A Freshman Course

PROCESS MODEL-BUILDING: AN INTRODUCTION TO COMPLEX DESIGN

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THE ENGINEERING SCALE model is more than a publicity ornament or marketing aid. It is used in all phases of project engineering from concept evaluation through design and construction. Other applications include maintenance and personnel training. Nearly all engineering endeavors involve some model effort. In fact, many engineering accomplishments survive only as models—long after the full-scale version has passed into oblivion.

In the chemical industry the engineering process model has become an essential part of engineering design [1-7], as well as being useful in construction[8], maintenance [9,10], and process analysis [11,12]. The model-building itself can be a critical path activity in project engineering [6]. Even the computer design of piping systems can be based on model measurements [7]. Numerous illustrations of such chemical [13] and nuclear [14] plant models can be found in the literature.

This study suggests that the design and construction of process models can serve as an effective introduction to complex design for engineering freshmen.

BACKGROUND

FOR SEVERAL YEARS the engineering curriculum at Clarkson College of Technology has included a two-course freshman engineering sequence. The principal objective of this sequence is to provide an introduction to computer programming and engineering design. The general organization and history of the sequence have been discussed earlier [15,16]. In particular, the second course, entitled "Introduction to Complex Design," extends throughout an entire fifteen-week semester. During this period, the student is primarily involved in a group design project.

Faculty members from all engineering departments are assigned to this design course as project supervisors. In addition to the faculty instructor, several undergraduate students are usually selected as student tutors for a project and are given an honorarium for this activity. Each instructor for this design course prepares a short project description for distribution to prospective students and from 30 to 70 freshmen are then assigned to a project on a preference-ranked basis. As a result, a chemical engineering project will usually involve students from other engineering disciplines.

There is no fixed format or content for this freshman design course. The only expressed goal is the involvement of the student in some phase of engineering design, preferably through a first-hand experience. As a result, the nature of the course has varied widely [17]. The most effective chemical engineering activities for these large project groups can be classified as design synthesis or design execution.

In the design synthesis approach [18], a loosely-defined process engineering problem is posed. The students, in three-man design teams, are gently guided through the steps of problem definition, flow charting, material and energy balance calculations, equipment selection, and economic analysis as needed to complete a preliminary design feasibility report. Typical projects have involved wet combustion of sewage, conversion of waste to oil, coal gasification, and heat exchanger parameter optimization. This approach is relatively effective for the large student groups involved and is economical to operate. It can easily be guided to completion so as to provide the students with a sense of accomplishment.

The design execution approach has emphasized the planning, construction, and testing of a design. The student, again as part of a three-man group, actually constructs a prototype design. Typical projects of this type have involved a fuel-cell parameter optimization, fuel-cell power system for a minibike, a hydrogen combustion engine, and a fermentation reactor optimization. Since a freshman engineering student at Clarkson College is not required to take any laboratory courses, this second approach offers the appeal of "gadgeteering" and hardware involvement that many engineering students seek. However, it is more costly and involves an extensive faculty effort to achieve enough hardware development for student satisfaction.

A third approach—process model-building—has now been developed to introduce engineering freshmen to complex design and project engineering.

INITIAL EFFORT

THIS MODEL-BUILDING approach was motivated by student responses on a survey questionnaire during the first class meeting in Spring 1974. The thirty-four students who had selected the project topic "Nuclear Power" expressed a surprisingly strong preference for building scale models of nuclear power plants over a variety of other analytical and laboratory choices. Two independent model-building sections of seventeen students each were rather hurriedly established without much prior planning. Two student tutors were assigned to one section and one to the other. Both sections were under the supervision of a single faculty member. At the second meeting of the class, the guidelines of Table I were developed after some amount of discussion.

