DEVELOPMENT OF CROSS-DISCIPLINARY PROJECTS
In a ChE Undergraduate Curriculum

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The Batchelor of Engineering degree in Chemical Engineering at the University College Dublin, established in 1952, is awarded after a 4-year program and is accredited by the Institution of Engineers of Ireland and the UK Institution of Chemical Engineers. As with most chemical engineering degree programs, design education plays a central role. During the third (junior) year, students traditionally work on a variety of design assignments, with particular emphasis on the design of process equipment. In the final (senior) year, the capstone design project forms a major part of the design education, with students working in groups of 5-6 on chemical and biochemical plant design. The scope of the project ranges from process identification and equipment design and specification to safety and loss prevention and economic feasibility.

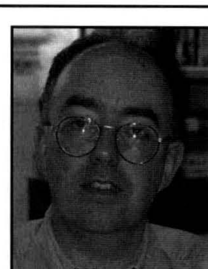
In March 2001, a workshop was held at University College Dublin with the objective of reviewing and assessing current practices in the area of chemical engineering design education in Ireland and Northern Ireland. It was jointly sponsored by the three third-level institutions offering degree programs in chemical engineering—Cork Institute of Technology (CIT), Queen's University of Belfast (QUB), and University College Dublin (UCD). Together with 13 academics involved in design education, there were 13 representatives of employers of chemical engineering graduates who attended the event. The attendees were also addressed by Professor Warren Seider of the University of Pennsylvania. A central recommendation of the workshop was that the increased need for chemical engineering graduates to function in cross-disciplinary environments should be reflected in the undergraduate curriculum. The facility to function in a multidisciplinary team-based environment is widely recognized as an increasingly important skill for engineering graduates.[1]

Subsequently, there were two steps necessary for implementing this recommendation in the undergraduate curriculum at UCD, both realized within the design course offered in the third year of the undergraduate curriculum. This course consists of both a formal "lecture-and-examination" element and a practical, project-based component—the changes to the course related to the project element. First, the author initiated an interdisciplinary design project involving third-year chemical engineering and third-year chemistry undergraduates. This development was facilitated by the fact that the Chemical Engineering Department has an option (titled "Chemical Engineering for Chemists") in the chemistry BSc program. Second, a cross-disciplinary project was established in conjunction with the Mechanical Engineering Department at UCD, with the assistance of Dr. Donal Finn, a lecturer in that department with responsibility for supervision of a heat transfer-related design project during a third-year mechanical engineering design class.

For both projects, the primary challenge was, and continues to be, identification of an appropriate problem statement that presents a suitable learning vehicle for each set of undergraduate students. This paper discusses the development of such projects and assesses the success of efforts to date.

PROJECT EXPERIENCES

Several examples of multidisciplinary engineering design projects have been presented that have either focused on senior-level design projects[2,3] or have concentrated on engineering students.[4] The objective of this particular curricu-



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lum development was to establish suitable assignments that could beneficially introduce, to third-year/junior-level students, the practice of design both in terms of the implementation of chemical engineering theory and the organizational interactions that characterize team-based activities.

Joint Chemical Engineering/Chemistry Project

Central to the development of this project was a process description supplied by a local pharmaceutical company for use in undergraduate design teaching. The information that was supplied is shown in Figure 1, and the first Project Statement developed is given in Table 1.

Cross-disciplinary groups of 5-to-6 students worked on this project for three 2-hour sessions. While the project was generally successful (about 75% of all students, based on anonymous questionnaires with a 90% response, rated it 'better than average'), it proved less satisfactory for the chemistry students, who felt excluded from much of the decision-making within the groups, despite the fact that the problem was formulated to facilitate active learning of process analysis techniques. This situation may be attributable to the relative imbalance in numbers between the two sets of students: approximately 10 chemistry students took the process engineering option, compared to 34 chemical engineering students. Inevitably, the chemists felt outnumbered in the group work. The majority of all students expressed satisfaction with the principle of cross-disciplinary interaction on such an assignment, however.

