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AN INTRODUCTORY DESIGN COURSE FOR ENGINEERING FRESHMEN

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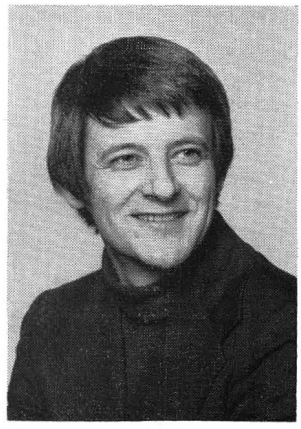
INTRODUCING BEGINNING ENGINEERING students to the profession in a meaningful way has long been a problem. At Clarkson College of Technology a variety of techniques have been tried, many meeting with a singular lack of real success. The methods used have ranged from informal orientation sessions to design to nothing at all. The long range effects of these attempts are difficult to measure, but one can be reasonably certain that the engineering profession loses a significant number of potentially productive members when capable students are "turned off" by their first exposures to engineering in college.

During the 1969-70 academic year, Clarkson's Engineering School faculty completed a major revision of its undergraduate curricula. These curricula provide for a common Freshman program for all engineering students including a two course sequence (3 semester credits each) in engineering taught jointly by faculty from each department. The first of these, titled "Introduction to Engineering," is devoted primarily to developing skills in engineering graphics and digital computing as a means of solving engineering problems. Some orientation to engineering and its major branches is provided by lectures on topics related to engineering design, the engineering profession, or the relationship of engineering to society. The second course, titled "Introduction to Complex Design," is much more loosely structured than the first. Depending on the faculty involved, the course has been conducted in a wide variety of ways but generally involving a design project of one sort or another. Typically, near the end of the first course engineering faculty members submit project descriptions to the students who are asked to indicate their preferences. Students are then assigned to sections for the second course, taking into account preferences and number limitations imposed by the nature of the project.

What follows will describe the methods that I used in teaching a section of "Introduction to Complex Design" each of the past two years. Centered about the design of a chemical plant, the course content and organization will be given in some detail and some measure of the students' response as well as my reactions to the course will be provided. Hopefully the information provided will be of some value to those teaching or planning a Freshman engineering course.

COURSE OBJECTIVES

I MUST CONFESS THAT I went into the course the first time with some trepidation. It never has been entirely clear to me just what such a Freshman engineering course should consist of. Broadly, the engineering school agreed that the course should provide an introduction to the engineering profession through a design experience. However, no specific guidelines as to content or structure existed. Moreover, I had never taught Freshmen and therefore had relatively little insight into the kinds of problems they could handle.



Gordon Youngquist received his BS from the University of Minnesota and his MS and PhD from the University of Illinois. Since 1962 he has been at Clarkson College of Technology where his teaching and research interests are in reactor analysis, crystallization and porous media.

I felt that the course should somehow introduce the student to a variety of engineering activities, hopefully in such a way as to motivate him to continue in engineering and to provide insight into his future course of study and career. More specifically, the following objectives evolved:*

1. **To provide experience at defining problems.**
   Nearly all of the problems students do have been defined for them by someone else. Consider typical textbook problems in science or engineering, for example. A student's candid response to some problems he was confronted with in this course: "How can I give an answer when I don't know what the question is?"
2. **To provide some introduction to the various aspects of engineering design.**
   Emphasis was placed on the distinction and interrelationships between process design and equipment design and also the important role of economics.
3. **To provide experience at working with and for others on a long term problem of broad scope.**
   Most of the work that students have done at this point has been on short, well-defined problems that they have completed by themselves. They have had little experience at planning work on a long term problem which requires the joint efforts of several individuals.
4. **To provide some experience at decision making.**
   Few engineering problems have but one solution!
5. **To provide a means of applying accumulated background to completely new problems.**
6. **To provide experience at technical report presentation, both written and oral.**
7. **To provide experience at evaluating the work of others.**

COURSE IMPLEMENTATION

TO ACHIEVE THESE OBJECTIVES, I decided to have the class do a chemical plant design using a format not unlike the one often used for our Senior design course. Table I provides general information about the staffing and structure of the course. The first four weeks of the course were devoted to relatively short, introductory problems The next eight weeks were spent on the design of a chemical plant. The final two weeks were devoted to evaluation of written design reports by the students themselves and to oral presentations by the students. The class met twice each week for two periods each day using two adjoining classrooms. These were standard classrooms with movable chairs, each accommodating about 50 students. In 1972, I had six and in 1973, eight teaching assistants working with me. The assistants, all undergraduate chemical engineers, were allowed 1 academic credit and given a very modest stipend for their participation in the course.

