ChE classroom

# INNOVATIONS IN A PROCESS DESIGN AND DEVELOPMENT COURSE

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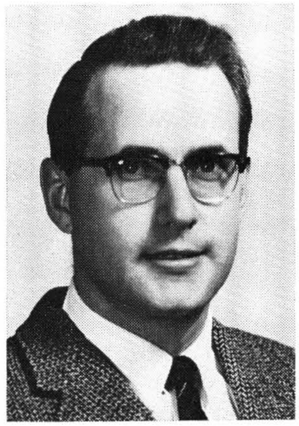
*To prepare a student to make decisions based on a financial criterion, a senior course is given that introduces the student to the structure of a process or plant and to cost estimation techniques and methods of comparing the financial attractiveness of proposals. The morphology of design or of plant operation decisions, the ability to handle uncertainty and methods of optimization are introduced. Then the principles are applied to design problems and to plant operation.*

*The innovations in the course are the development of an approach to help the students be creative, i.e., generate alternatives, through functional analysis of processes combined with in-plant lectures. Secondly, emphasis is placed on setting-up economic balance equations, and an approach is suggested for balancing calculational time with the accuracy expected. Computer-aided optimization work is done on the models made for the simulation of a sulphuric acid plant. Finally trouble-shooting problems are uniquely used as case studies to illustrate the strategy of tackling problems, and the value of time.*



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Two media are used to convey senior level design experience at McMaster: a four-credit semester lecture course to illustrate the fundamentals and a four-credit project laboratory that has no lectures. This paper describes some experience from teaching the lecture course. First a sketch of the course content and emphasis is presented; then some attempted innovations are described. The project laboratory is described elsewhere.[1]

## COURSE CONTENT

The course is divided into three sections: understanding the background of processes and learning about cost estimation, developing the general principles of devising economic balances and of optimization, and applying the principles to the industrial problems of design and operational efficiency.

**Understanding the Background.** Students are used to thinking about commodity balances; i.e., they meet mass balances, then momentum balances, heat balances and component mass balances. Happel's[4] concept of money balances is a useful extension of this training. One characteristic of any such balance is that the balance is made over some region or envelope and it is on the commodity money. The overall craracteristics of chemical industry are discussed first. A detailed look at specific processing systems is obtained by functional and structural analyses. Equipment design and safety considerations are discussed. This material is often supplemented by a visit to a local firm that has this process. Next, methods of cost estimation and of reporting the financial attractiveness of proposals are presented.

**Developing the General Principles of Devising Economic Balances and of Optimization.** Now that the students appreciate the two necessary ingredients for economic balances, they learn to combine them into balance equations. The general strategy for developing the equations is presented, and the application of the strategy is outlined. The problem of handling uncertainties (as described by Rudd and Watson[5]) can be introduced but because of time limitations that material usually has to be reserved to the graduate course. Nevertheless, the uncertainty because of limited calculational time is a topic the seniors should master. This includes making good assumptions, minimizing calculational time and project planning. A variety of optimization techniques are briefly outlined. Depth was gained only with Golden section and dynamic programming. This section of the course draws heavily from Rudd and Watson.

**Applying the Principles to Industrial Problems of Expansion and Efficiency.** The principles are then applied to many cases to illustrate the fine points. First, problems are given to illustrate the application of the strategy to design. These cases are carefully selected for their open-endedness and their ability to illustrate different aspects of the strategy. Secondly, problems illustrate plant improvement through changing operating conditions, replacement studies and through troubleshooting problems.

## INNOVATIONS ATTEMPTED

Course descriptions convey only part of the concept about any course. It is the emphasis and new ideas tried that probably provoke the most interest. The students had difficulty in defining open-ended problems, and they had trouble setting up economic balance equations. They could see how one might approach an optimization problem but did not see how the expression for the objective function was obtained. They had difficulty being creative—or generating alternatives, and they could not see what types of assumptions were needed if the calculation time was limited. The students could easily memorize the design morphology but did not put the information to work when they tackled realistic problems, had difficulty in asking the right questions when such an opportunity was afforded them, and did not appreciate that all aspects of chemical engineering including plant operation could be challenging and exciting. Innovations were introduced to attempt to overcome these problems. Here is what was tried and the results.