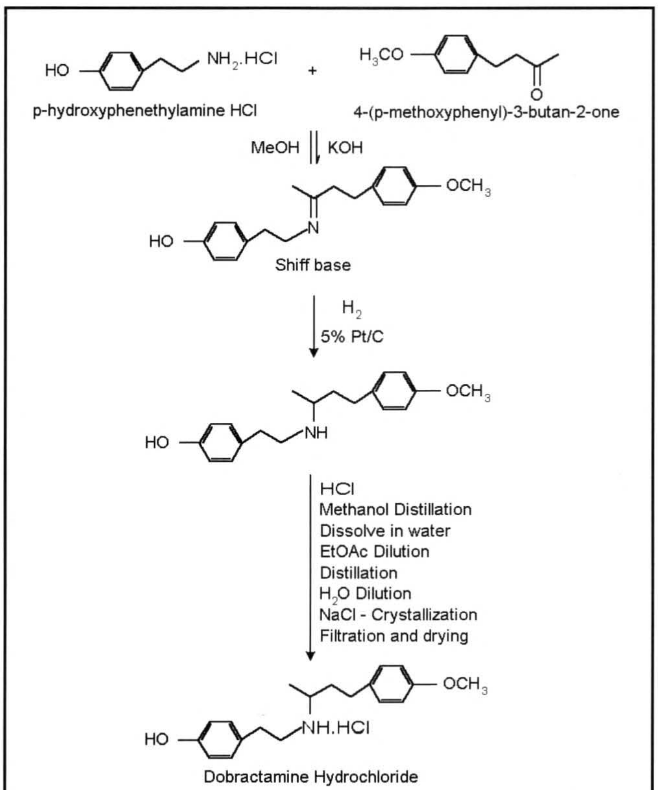


Figure 1. *Dobractamine HCl process description and reaction scheme.*

Other criticisms were of the generic sort, typically leveled at group undergraduate projects ("Some people in the group didn't do any work"; "The lecturer should assign specific tasks to each member of the group"; "Problem specification was too general, and it took us a long time to figure out what we should be doing"; "It was very difficult to find all the necessary data"). This experience is reported elsewhere during the development of multidisciplinary projects.[1]

In the following academic year, the project description was modified in an attempt to more effectively integrate the two groups of students. The effort was also aided by an improved student balance, with 21 chemistry and 31 chemical engineering students. The process was divided into two parts—Part A and Part B. *Part A* focused on the first reaction step in Figure 1, while *Part B* focused on the second step (hydrogenation reaction). The instructions issued to students completing *Part A* are reproduced in Figure 2 (next page). A similar set of instructions was issued for *Part B*.

This modified project proved much more successful, from a number of aspects. First, with the scope of the project reduced, all students could contribute more fully to the overall task. A single, three-hour session was allocated for completion of the assignment to ensure that the students used all members of the group as effectively as possible. Rather than one or two individuals within the group completing all the work, with the other students passively looking on (or not), this assignment required full participation if it was to be completed on time. The instruction sheet produced at the end of the session formed the basis for group evaluation. This assessment was then largely completed by the students themselves. During a succeeding session, the groups had been partially reassigned, so that only some of the original group members remained. These new groups then completed a preliminary safety assessment of the previously prepared instruc-

TABLE 1
Initial Joint Engineering/Chemistry Project Statement

The object of this assignment is to complete a "process fit" based on the process description provided for the production of a pharmaceutical product, Dobractamine HCl. In particular, it is required to specify the equipment train necessary for timely completion of a single production campaign of 50 tons of product. The following conditions apply:

- Available equipment includes a 2400-litre hydrogenation reactor
- Assume the first reaction takes 2 hours
- Assume an average hydrogenation time of 12 hours

The finished report should include the following information:

- Process flow diagram
- Complete mass balance, indicating composition and flow rates for all process streams
- Cycle times for each vessel
- Calculation of overall batch time
- Determination of length of production campaign

tion sheets and highlighted any potential safety or operability issues that might arise during implementation of the batch sheet.

In addition to the improved student participation in the exercise, the problem assignments presented a number of opportunities to better illustrate various important safety aspects of chemical processing. Nitrogen inertion, leak testing, solids and liquids handling, control system operation, safety alarms and interlocks, and instrumentation reliability were some of the topics that arose during completion of the assignments. The principal modification to the project proposed for future years is to introduce the assignment as early as possible during the course to provide more time for discussion of these and other various topics during the accompanying lectures.

