

PROCESS ENGINEERING – THIRTY YEARS OF DESIGN AND PROBLEM-SOLVING CLASSES

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Abstract $\frac{3}{4}$ For over thirty years open-ended problems and design activities which bring together all their chemical engineering knowledge have been posed to chemical engineering undergraduate students at the University of Melbourne in a series of subjects that continue over three years. Known as Process Engineering the aim of these subjects is to enhance the students' engineering problem-solving and communication skills by a series of assignments and activities in which ill-defined and open-ended engineering problems are tackled. Students are faced with the type of problems that they will face in industry. Some activities are for students working as individuals while others are team-based. The activities range from single-session trouble-shooting activities which can be solved with the application of very simple thermodynamics to the more complex design scenarios involving all stages from concept to design. Because the subjects test sets of skills not often tested in written examinations we often find that the top performing students in these subjects are not the same as those who perform well in traditional written examinations.

Index Terms $\frac{3}{4}$ chemical engineering, problem-based learning, process engineering, product engineering

INTRODUCTION

At many universities it is often not until the final year of their studies that chemical engineering students are presented with problems that allow them to bring together all their chemical engineering knowledge to solve a single problem. This activity often takes the form of a design project in which students must apply and combine their knowledge of material and energy balances, transport phenomena, chemistry, reaction engineering, control theory, mechanical design and process economics with safety and environmental considerations.

At the same time many engineering subjects with exam-based assessment students are rewarded for calculating their way through a problem to conclude with a single, correct numerical answer. Students know that they would never be presented with a problem that

- did not have a single 'right' answer;
- they did not have all the information required to get the correct answer;
- had conflicting information;

- they would have to make assumptions about the information;
- had any form of ambiguity;
- could not be answered in a few seconds to minutes;
- does not have a numerical answer because engineering is based on mathematics;
- could not be solved simply and quickly by identifying the appropriate mathematical procedure and then carrying out the calculations accurately on this basis.

Their high level of confidence in the above is based upon their experience at school and with many other, early engineering subjects.

Since the late 1960's a series of problem-based subjects have been part of the core curriculum of the undergraduate chemical engineering course at the University of Melbourne. Known as Process Engineering the aim of these subjects is to enhance the students' engineering problem-solving and communication skills by a series of assignments and activities in which ill-defined and open-ended engineering problems are tackled. Students are faced with the type of problems that they will face in industry. Some activities are for students working as individuals while others are team-based. The activities range from single-session trouble-shooting activities which can be solved with the application of very simple thermodynamics to the more complex design scenarios involving all stages from concept to design. Because the subjects test sets of skills not often tested in written examinations we often find that the top performing students in these subjects are not the same as those who perform well in traditional written examinations.

Presently Process Engineering is taught in three 52-contact-hour subjects in the second, third and fourth years of the course. This paper describes these subjects and presents some of the activities undertaken by the students.

OVERVIEW

The first Process Engineering subject, taught at second year level, reinforces the students' training in material and energy balances which is the only prerequisite engineering subject stipulated. Students are challenged to combine this knowledge with some aspects of their mathematics and chemistry background and a good dose of logical thinking. Introductory design lectures are provided early in the course to enable students to begin tackling simple ill-defined design

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**Process Engineering
Information Request Sheet**

Note : This sheet is to be submitted at the conclusion of the session.

Session : 3

Date : 17/5

Name of Student : ██████████

Name of Tutor : ██████████

Filled in by Student	For use by Tutor		
	Information	Comment	Time
How far is the river from our plant?	About 100m at closest point.		2:30
Why are the fish dying?	Don't know.		
How can chemicals from our plant enter the river?	—	You tell me.	
What hazardous chemicals do we discharge into the river?	None		2:37
Do we discharge anything?	Yes		2:43
What do we discharge?	Cooling water.		2:47

FIGURE 1

A PARTIALLY COMPLETED INFORMATION REQUEST SHEET.

and trouble-shooting exercises. At the third year level, students have completed more of the core engineering subjects and have improved their problem solving skills, so the scope and complexity of the the problems increases, with some exercises continuing in successive stages over several weeks. At fourth year, the Process Engineering course focuses on one main project, tackling different aspects from a feasibility study through to detailed design aspects in each three-hour class. This is a direct leadup to the major final year design project undertaken in the next semester.