*Evolved is a most accurate description here. Some of these I had in mind before the course started. Others developed as the course progressed.

Students who took the course had, early in their course of study, a broad range of experience and exposure to engineering that our typical student has never had in the past.

The initial four week period served to orient the student's thinking toward the solution of engineering problems and to develop certain problem solving skills that they would need later in the semester. Typically, the first half hour or 45 minutes of the class was devoted to lecture-discussion of a problem. During the remainder of the class period, the students divided into 5 or 6 man groups to pursue the problem further

TABLE 1

STAFFING AND STRUCTURE

Instructor:	G.R. Youngquist, Associate Professor of Chemical Engineering.
Assistants:	One undergraduate assistant for each 5 students. These were juniors or seniors in Chemical Engineering.
Students:	All were Freshmen. In 1972, 34 students and in 1973, 42 students, took the course. Of these about 2/3 were intending to be Chemical Engineers, a few were intending to be Civil or Mechanical Engineers, and the rest were undecided at this point.
Classrooms:	Used two adjoining standard classrooms.
Schedule:	Class met two days per week, each day for two 50 minute class periods.
Overall format:	The semester was fourteen weeks long, divided as follows: 4 weeks—Introductory problems covering some principles of material and energy balances. Some lectures, some group activity, some individual activity. 8 weeks—Plant design project by student groups of 5 to 6 culminating a written design report. 1 week — Student evaluation of written design reports 1 week — Oral presentations of designs; award made for best presentation.

Clarksen's curricula has a two semester common freshman program taught jointly by faculty from each department . . . the first is devoted to orientation to engineering, engineering graphics and digital computing . . . the second involves a design project of some sort.

through discussion and analysis. Three or four groups worked in each classroom to avoid congestion. One assistant was assigned to each group to answer questions, to stimulate discussion if necessary, and to provide general guidance. I circulated from group to group to provide additional assistance. In some cases, this activity culminated in a homework assignment to be submitted by individual students.

The basic subject areas introduced during this time were only two: energy conservation and mass conservation. Generally I started with an ill-defined problem and worked towards a well-defined problem which could be made quantitative. For example, on the first day of class I asked the students to "design a system which could be used to heat 10,000 gallons of a solvent from ambient temperature to 100°C." The problem statement was made deliberately vague to cause them to ask a large number of questions, the answers to which would serve to define the problem. The students worked on the problem in groups, making up a list of such questions, and also developing a number of alternative ways that could be used. All of the groups considered batch-wise steam heating as an alternative, placing the solvent in a tank with an internal heating coil. For the next class period, I restated the problem providing answers to many of the questions they had posed. We then looked at quantitative aspects of the problem, asking in particular how one might determine the required size of the steam coil. This led naturally to a discussion of the factors which influence the rate of heat transfer. The notions of the temperature driving force and the overall heat transfer coefficient were introduced. From these, we developed an unsteady state energy balance for the system making use of the definition of the derivative to arrive at an appropriate differential equation. Then, for a group activity I asked them to solve the differential equation and to calculate the required heat transfer area. Although they had no prior exposure to differential equations, they quickly caught on to separation of variables and recognized how to solve the result either analytically or numerically. Following this, I introduced the log-mean temperature difference, albeit in the context of a batch system. Subsequently, I asked the students how the heat exchange system might be made continuous. Of course, they first suggested using the tank of the batch system with continuous flow. We discussed the merits of this suggestion and with a little bit of prodding they soon arrived at the concepts of double pipe and tube and shell exchangers. I brought a small tube and shell exchanger to class for their inspection. The students found this heat exchange problem very satisfying. Among other things, it was easy for them to visualize; they could use their intuitive skills readily; they saw how the mathematics they were studying could be applied to a practical problem; and it revealed the broad implications of batch versus continuous systems. Above all, they got some feel for the importance of defining a problem and using what they already know to solve a problem they had never seen before.

From here, we went on to look at a couple of elementary mass balance problems involving chemical reactions, then to combined mass and energy balances (adiabatic flame temperatures, e.g.), ending the four week period with a qualitative discussion of rates of chemical reactions and the characteristics of various types of chemical reactors.