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**Functional Analysis of Processes and In-plant Lectures.** Although students had some industrial experience they did not appreciate what goes together to constitute a process. In addition they should be introduced to a spectrum of practical know-how and safety: such simple things as steam traps, barometric legs and pressure relief valves. Practice in defining problems should be introduced early in the program. In addition they should gain confidence in their ability to generate alternatives. All these can be satisfied by doing a functional analysis of a process. Often the process selected is that used in the project laboratory.[1] The functional analysis technique is adopted from value engineering.[10] The analysis steps are:

1. Classify the major sections of a process,
2. define the functions of each piece of equipment,
3. rephrase the functions to eliminate semantic barriers,
4. generate alternatives that satisfy the functions using free-wheelings brainstorming sessions, and
5. evaluate the alternatives based on technical feasibility.

To promote discussion it is useful to require each student to bring to class a flow diagram of a process to serve a given function. That is, the students are given the raw material in a given condition (e.g., soya beans in bags sitting on the deck of a ship docked in Burlington Bay) and a required end product (e.g., deodorized soya bean oil in a large storage tank, lecithin in drums and bagged soya pulp stored in a warehouse). The major steps of reaction, purification and or separation, and changing the physical form are identified. Then from the collection of flow diagrams a typical flow diagram is selected. For the typical diagram each piece of equipment is identified by number to avoid later semantic difficulties. The next step is to critically define the primary and secondary functions of each piece of equipment. This is done by the class as a group. If there are more than three primary functions, then we attempt to reevaluate the functions. Next the function statements are rephrased in words that are the least restrictive and yet appropriately describe the function. For example, one function might be to "dump the soya beans from the bags." This is rephrased to "separate the soya beans from the containers." The substitution of "containers" for "bags" allows us to think of the possibility of using other types of containers for which the separation step might be cheaper. Then, the class period is devoted to brainstorming. No criticism is allowed; all ideas are accepted. When the generation of ideas starts to slow down, the introduction of outlandish or far-out possibilities usually starts a deluge of new ideas. To preserve the brainstorming atmosphere, it is useful to consider about four pieces of equipment at a time so that the brainstorming session can last a full class period. The use of overhead transparencies aids in keeping track of ideas from session to session.

A sample worksheet illustrating a student's attempt to do a functional analysis on his own is given in Figure 1.

The ideas suggested during the creative brainstorming sessions are then criticized. This is an excellent opportunity to describe technology and know-how that they have not experienced before. Sometimes we take one of the 'wildest' ideas and see how we would attempt to make it work. Here, it is emphasized that unless an idea is presented or created it cannot be analyzed. The students also see that the separation of the creative from the critical mental stages brings out practical ideas that would probably be lost if the creative and critical stages were attempted together. That is, we tend to dismiss as 'unworkable' valuable creative ideas if we criticize as we create.

**FIGURE 1. SAMPLE FUNCTIONAL ANALYSIS WORKSHEET**

Functional Analysis of **Soya Bean Plant**

| ITEM | FUNCTION | GENERATE ALTERNATIVES |
|---|---|---|
| Soya Beans in Bags | Separate Soya Beans from container | Cut open and dump { machine / manually<br>Grind up bag & beans and separate via density,<br>cut top open<br>Dissolve the bag<br>Burn away the bag<br>Roast away the bag |
| Miller Hopper | Direct beans to transportation system: meter flow; buffer hold-up; protect from weather | Tank with conical bottom. Pile on floor in covered building & dozer; Store as bags on the floor & carry. |
| Conveyor | Transfer beans from storage to cleaning units; meter flow | Conveyor belt; bucket elevator; gravity; continuous pneumatic conveyor; discontinuous, high pressure conveying system; carry them; float them; blow them; lift them, float conveyor with air/with water/short them, blast them. |

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This classroom exercise can be greatly enhanced if it can be complemented with a visit to a local company that has a similar process.

At McMaster, the process often selected resembles the operation of the local industry Canadian Vegetable Oil Processing Ltd., that handles soya beans. The student now can see some of the equipment discussed during the functional analysis and understands some of the reasons why it might have been selected. We discuss what the student might do if he was working for the company and if a given piece of equipment was to be replaced. Later a frank discussion with company personnel about present operating problems helps to illustrate the value of functional analysis as sound background work for any process.

From an instructor's viewpoint, this approach is easy to do and well worth the time. The approach is enhanced immensely by the in-plant visit, and the process chosen for the class functional analysis was determined by the availability of such an opportunity. The in-plant visit was unique in that it was **not** a plant tour. **We were** permitted to go about the plant on our own; we were not given a plant tour by company personnel. We spent as much time as we wanted discussing among ourselves any aspect of the operation.