DEAD FISH

You are a process engineer employed by a petrochemical company. Recently your site's General Manager has received complaints from members of the local community that fish are being found dead in the local river. They accuse your company of causing the deaths through the operation of the plant. The GM now asks you to investigate and recommend what actions, if any, the company should take, and how the GM might respond to the complainants.

The above open-ended problem is one of the first open-ended engineering problems the students are faced with in the second-year Process Engineering subject. It is conducted in a three-hour session at the end of which they must submit their report with recommendations. The students are told that they cannot properly complete the activity without further information. This they can obtain by approaching one of the tutors present in the room.

Each student in the class is assigned to a tutor, who is usually a graduate student trained in the operation of the class. The number of tutors present depends on the size of the class, with between 12 and 15 students assigned to each tutor.

Students must write their questions on an Information Request Sheet. They can only ask for specific information. They cannot ask for the tutor to make any sort of judgement or decision on their behalf. For their part, the tutors are instructed to answer only the questions the students have ask as written, not the questions they wanted to ask. Figure 1 shows a typical Information Request Sheet with some early questions.

The tutors are instructed that, when possible, they are to give different answers to each question. Thus, two students approaching the tutor with identical questions may leave with different answers. As a consequence the students may end up working on two fundamentally-different problems. For assessment purposes, when submitting their recommendations at the end of the session the students must also submit their completed question and answer sheets.

During the session the students are permitted to quietly talk amongst themselves. Students benefit from discussing the task with their colleagues. Too close collaboration is usually not possible as the diverging answers to similar questions often mean that no two students are working on the same problem. Notwithstanding this the class usually recognise when one of their number has asked a particularly insightful question. By having the tutors note down the time on the Information Request Sheet when each question is asked the originators of the better questions may be identified.

Students adopt different approaches to gather information. Some adopt the shot-gun approach asking question after question with little thought given to the responses they receive. As the students are limited to asking just four questions at a time, they often spend most of their time standing in a queue waiting to see their tutor. Other students ask fewer but more considered questions.

The questions shown in Figure 1 are reasonable questions that might be asked initially. Other useful questions that students could ask initially include the following:

- Are the river fish dying upstream or downstream of our plant?
- Are their other chemical plants close to both our plant and the river? If so, are they known to discharge into the river?
- Can storm water run-off from our plant enter the river?

Once the students have asked these and the questions in Figure 1 then the best questions ask will depend upon the previous answers. For example, if the students are informed that water from the river is used as cooling water before being returned to the river, they might like to know the discharge temperature of the water, as well as the flow rates of the river and the discharge stream. It may be that one student concludes that the fish are dying because of heat stress caused by the discharge of water at too high a temperature and too high a flow rate. Another student might conclude however that their operation is probably not to blame and that the other local plants may be responsible. The emphasis of the exercise is that students should follow a logical route of investigation and then be able to reach well-reasoned conclusions and recommendations with the support of calculations as required. The quality of the written report is a key factor in the assessment.

This example has been used at the second year level in various forms for 30 years. It encourages students to think their way logically and objectively through a problem. The

difference in responses to this exercise is always interesting with some students automatically assuming that their company is responsible before they gathered any information while other students will begin by trying to identify whether there are any hidden motives to the actions of the complainants.

STORING DANGEROUS CHEMICALS

The August 1991 fires and explosions at the Coode Island bulk liquid chemical facility in inner-Melbourne inspired the following multi-session activity. There was an immediate public outcry that such a large and hazardous facility could be allowed in central Melbourne, even though the facility had been used for storing dangerous chemicals for nearly a century. A series of activities were developed for use in the third year classes to look at the possible relocation of the facility away from residential areas.