During the next four class meetings, sixty-minute lectures were scheduled on the following topics:

- **Nuclear Power History**
- **Nuclear Power Industry-Today**
- **Reactor Plant Descriptions (PWR, BWR, HTGR)**
- **Project Engineering (Organization, Schedule, Design and Construction)**

Textbook and journal references were provided to stimulate a literature search, reading, and discussion. In addition, the multi-volumed "Preliminary Safety Analysis Review" (PSAR) and "Supplement to the Safety Evaluation Report" (SSER) of both the Diablo Canyon I and Nine-Mile Point I reactor plants were made available. Reasonably thorough system descriptions of the

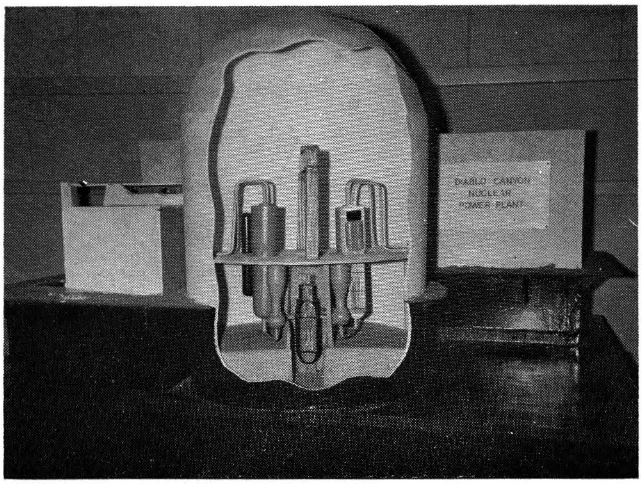

FIGURE 1. Diablo Canyon 1 Nuclear Power Plant Model.

BWR and PWR plants (by General Electric and Westinghouse) were also provided.

The remaining time during the first five weeks was largely spent in student discussions on what to build, where to get suitable information, and how to proceed. The projects were identified as the "Diablo Canyon I Power Plant" and the "Oconee I Reactor Building." These choices appear to have been based on the large amount of PSAR information in the first case and on the availability of a good journal feature story in the second case. The first project quickly named a manager and started to develop as a project team. The other project never selected a manager and tended to operate as independent sub-system groups. At the beginning of the sixth week, the student tutors were encouraged to take a more active role in helping the students develop better project organizations.

From this point on, the Diablo Canyon section quickly evolved into a coherent project group. These students made effective of the many engineering drawings in the Diablo Canyon PSAR. They were able to analyze and interpret the drawings, even to the point of finding two inconsistencies in the drawings. However, the actual model construction was very slow. This can be attributed to the lack of experience characteristic of these students. During the entire semester the students maintained a high level of interest and activity. This produced the Diablo Canyon plant model shown in Figure 1. This section also prepared a well-written report and made an effective oral presentation.

The Oconee section never really managed to develop an overall project organization. However, the various sub-groups proved to be quite competent at developing drawings and constructing models. This section required considerable direct help from the student tutor. A final crash effort produced the Oconee Reactor Building model shown in Figure 2.

The overall effort, interest, and accomplishment of the two sections were better than had been anticipated. The quality of the models was high enough to utilize them as instructional aids in upper-level engineering courses and as displays. On the negative side, a few students were bothered by the amount of shop or craft work, which they felt was a waste of time. Several students were never really able to adapt to the demands of a group effort and, as a result, lost the sense of participation in the overall project. However, the most severe problem was the lack of prior planning for this venture by the faculty supervisor. This, coupled with a lack of experience for the activity, led to an excessive emphasis on "fire-fighting" activities instead of planned guidance.