At times when they were struggling with the definition of a problem, the students were quite frustrated. In this respect, I tried to emphasize strongly that adequately defining a problem often is the most difficult part of finding a solution. I was continually amazed at the students' ability to use intuitive reasoning—much better than seniors, I often felt. They were adept at generating sound ideas, both for processes and equipment, and were especially sensitive to the economic implications of their ideas. The latter I found especially pleasing, the importance of money in design arose quite spontaneously throughout.

ON TO PLANT DESIGN

THE NEXT EIGHT WEEKS of the semester were devoted to the design of a chemical plant. At the beginning of this period, I asked the class to divide themselves into 5 or 6 man engineering "companies," each selecting their own chief engineer. One teaching assistant was assigned permanently to each company as a technical consultant. Half of the companies, each doing its own design, designed a plant for the wet oxidation of sludge from a waste treatment plant while the other half designed a plant for converting the sludge to oil. Table 2 shows the letter which was used as the problem assignment. These two processes were selected because of their obvious relevance, because a reasonable amount of background information was available, and because the problems were sufficiently broad in scope that the interests of potential Civil and Mechanical as well as Chemical Engineers could be served. Furthermore, I have some related research interests and the two processes are quite similar so I would not spread myself too thin in terms of background. At the outset, I provided each of the groups with a few pertinent papers about each process. Each group organized its activities as it saw fit. I asked for very brief weekly activity reports from each company and two progress reports in addition to a final written design report, but beyond this imposed no specific structure. No formal lectures were given during the project period. I did expect the students to show up for each scheduled class, so that they

TABLE 2
DESIGN PROBLEM STATEMENT

Integral Chemical Company
209 Peyton Hall
Potsdam, New York 13676

February 6. 1973

——————Consultants, Inc.
342 Snell Hall
Potsdam, New York 13676

Gentlemen:

Our chemical processing facility in Potsdam has a waste treatment plant which produces 300,000 gallons of effluent per day. The effluent is about 3% by weight solids (the rest is water) and the solids are 75% organic. The composition of the organic material can be represented by the empirical formula $C_{118}H_{170}O_{51}N_{17}P$.

At present we are dewatering the effluent by vacuum filtration to 25% solids and the solids are incinerated using fuel oil as an auxiliary fuel. The residual ash is landfilled. This process costs us about $20 per ton of dry solids. The filtration step has been no end of trouble to us, however, since to be efficient incineration requires rather close regulation of the water content and our filters have been difficult to control. In addition, both the State and Federal Environmental Protection Agencies are putting pressure on us to reduce both particulate and chemical emissions from our incinerator stacks.

As a result, we have been looking for alternatives to incineration for disposal of our wastes. Two such methods which have come to our attention recently and which appear potentially attractive for our purposes are: 1) wet oxidation (i.e., the Zimpro process) and 2) conversion of the wastes to oil.

Some of the possible advantages we see for these processes are the following. In the wet oxidation process, the organics may be more or less completely oxidized to carbon dioxide and water in the presence of liquid water and air. With liquid water present fly ash is no problem and many of the oxidation products will form water soluble salts. Filtration of the effluent possibly may be unnecessary. Also, it might be possible to generate electrical power by expanding the high pressure, high temperature gases which result from the process through a turbine.

In conversion to oil, the organics are reacted in the presence of carbon monoxide and liquid water to produce fuel oil. This oil may be especially valuable to us in light of recent shortages. As with the wet oxidation process, the emissions problems attendant to incineration should be largely checked.

On the negative side, with either of these processes we will still have to meet the local pollution standards for both our off gases and our waste water. The residual insoluble solids will likely have to be separated and landfilled. In addition, since both processes require moderate reactor pressures and temperatures, capital costs for plant installation may be high.

Since these processes do look reasonably attractive to us, we would like your firm to do a plant design for one of them. This design should provide us with the basis for determining the advisability of proceeding to the final design and construction stage. As a minimum it should include reasonably complete process and equipment specifications along with your best estimates of capital and operating costs. We require that your final design report be submitted to us by April 19, 1973. You should also be prepared to make an oral presentation to our staff on May 1, 1973.