This functional analysis technique introduces plant know-how, illustrates the importance of clearly defining problems and lays the foundation for all creative activity for the rest of the course.

Another in-plant lecture is arranged later in the course to illustrate trouble shooting problems and to again introduce practical design techniques. This lecture concentrates on a three-tower distillation unit and was arranged through the cooperation of Mr. E. W. Blackmore, Domtar Chemicals Ltd.

The in-plant visit was unique in that it was not a plant tour. We were permitted to go about the plant on our own.

**Devising Economic Balance Equations.** Students have difficulty in doing cost balances over pieces of equipment because they do not recognize an overall strategy for tackling large, open-ended, cost-oriented problems and because of their inexperience in defining problems. They also have difficulty establishing a uniform accuracy level demanded for the problem. This affects their choice of fundamental and cost details that they include in the balance.

To combat this the emphasis on the course is essentially on how to apply a consistent, organized strategy and how to define problems. The background information given to the students describing a consistent strategy is outlined in reference 11. This is supplemented by several detailed examples to illustrate the application of the strategy. Happel's[4] examples; p 182ff, and in Appendix B; are easy to recast into the strategy; they are simple enough that the students do not become overwhelmed by details. This material is the backbone of the course and a lot of time is spent devising balances and defining problems.

**Balancing Calculational Time with Accuracy.** Knowing what assumptions to make so that an open-ended problem could be solved in the available time is a challenge that most students had difficulty in overcoming. The available time for calculations can be divided into three sections:

1. time to define the problem, make assumptions and select the equations needed, $t_e$ minutes.
2. time to collect the input constants, physical properties, and cost operating and equipment data, $t_p$ minutes
3. time to actually perform the calculations, $t_c$ minutes

That strategy suggested is shown in Figure 2. In general information on this problem was difficult to locate.

To appreciate how an engineer might select assumptions the medium chosen was the imaginary conversation between a knowledgeable but novice engineer, E, and a devil's advocate, DA, suggested by Rudd and Watson. The students found this conversation approach very interesting; so interesting that it was worthwhile to recast previous course illustrative material into this format. A unique way to present this material was to let the students role-play and attempt to develop the conversation themselves. The mechanics were:

1. to prepare the conversation ahead of time,
2. divide the class into two to play the two roles
3. the students playing each role would try to state or answer questions according to their respective role without the aid of the conversation sheets; that is, those playing the role of the DA would try to formulate the best question to ask. While they were doing this, those playing the role of the E could look at the prepared conversation sheet to see the suggested question. Through interplay between the students playing the E roles and the instructor with the students playing the DA roles the DA's eventually pose a question similar to the prepared question on the conversation sheets. Then, the play is reversed, the E's must answer the posed question. The DA's and the instructor can see the answer on the conversation sheet and through other questions the DA's care to pose the E's answer the question.

Sample conversations are given by Rudd and Watson.[7]

The students had already had experience with locating information through a sophomore course on "Information Management and Technical Writing."[12] Hence, they did not have much difficulty in realistically estimating time $t_p$.

The students did not have much experience in estimating the required calculational time for large systems involving a lot of recycle. Class material, examples and problems were based on the material of Rudd and Watson.

In general, the overall concepts were difficult to get across and much development work is needed for this part of the course.

**FIGURE 2. SUGGESTED STRATEGY FOR BALANCING TIME WITH ACCURACY**

| | | |
|---|---|---|
| DEFINE and PLAN | 1 | Determine things needed for the calculation of the answer. List all and study contribution of each to the accuracy of calculated answer. (Is the contribution significant?) |
| | 2 | List the alternative equations that can be used to calculate each contribution. Try to list in the order of decreasing calculation time. |
| CARRY OUT and LOOK BACK | 3 | Estimate the three times, $t_e$, $t_p$, and $t_c$, and compare these with the total time available for each combination of equations and constants. |
| | 4 | Select the combination of equations and constants that can be used in the time available and that will yield consistent accuracy in all the contributions. |

**Computer-aided Optimization.** The objective of this part of the course was to introduce some ideas, concepts and methods available for optimization. Methods of optimizing the use of optimization techniques were deferred to the graduate course. Some depth was given in only two areas.

