)$$

Elimination of r in Eqn. (2) using Eqn. (3) gives:

$$A = \frac{2}{\sqrt{\pi}} \sqrt{\frac{MH}{\rho_b}} \qquad (4)$$

The mechanical power for overcoming wind resistance is:

$$P_{wind} = F_{wind} \cdot v \qquad (5)$$

Substituting Eqns. (1) and (4) in (5):

$$P_{mech} = \frac{2}{\sqrt{\pi}} C_d \rho_a v^3 \sqrt{\frac{MH}{\rho_b}} \qquad (6)$$

The error resulting from the incorrect assumption of cylindrical form is cancelled by calculating C_d from experimental data [5] for the drag force on the body during running. Defining $\rho_b = 1000\ kg/m^3$, the drag coefficient C_d is found to be 0.50.