Very truly yours,
I. N. Tegral, President

. . . The course should provide an introduction to the engineering profession through a design experience . . . and motivate the student to continue in engineering and to provide insight into his future course of study and career.

could consult with the assistants, myself and each other. Most of the companies stumbled around for two to three weeks trying to get themselves organized effectively and, subsequently, trying to define the problem. I did not interfere with this, except to make suggestions when asked. It took the students a while to recognize the value of a process flowsheet, but once this was done they were off and running. To assist the companies in getting started with the necessary material and energy balance calculations, I made up two lectures on cassette tapes. This proved quite effective. In addition, I regularly brought to class references such as *Perry's Handbook, Popper's Handbook for Cost Estimation, Handbook of Chemistry and Physics,* and Peters and Timmerhaus *Plant Design and Economics.* Especially towards the end of the project, these were used heavily. The students often had considerable difficulty in using library sources, primarily because most of the potentially useful texts were written in language that was too advanced.

The companies organized themselves in a variety of ways, but I am certain that all came away from the design project with a good appreciation of the difficulties of working with and for people in a situation where crossflow of information is vital. In most cases, the company engineers became "experts" in different aspects of the process, sharing their knowledge in discussions both in and out of class. The assistants were quite effective in working with the companies, developing good rapport with their groups. As in the first four weeks, I circulated from company to company during class meetings providing guidance wherever it was most needed.

The competitive spirit which pervaded during this time was tremendous . . . companies went all out to make good presentations . . . Students were able to ask penetrating questions and discussions following were very spirited.

At the start of the design project, most of the students were a bit overwhelmed, feeling that a plant design was more than they could handle. By the end, most were surprised and pleased at how far they had progressed. (Frankly, so was I!). Their final written reports were submitted on time, were remarkably complete, and generally of high quality. The reports reflected some technical naivete, as you might expect, but I felt showed considerable imagination and creativity in treating some genuinely complex engineering problems.

FINAL REPORTS

ON THE DAY THAT the final reports were submitted, I asked each student to evaluate the members of his company, without identifying himself. An evaluation form was provided for this purpose. Many of the students commented later that they did not like this peer evaluation, but I felt that they responded conscientiously. At this same time, I also requested a course evaluation by written response to four questions. The results were very interesting and will be presented later.

In class during the week following submission of the final reports, each company read and evaluated the written reports of two other companies. Identifying features of the reports were removed so that the companies did not know whose report they were evaluating. The students took this seriously and did a good job of constructive criticism. I believe they found this activity very revealing, for it demonstrated the importance of good written communication and also gave them the opportunity to see in detail what approaches other students took in solving the design problems.

The final week was devoted to presentation of oral reports on their design work. Four judges (a faculty member, a graduate student, a senior, and a freshman not involved with this section of the course) were asked to evaluate the presentation and an award was made for the best report. The competitive spirit which pervaded during this time was tremendous, and the companies went all out to make good presentations. Because they all had worked on substantially the same design problem, the students were able to ask penetrating questions and the discussions which followed each presentation were very spirited.

For the most part, I tried to play down the importance of grades in the course. No examinations were given. A few homework assignments at the beginning of the course were collected and graded, but these were not considered at all in determining final grades. Final written reports and oral reports were given a letter grade, but these were considered as collective grades for the

company. To determine grades for individuals, I relied on 1) the peer evaluation mentioned above, 2) evaluations by the assistants, and 3) my personal evaluations as they developed over the semester. Generally I looked for such qualities as leadership, creativity, analytical ability, reliability, cooperation and effort by the students. Since both the assistants and I worked closely with the students, it was relatively easy to determine which students knew the various aspects of the problems, which were leaders, and so on. The three evaluations cited above were remarkably consistent, and I have full confidence that the grades assigned were fair and justified. Considering the nature of the course, a pass-fail grading system may have been more appropriate.

Students found their design project challenging and realistic engineering . . . they liked the relatively flexible and informal organization of the course. They discovered engineering can be a lot of work and that information gathering is a significant part of that work.

COURSE EVALUATION

EVALUATING A COURSE is never very easy. The standard evaluation forms that one often uses for lecture courses are inappropriate for a course of this type, so I decided to ask the students for written responses to four questions. These were:

1) What aspects of the course did you like the best? 2) What aspects of the course did you like the least? 3) What are your chief criticisms of the course? Do you have any suggestions for improving it? 4) Has the course encouraged you to continue in engineering or discouraged you from doing so? Why?