Joint Chemical Engineering/ Mechanical Engineering Project

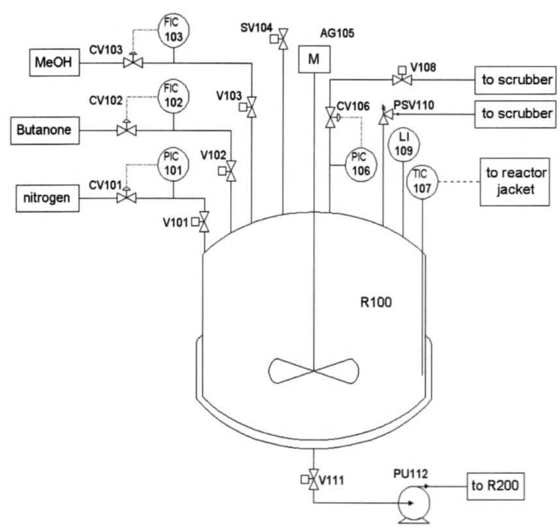
As a first effort in the development of this project for a Chemical-Mechanical Engineering audience, the pharmaceutical process described in Figure 1 was reduced to a generic process flow diagram (Figure 3). The first assignment was attempted by 16 chemical engineering and 16 mechanical engineering students. Split into 4 groups of 8, they were asked to specify heating and cooling utilities to meet the process requirements. The actual project description given to the students is reproduced in Figure 4. Each group was given a slightly different process description (varying heat loads, process times, *etc.*), but otherwise was asked to complete identical assignments. As with the projects described above, the assignment was constructed with the expectation that many of the important design issues raised during the course of the project could be further discussed both within the design sessions (of which there were three 3-hour periods, followed by a presentation) and within the formal lecture classes which accompanied the project work.

Student feedback from this project indicated that the mechanical engineering students felt that the groups were dominated by the chemical engineers, who were far more familiar with the processing aspects of the problem. Additionally, the chemical engineering students had covered more heat transfer theory than their mechanical engineering peers.

Based on experiences with this project, a completely revised project statement was developed for the following year. Rather than basing the problem on a batch process, a simple distillation system was chosen, and the students were asked to specify the associated process components (pumps, heat exchangers, pipework, *etc.*). The problem statement is reproduced in Figure 5. As the mechanical engineering students are almost entirely unfamiliar with the principles behind the operation of a distillation column, a basic introduction was provided. Of particular use was a CD, developed in conjunction with the text *Process Design Principles,*[5] which contains still- and video-images of a distilla-

A proposed Piping and Instrumentation Diagram (P&ID) for the vessel used in this process step is given.

Establish a batch instruction sheet to complete this process step. The instruction sheet should address all activities required to ensure that the process operates appropriately.



The following assumptions can be made:

- All solids (KCl, p-HCl) are available in the correct amounts for charging through the solids valve (SV104),
- Methanol and butanone are charged from supply tanks.
- Nitrogen is used to ensure that an inert atmosphere is maintained in the vessel.
- The reactor jacket system will maintain the reactor temperature at the appropriate level, if required.