Working Paper

In the first session the students are shown a video of the local television news of August 1991 showing the fires, explosions, the thick black plume of smoke and the emergency services responding to the situation. The video also shows interviews with local residents concerned for their safety and health and shocked and outraged at the events that have occurred so close to their homes. While the Coode Island facility is only located some 3 km from the University of Melbourne few students know of its existence. It is therefore important to explain to the class exactly where the facility is and what surrounds it. In this first session the students are shown a letter that has supposedly been written by the Premier of the State of Victoria (see Figure 2). The students are then required to develop a single-page working paper and agenda as described in Figure 3.

The working paper developed by the students should have the following elements:

- a statement of the problem describing the current situation and the need to make changes
- a list of the key decisions that will need to be made
- a short list of the major criteria that may be used in coming to the correct decision
- identification of the information that will be needed in order to make informed decisions
- development of a strategy to obtain the additional information
- a suggestion for the next step in the process.

Students are also introduced to the concepts of meeting management and the role and purpose of the agenda. The students are assessed on how their written submissions address each of the points above. Their submissions are due in at the end of the three-hours session. It is explained to students that in the real world secretarial services may not be available if the report is submitted even a minute late. For this reason students must submit their work on time.

You are currently employed as an engineer by the Victorian Government's Department of Labour and Industry. The attached letter has been passed to you by the Minister for Labour and Industry. A meeting has been arranged between the Minister and senior department officials for early tomorrow morning. Given the current political situation in Victoria both the Minister and the Premier are very keen for the State to settle this matter immediately. Please prepare a working paper for discussion at the meeting. Also prepare an agenda for the meeting.

Note that in order for the paper to be typed, copied and distributed before the meeting, it **must** be submitted by 5:15 pm this afternoon. No late submissions will be accepted.

FIGURE 2

THE LETTER FROM THE 'PREMIER' DIRECTING THAT ACTION BE TAKEN.

Premier's Department
State of Victoria

July 29, 2001

The Minister of Labour and Industry
Victorian Government,
MELBOURNE

Dear Minister,

Following the serious chemical fires that occurred within the bulk chemical storage facility located at Coode Island, this Government has been approached by many concerned citizens, community groups and local councils to have the facility re-located immediately on the grounds of safety. Would you be so kind as to advise me of your recommendations concerning the re-location of the facility.

As a state election is due shortly I anticipate a prompt and considered reply on this politically-sensitive matter.

Yours sincerely,

Albert Parkes
(Premier of Victoria)

FIGURE 3

THE ASSIGNMENT TO DEVELOP A WORKING PAPER AND AGENDA

Site Selection Criteria

In the second 3-hour session the students are asked to identify the factors which must be considered in identifying suitable, alternative sites for the storage facility. They are asked to list at least twelve different selection criteria. Below is a list in no particular order, of some of the criteria that they might develop.

1. Is the site close to an existing deep water wharf or jetty? If not, can one be built and/or a channel be dredged?
2. Is the site close to an existing rail freight line? If not, can one be built to the site?
3. Is the site close to existing roads capable of handling the increased traffic? If not, can a road be built to the site, or can an existing road be strengthened?
4. Is the site close to the chemical users/products? If not, is the risk in transporting the chemicals to the remote sites unacceptably high?
5. Is the site politically acceptable?
6. Can the site be readied in time?
7. Is the site in an environmentally-sensitive area (e.g. flora, fauna and coastal processes)? If so, would construction at the site do unacceptable damage?
8. Is the site in an archaeologically-sensitive area? If so, would construction at the site do unacceptable damage?
9. Is the site near existing emergency services? If not, can they be built?
10. Is the site close to populated areas?
11. Is the site in an area subject to extreme weather conditions (e.g. snow, high tides)?
12. Will use of the site have a significant impact on other users (planned or existing) of the land in its immediate vicinity?
13. Will use of the site have a significant impact on the recreational activities in its vicinity?
14. Are the costs associated with preparing the site, purchasing surrounding land and paying compensation to neighbours acceptable?
15. Are the costs associated with transporting the chemicals to/from the site acceptable?
16. Does the site have scope for expansion of the facility in the future?
17. Is the new facility and associated operations such as transport at least as safe as the current Coode Island facility?