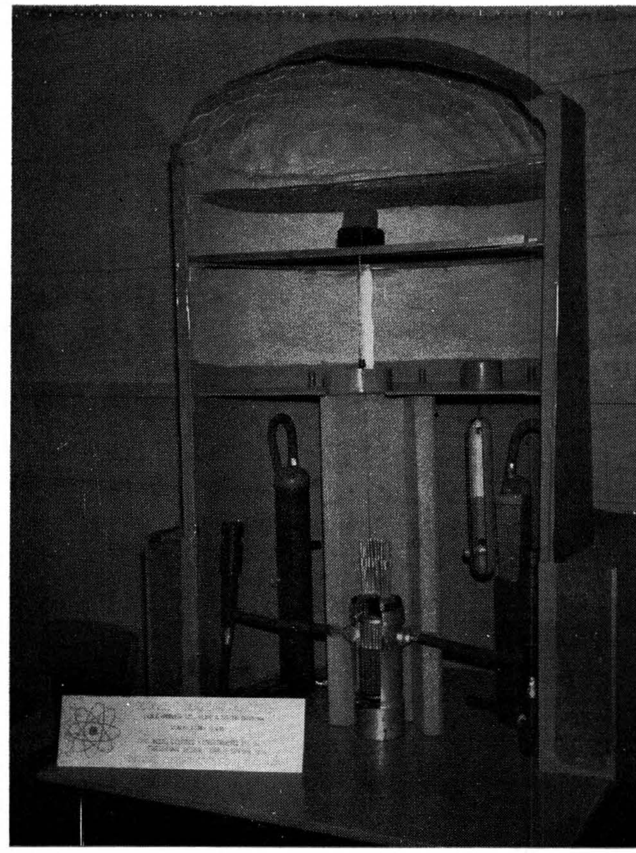

FIGURE 2. Oconee Reactor Building Model.

SECOND EFFORT

THE NUCLEAR MODEL-BUILDING activity was repeated with a group of 37 freshmen in Spring 1976. Four project teams were organized and an undergraduate tutor was assigned to each. A number of significant changes were made in order to accelerate the initial effort and to introduce the students to project engineering.

The first change was the addition of three more guidelines. The project schedule mentioned in Item 2 was a typical manhours schedule for the entire project. Scheduled manhours for future activities were shown for the appropriate dates and actual manrours for past activities were listed where expended.

At the first class meeting the students were asked to organize themselves into four independent project groups. Source material from reactor plant vendors, utilities, and government agencies were made available and other literature sources were listed. The students were asked to select a project and define the model scope by the end of the second week. This definitely improved the student effort during the first part of the course.

The lectures given to the class in 1974 were repeated, but were spread out in short segments over the first six weeks of the course. In addition, specialized mini-lectures were given in response to requests from the individual project groups. This permitted the groups to schedule a faculty lecture at their convenience and to request specialized topics relating to their particular project.

The four projects of this second effort were (A) Pickering Reactor Building, (B) Fulton Generating Station, (C) Diablo Canyon Reactor Building, and (D) Gentilly II Generating Station. The results, represent a significantly higher level of accomplishment than before. This improved performance probably can be attributed to better planning and organization of the course. The significant factors were (a) better development of the tutors as project consultants, (b) acceleration of the initial project phases, and (c) the requirement of weekly progress reports.

FUTURE EFFORTS

THE DEVELOPMENT OF additional project management techniques for this model-building effort might be effective in generating student interest and providing an introduction to such methodology. Computer programs could be prepared to provide the printouts and graphs characteristic of the methods used in project management practice. Using these, the students could prepare schedules, control costs, allocate effort, and develop a better sense of ongoing project management. This would help to illustrate the use of the computer as a managerial tool. It would add realism to the project management task and provide a meaningful management assignment for the students who dislike the shop construction activities.

A freshman-level textbook could be developed for model-building courses. While model-building references exist (19,20) and specialized supply sources are available (21), a need exists for a student textbook covering (a) the specialized techniques of engineering model-building, (b) descriptions of chemical process equipment and their function, and (c) an inttroduction to project management techniques. This should include numerous illustrations and examples, as well as sample management programs.