Figure 2. *Project assignment (Part A) for reaction scheme (step 1).*

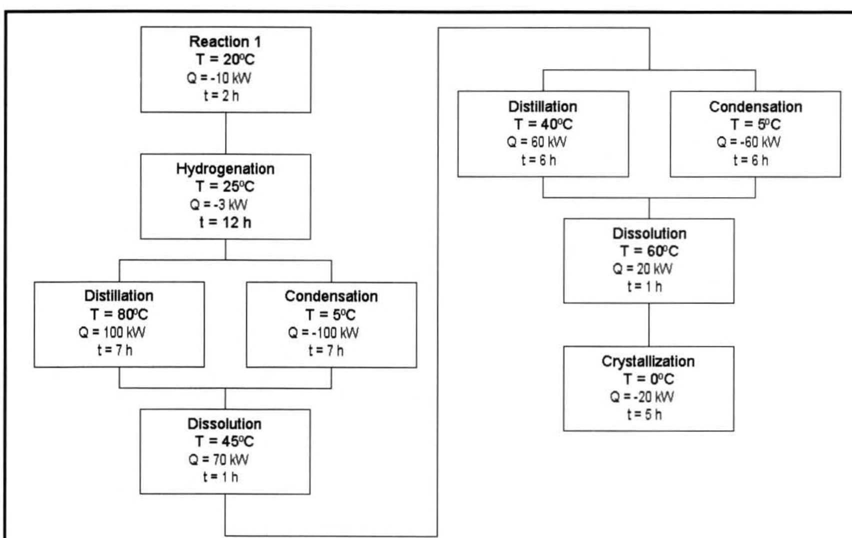


Figure 3. *Process flow sheet for production of bulk pharmaceutical product.*

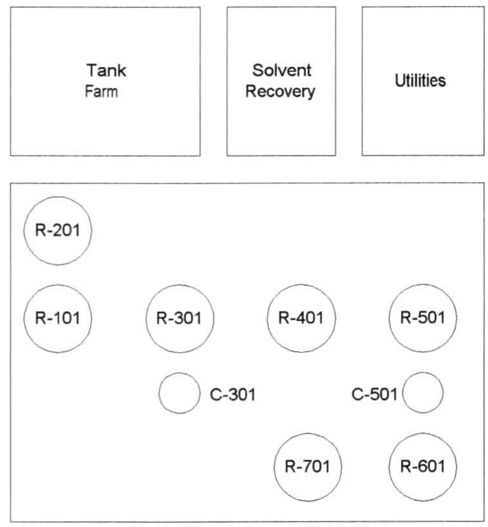
Project Outline
For the production of a pharmaceutical product, it is proposed to meet the plant utility requirements using a single heat-transfer fluid. The fluid is to be provided to the plant vessels via a closed circulation loop. As required, connections to individual vessels can be made at various points along this loop. It is necessary to provide the fluid at both a high (120°C) and low (-5°C) temperature. The design pressure of the system is 13 barg. The proposed site lay-out is shown below.

Project Scope
The designed system should provide a hot and cold service to the plant under the conditions described above. The capacity of the system should be sufficient to meet all anticipated heat transfer demands over the course of a typical production year. The project should address the specification and design of the heating and refrigeration plants and the heating and cooling circulation circuits.

The plant should be designed for year-round operation. The circulation systems should be designed for a maximum heat transfer fluid temperature change of 10°C. Details of a range of possible heat transfer fluids will be provided.

The following items should be considered:

- Materials of construction
- Circulation loop layout and components, including
    - Pipework and connections
    - Recirculation pumps
- Insulation requirements
- Refrigeration requirements, including
    - Type
    - T-S and P-H diagrams
    - COP performance rating
- Heating requirements, including
    - Type
    - Heat exchanger requirements
- Any additional requirements to address the following issues:
    - Oxidation of the heat transfer fluid in the presence of air
    - Density fluctuations in the heat transfer fluid

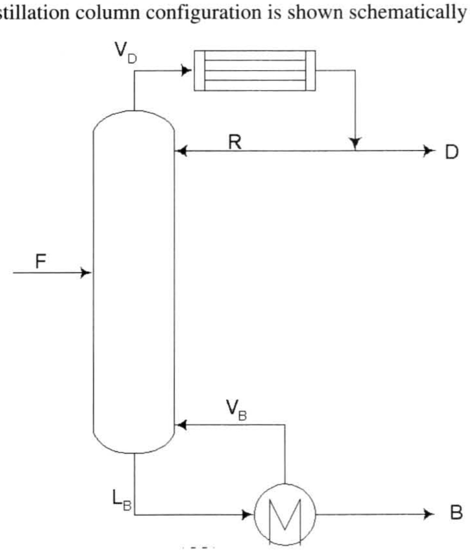


Proposed plant site layout (part of). Process vessels shown are located on second floor, which is 8m above ground level. (Assume the process area shown is 30-m long.)