Emphasis was placed on selecting criteria. Although financial attractiveness is the commonly accepted criteria, the importance of technical, time and resource, environmental, originality in design, social, product acceptance and market-volume feasibilities were discussed. The use of a decision matrix of all these criteria was discussed following the guidelines suggested by Dean **et al.**[3]

The depth was gained—without having to resort to a time consuming computer programming exercise—through the use of mathematical models developed in a simulation project from previous years.[1, 2, 6] For example, an optimization program for a single decision variable search using Golden Section and for the single bed reactor to convert sulfur dioxide to sulfur trioxide had been developed by Professor C. M. Crowe. Since four beds with intercoolers are used on the plant the class used dynamic programming to optimize the conversion to sulfur trioxide with bed inlet temperature as the decision variable. The students enjoyed the exercise and felt it well worth the time.

**Trouble-shooting Problems.** The third section of the course on the application of the principles to design and process operation depends mainly on the judicious selection of problems that can most effectively illustrate problem diversity as well as the uniformity of strategy used. This section most aptly is described as a series of case studies. An innovation tried was to use trouble-shooting problems for plants that have already been designed. Their use emphasizes the diverse applicability of the strategy and shows that plant operation presents challenging problems. This technique[7,8,10,11] and some sample problems are described elsewhere. The instructor has a variety of ways in which these problems can be used: individuals solving the problems,[13,11,14] group solution to the problem, and group defining a strategy.[8] This past year we experimented with the group solution to the problem. In this approach the group discuss the strategy, decide on an action and pose this action through the instructor (who acts a Devils Advocate and screen for the questions) to a teaching assistant who supplies realistic answers to the proposed action. This approach allows the group to experience more problems in a given period of time. However, the individual does not suffer the consequences of his own action. Now, through the cooperation of Shell Canada Ltd, we are developing short film loops to present the problem to the students with visual impact!

## SUMMARY

A four-credit senior course presents a background understanding of 'what is a process,' cost estimation techniques, introduces a strategy that can be used to define problems and to devise economic balances, and surveys methods of choosing criteria and choosing the best. Many problems or short case studies are used to apply these concepts to real industrial problems of both design and process operation.

From past experience the major difficulties encountered by the students were in defining problems, devising economic balance equations, being creative, making good assumptions, applying design morphology, and asking the right question. To overcome these and other difficulties, several innovations have been tried.

Functional analysis of plants or parts of plants together with in-plant lectures have been useful and interesting to the student. Here the primary and secondary functions of pieces of equipment are defined, alternative means of satisfying the functions are generated through creative brainstorming sessions and the resulting alternatives are later critically analyzed through group discussion for technical feasibility. In-plant lectures then were used to illustrate a system, and opened the discussion of feasible design and operating conditions.

A second innovation was the emphasis placed on devising economic balance equations. Similarities in strategy for tackling large, open ended aspects of handling uncertainty were discussed following the guidelines of Rudd and Watson.

Teaching the students how to make good assumptions so that the problem can be solved in the allotted time was not very successful. Perhaps this is too harsh a judgment because evaluation is difficult. The media used was a strategy plus examples and a 'role-playing' session illustrating the conversation between a novice engineer and the devil's advocate.

Optimization techniques were briefly surveyed; selection of criteria was emphasized and some details of one optimization technique were given. The detailed look at a dynamic programming solution for a two stage system with a single decision variable for each stage was possible because of the availability of the computer programs.

Trouble-shooting problems were used as short case studies where the students played the role of an engineer trying to get a plant functioning correctly for a minimum cost. This innovation was enthusiastically received by the students.


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# CHEMISTRY FOR CHEMICAL ENGINEERS*


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Dr. Watkins is employment coordinator for the Esso Research and Engineering Company. He holds BS, MS, and PhD degrees in chemical engineering from Virginia Polytechnic Institute. Dr. Watkins taught at VPI and in 1956 joined Esso at Baton Rouge in development engineering. He was a campus recruiter and may visit your campus—watch for him.

*The type and amount of chemistry required in the Chemical Engineering curriculum has been a controversial topic over the years. Chemistry is an important part of the undergraduate curriculum and the practicing chemical engineer continues to need a thorough understanding of the fundamentals of inorganic, organic and physical chemistry and the theory and techniques of analytical chemistry. Since he will use chemistry as one of his tools in his decision making processes, the courses should emphasize application and problem solving. His chemical engineering courses in turn should offer him the opportunity to apply his chemical knowledge to the maximum amount possible.*

It is a pleasure to discuss with you the very critical question of what chemistry should be included in the chemical engineering curriculum. I think the fact that we are willing to discuss this

*Presented at the Annual Meeting of ASEE, June 19,-22, 1967.