PRELIMINARY PREPARATION

AS NOTED ABOVE, the preliminary planning for this course is particularly important. A set of project guidelines should be formulated before the course begins. Those given in Tables I and II evolved from the problems encountered in the initial effort. Other items that should be considered include:

• Adequately documented reference materials, particularly in the form of drawings and photographs, should be assembled for several different projects so as to simplify the design choice, minimize literature searching, and help give the sections an early sense of direction.

• Laboratory areas with sufficient space, work tables, storage cabinets, and tools should be set up for this activity. It is important that each project have a separate defined area. This can be achieved if a "model-table" and related space are assigned to each project group. Additional nearby space should be available for project conferences, writing, drawing, and minilectures.

• A clear definition of the role of the student tutor should be developed. Without this, it is possible for the tutor to assume such conflicting roles as instructor, faculty assistant, consultant, project manager, or freshman colleague. A proper balance must be established between guidance and assistance in both faculty-tutor and tutor-freshmen relationships.

• Project conferences and mini-lectures should be planned to introduce the unit operations and chemical processes associated with the prototype. This helps to focus attention on the fullscale prototype as a functional unit.

• Some instructional effort should be devoted to the concept that model-detailing is the art of creating an illusion of reality, rather than true prototype miniaturization. When student effort seems to be misguided, it is particularly effective to offer one possible solution and challenge the project team to seek other solutions.

DISCUSSION

AS AN INTRODUCTION to complex engineering design, this model-building approach provides an outlet for the creativity, curiosity, and ingenuity that characterize many engineering freshmen. Even though miniaturized, it tends to focus upon the *total art* of engineering design [22] through practice in a real-world environment.

The student is not involved in analytical design or actual equipment operation, as he would be in the other types of chemical engineering projects mentioned earlier. However, he is introduced to the techniques and needs of project engineering, as well as learning to function as part of a large project team. It is also possible to use this model-building project to acquaint the student with the appearance, purpose, and function of process equipment used in the prototype.

The faculty supervisor can utilize the modeled process as a vehicle around which to develop problems in upper-level engineering courses. One possibility is to have the freshmen model a project that is being studied concurrently by a senior design group. Another approach is to utilize area industry as prototypes and include plant tours as part of the course. Incidentally, a faculty member can even generate interest in his research specialty by developing a model project that relates in some way to his research.

From an administrative point of view, this model-building approach should be of interest because (a) it can be made appealing to a wide variety of engineering students of all disciplines, (b) a reasonably large number of students can be accommodated effectively and economically, and (c) it involves the freshman student with a real design experience that can be satisfactorily completed in a fixed time schedule. This type of course could even be offered to non-engineering freshman as an introduction to engineering.

The student tutors, who usually are juniors and seniors, can gain an invaluable educational experience by working with a process model-building group. This is particularly true if they are given considerable responsibility for helping the freshmen develop an effective project organization and complete the project on schedule.

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file of reaction engineering problems. This file, which has been organized and maintained by manual methods with no great effort, has been found to be very useful in an educational environment. It should be obvious, moreover, that these same methods should be amenable to other instructional areas of chemical engineering. Thus, one should be easily able to construct similar files, if one is interested, for such areas as thermodynamics, unit operations and process control, to name a few. □

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BOOK REVIEW: Astarita

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than precise. Professor Astarita attempts to explain the *methods* in a setting which anticipates the heavy technical needs of the final chapters on fading memory, a strategy which I think taints his exposition of fundamentals with a vagueness impossible to avoid in such an ambitious undertaking.

For example, I believe Chapter 4 is seriously flawed by its opening section which, in anticipation of Chapter 5, deals with differentiability of functionals with respect to present values of temperature. This discussion is too vague to be of much use, plays no real role in the balance of the chapter, and is likely to detract from the effectiveness of the pedagogically critical sections immediately following. I wish Professor Astarita had chosen to divorce his exposition of methodology from his skillful, but necessarily sketchy, description of Coleman's work on fading memory.

I wish also that literature citations had been heavier so that readers could more readily make contact with the original literature—indeed, the crucial Coleman-Noll paper of 1963 is not cited at all.