Once the tutors have checked the students' list of criteria the students are asked to develop a flow chart. The chart should test each of the sites in a logical order, eliminating the most number of sites with the least amount of work. The object of applying the flow chart to the site is not to choose the best site, but to shorten the list of possible sites. Both the criteria list and the flow chart are submitted for assessment at the end of the session.

Short-Listing the Sites

In the next 3-hour session the students are asked to illustrate the use of the flow chart by applying it to a list of five different sites. The tutors are supplied with information on each site which they can provide to the students upon request. They again use the Information Request Sheet to request the required information. This allows the tutors to respond to the same questions differently for each student. Note that it is important that the students must apply their own flow charts in address this exercise.

The students' submission is in two parts. The first illustrates the use of the flow chart while the second includes a brief report on their findings. The Information Request Sheet as well as the flow chart prepared the week before must be submitted with their work.

In this exercise one of the biggest challenges for the student is time management. They are strongly advised to spend at least 45 minutes preparing their final report.

Plant Layout Design

In the next session the students are advised that the storage facility is to be relocated to a mythical site not far from Melbourne. They are advised that while petrol and low-risk chemicals such as tallow and vegetable oils will continue to be stored at Coode Island, the more high-risk chemicals such as acrylonitrile, benzene and propylene oxide will be relocated to the new site. Their task is to design the layout for the new facility (Figure 4).

A new facility is to be built at the Cove. The land in the area is flat, sloping gently to the sea. The proposed site is well above the high tide mark and is not prone to flooding. The site is surrounded by a 2½ km wide buffer zone on all sides. As the site is in an area without prior development there are no facilities at the site such as water, power, sewerage or telephone. The nearest road is one kilometre from the site to the north. At the Cove the prevailing wind directions are from the north and west.

The Minister requires a preliminary layout of the new facility. The layout should show the positions of the major tanks, bunds and roads as well as the locations of the facilities such as the control centre, the offices, workshop, employee carpark and utilities area. The plan should take into account the requirements of the relevant government legislation, such as the Dangerous Goods Act 1985, and should comply with the relevant Australian Standards, such as AS1940-1988 The Storage and Handling of Flammable and Combustible Liquids.

You are to prepare a neat plan of the new bulk chemical storage facility. Specify as much detail as possible, such as the minimum containment volume for each bund area. Support your engineering decisions in a document accompanying the plan. This document should briefly describe your proposed layout, and then should state the reasons behind your location of the various objects within the site. Do not include the 2.2 km jetty in your plan.

FIGURE 4

THE ASSIGNMENT TO DEVELOP A PLANT LAYOUT

The students are given a lecture on the safe design of bulk liquid chemical facilities. They are given copies of the relevant standards and government regulations which they must consider in designing the new facility. They are also given a complete specification of the chemicals that must be stored. They are typically given two weeks to complete this take-home assignment.

Environmental Effect Statement

In the last session based upon the bulk liquid chemical storage facility relocation the students are required to prepare an environmental effects statement. Following a lecture on such statements the students are given three hours to complete one for the relocated facility. By this time the students understand the exact purpose of the facility and are well paced to develop a well-reasoned statement.

Other Sessions

The sessions described above provide excellent preliminary design experience in third year before they are exposed to the major design project in their final year. Since they were originally developed in 1992 the exercises based upon the storage facility have been used four times. Other activities based around the supply of Australian natural gas to South Korea and the construction of an oil refinery in Papua New Guinea have also been developed and are used in alternate years.

CONCLUDING REMARKS

The use of problem based learning to teach design, problem-solving and improve communications skills starting as early as the second year of an engineering course has proved to be an effective strategy. Students report that they find the problem solving classes challenging, intellectually stimulating and, on occasion, stressful. However, many graduates working in engineering roles in industry tell us that the experience is one of the most valued from their undergraduate course, often saying that "Life is just like a Process Engineering problem!"