The students responded conscientiously with some very candid, meaningful, and interesting comments. These are too lengthy to reproduce here, but interested readers may obtain copies typed exactly as they were written by contacting the author directly. Table 3 briefly summarizes the responses. It is clear that the students found their design project to be challenging and realistic engineering from their vantage point and that they liked the relatively flexible and informal organization of the course. They discovered that engineering can be a lot of work and that information gathering is a significant portion of that work. Many suggested that I provide more information through additional lectures and materials, but this seems directly related to inexperience at defining problems and organizing work effort. Others suggested that the design problem was too advanced for their background, but judging from what they were able to achieve I do not feel that this was the case. Significantly, only a small

TABLE 3
SUMMARY OF COURSE EVALUATION

	No. of responses 1972	1973
What aspects of the course did you like the best?		
1. Work on a realistic engineering problem; opportunity to see the work of an engineer.	9	13
2. Work in small groups; learning how to work with others.	9	8
3. Informal class organization; flexible scheduling of work; freedom to work independently.	9	14
4. Challenging, relevant, different, interesting design problem.	10	10
What aspects of the course did you like the least?		
1. Materials or information hard to find, or interpret; design problem too sophisticated.	8	10
2. Design problem too much work; work not shared equally by company members.	3	10
3. Course organization; location; scheduling	10	6
4. Difficulty in getting started on design problem.	3	5
What are your chief criticisms of the course? Any suggestions for improving it?		
1. Give a better idea of what is expected early; provide more information immediately.	5	8
2. Provide more reference materials written at our level; give additional lectures; better assistants.	6	9
3. Do shorter project, simpler project.	5	3
4. Arrange field trips.	2	5
5. Make scheduling more flexible; do not require class meetings.	3	2
Has the course encouraged you to continue in engineering or discouraged you from doing so? Why?		
1. Encouraged me.	22	30
2. Discouraged me.	4	1
3. Neither.	4	8

fraction (5 of 69) indicated that the course had discouraged them from continuing in engineering. Some of these made comments like "Now that I have seen what engineering may be like, I have decided it is not for me."

On the whole, I feel that the course was highly successful. The course was exciting and challenging to teach and I enjoyed it immensely. The response of students was quite gratifying. It seems clear that much of what I tried to build into the course met with reasonable success. Whether any long term benefits will accrue remains to be seen. Certainly the students who took the course have had very early in their course of study a broad range of experience and exposure to engineering that our typical student has never had in the past. Several of the assistants commented that they wished they had had such a course as freshmen, indicating that it would have given them much insight into their subsequent courses.

At the beginning of the semester, at least the first time I taught it, the course consumed a great deal of my time. This was due partly to my inexperience with the course, but partly due to the fact that all of the planning and course development had to be done by the instructor. I found no suitable text to use as a guide or to provide problems. (The course just might be pretty sterile if there were!) Moreover, the course needs to be very flexible if it is to respond to the needs and interests of the students. Towards the end of the semester, especially as the design projects got well under way, little time was required beyond that spent in class. Teaching the course the second time was much easier. I made some minor modifications, but used essentially the same material and format as the previous year. This, plus the fact that I then knew how the students would react, reduced my time commitment to a minimum.

Provided assistants are available, I believe that the course could be run in this fashion with as many as 50 students per section. For group projects, there should be no more than 6 students per group. However, as the class size increases one does risk destroying the informal and personal atmosphere of the course. This could defeat the purposes of the course. Also, larger class size probably would mean a greater diversity of interests among the students. This makes it more difficult to select projects consistent with their interests. In any case, the instructor should limit the spectrum of design problems going simultaneously in the course to avoid spreading himself too thin in terms of his own interests and background. □

CACHE COMPUTER PROBLEMS

$50 PRIZE FOR EACH PUBLISHED PROBLEM

CHEMICAL ENGINEERING EDUCATION, in cooperation with the CACHE (Computer Aides to Chemical Engineering) Corporation, is initiating the publication of proven computer-based homework problems as a regular feature of this journal.

Problems submitted for publication should be documented according to the published "Standards for CACHE Computer Programs" (September 1971). That document is available now through the CACHE representative in your department or from the CACHE Computer Problems Editor. Because of space limitations, problems should normally be limited to twelve pages total; either typed double-spaced or actual computer listings. A problem exceeding this limit will be considered. For such a problem the article will have to be extracted from the complete problem description. The procedure to distribute the total documentation may involve distribution at the cost of reproduction by the author.

Before a problem is accepted for publication it will pass through the following review steps:

1) Selection from among all the contributions of interesting problems by the CACHE Computer Problem Advisory Board
2) Documentation review (with revisions if necessary) to guarantee adherence to the "Standards for CACHE Computer Programs"
3) Program testing by running it on a minimum of three different computer systems.

Problems should be submitted to:

Dr. Gary Powers
Carnegie-Mellon University
Pittsburgh, Penn. 15213