Despite these remarks, let me state once again that the book is an important one for academic chemical engineers and might substantially influence the way we think about thermodynamics. It deserves reading, as do the source papers and the monographs by Truesdell and Day. Professor Astarita has reached beyond our own literature and brought to it something of value.

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WARD: Process Model-Building

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ACKNOWELDGMENT

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CHEMICAL ENGINEERING DIVISION ACTIVITIES

Nine ChE's Receive Awards at ASEE Meeting

ASEE president George Burnet has pointed out that at the recent ASEE Annual Conference at Knoxville a number of chemical engineers received special recognition. Following is a list of awardees.

Lamme Award	**John J. McKetta**
Curtis W. McGraw Award	**John H. Seinfeld**
3M Lectureship Award	**Abraham E. Dukler**
Western Electric Fund Award (Illinois-Indiana Section)	**Ralph E. Peck**
Western Electric Fund Award (Middle Atlantic Section)	**Angelo J. Perna**
Western Electric Fund Award (New England Section	**James R. Kittrell**
Western Electric Fund Award (North Central Section)	**Alan J. Brainard**
Western Electric Fund Award (Pacific Southwestern Section)	**Fred H. Shair**
Western Electric Fund Award (St. Lawrence Section)	**Joseph Estrin**

Dr. Burnet also requested that it be reported that the editor of *CEE* received a special award from the Chemical Division which was accepted on behalf of the staff of *CEE*.

LETTERS: Carberry

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How, for example, in the name of God, Zeus or whatever diety prevails in Buffalo, is Yale* placed in the tail end "of the class" relative to Buffalo? How is it that Yale University is ranked with Judas in the Gill report when, in fact, an even casual survey of their research endeavors would prompt even a Big-8 anti-Ivy league-type to conclude that the graduate research-study program at Yale is vastly more fundamentally significant than that of one-half of those departments blessed with top 20 categorization by Gill et al.? How is it that perhaps several of the departments assigned a rank in the top twenty by Gill et al. (including, oddly I contend, his university) would, on survey, be totally innocent of the nature of Yale's labors and the Journals within which the Yale Chemical Engineering people deposit their findings?

I leave it as an exercise to Gill enthusiasts to seek out those non-AIChE Journals in which Yale Chemical Engineering people choose to publish their research findings, which areas *they* choose to pursue as *ultimately* relevant to the science of chemical engineering.

We, in chemical engineering, have gone well beyond the usual pedestrian levels of research inquiry. Survey your colleagues, dear reader: where do they publish? Perhaps in an AIChE publication; perhaps elsewhere. Our noble calling has become, happily, diffuse insofar as borderlines between chemical engineering and chemical physics are no longer clear and well defined interfaces. This I welcome. Provost Gill's survey respects not this reality.

Yale has been and is and will always be a great university, a summation of innovative departments of distinct, unique insight whether in the area of literature or chemical engineering. Having had a distinguished department of traditional chemical engineering for enough decades to even inspire a Buffalo, they now choose to pursue a program of education and research in the chemical engineering sciences, which enterprise might ultimately enlighten over-inflated Buffalo.

As this comment is quite personal, permit me to fashion the "Carberry Report"—an evaluation of graduate chemical engineering departments in two categories: general (catholic-note, please, the lower case c) and specialized (I leave it to reformation theologians to fashion a more definitive category):

General:	**Specialized:**
1. Minnesota	1. Stanford
2. Delaware	2. Yale
3. Berkeley	3. Princeton
4. Carnegie-Mellon	4. Pennsylvania
5. Illinois	5. Wisconsin
6. Northwestern	6. Everyman's School

Beyond that, my friends and enemies, its "to each his own." As for the unmentioned, do your own grand thing. The "Carberry Report" respects all who labor in the vineyard, even Gill's Buffalo.

U. of Notre Dame
J. J. Carberry

*of which I am proud to be an alumnus.