Figure 4. *Joint chemical/mechanical engineering design project.*

Design Project
You have been asked to specify the process components (pumps, heat exchangers, pipework, etc.) associated with the distillation of methanol as part of an overall methanol production plant. In the final stages of the methanol manufacture, an aqueous methanol stream (F), containing 15,000 kg/h of methanol and 10,000 kg/h of water, is produced at 25°C. To purify the mixture, it is necessary to remove the water using a continuous distillation column (height = 13.0 m; diameter = 1.0 m). The column produces a distillate (D) of essentially pure methanol (b.p. = 65°C), and a bottoms product (B) of essentially pure water b.p. = 100°C).

The distillation column configuration is shown schematically below.



The following table summarizes the streams and their states. All streams are saturated at the point of entry to and exit from the column (*i.e.,* all liquid streams are at their bubble point and all vapor streams are at their dew point). The column is operated at atmospheric pressure.

Stream	Phase	Flowrate (kg/h)	wt% methanol
F	L	25,000	60
D	L	15,000	100
B	L	10,000	0
R	L	37,500	100
V_D	V	52,500	100
V_B	V	52,500	0
L_B	L	62,500	0

The distillate and bottoms products are required at 25°C for storage purposes.

Figure 5. *Revised joint chemical/mechanical engineering design project.*

tion unit, showing typical condenser and reboiler arrangements and associated piping. Completion of the project placed little emphasis on the process aspects of the column, other than determination of the various stream temperatures. Students again worked in groups of 8.

Overall, this project has proved more successful in terms of achieving better student integration between the two cohorts. Neither group felt excluded from the project activities, and the completed reports exhibited clear signs of good cooperation. As is often the case with student assessment of group project work, some students were critical of the relatively loose nature of the problem specification and did not appreciate the fact that they had to struggle for some time to come to terms with what exactly was required of them. This criticism formed the basis of a subsequent lecture on project management and quality assurance aspects of design!

CONCLUSIONS

Working in a cross-disciplinary environment is an important part of the chemical engineering profession. Recognition of this fact has led to the development of a number of projects in the chemical engineering curriculum at the University College Dublin, which brings chemical engineering undergraduates (at third year/Junior level) together with chemistry and mechanical engineering students. Based on the experiences of a number of years, sample projects are presented that appear to offer good learning opportunities for each student group. We hope to further develop these projects in coming years to better integrate the project work with formal lecture classes, with the potential for joint lecture classes between each set of students.

Successful implementation of this type of endeavor inevitably depends on scheduling constraints and on the willingness and flexibility of the home departments of the students. Equally problematic are the differences in learning objectives for students in various departments, which clearly influence the choice of project. In the case of the chemical engineering undergraduate course discussed here, development of teamwork skills, along with a capacity to tackle loosely specified project assignments, are regarded as key learning outcomes.

Based on the experience to date, these cross-disciplinary projects are regarded as a successful addition to the chemical engineering curriculum at the University College Dublin. We anticipate that they will continue to be a part of the undergraduate program for several years to come.

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Block-Scheduled Curriculum

Continued from page 295.

lator software into the systems and dynamics pillar for the inclusion of industrial-style examples, as well as molecular effects on processes through changes in thermodynamic equations of state, etc. Also, optimization (a topic not generally covered in chemical engineering curricula), can be added to the curriculum. In the design course, process interactions between (feedback) control and design will be explored to demonstrate how changes in plant-operating state alter the difficulty of the controller design problem, thereby leading to design for control. Finally, product design will be introduced alongside of process design to highlight the similarities and differences that exist.

THE POTENTIAL FOR SUCCESS

The focus of chemical engineering, and indeed all of engineering, is changing. One needs only to scan the literature to find numerous references to "self-assembly," "nano-structured," "biomimetic," etc. All these topics are as foreign to the traditional chemical engineering curriculum as Beowulf, Jung, or (literally) Greek. The changing engineering landscape is quickly pushing chemical engineering into a third paradigm—the product design (molecular manipulation) paradigm. Without a shift in the curriculum, undergraduates will be wholly unprepared for what may well be their job in the near future. At the same time, even biomimetic or nano-structured materials need to be manufactured, likely in a plant; therefore, we clearly still need chemical engineers to fulfill traditional roles. The ideal new curriculum will balance these needs such that chemical engineering students maintain the versatility that they have enjoyed for years, while at the same time becoming more prepared for today's (and tomorrow's) marketplace. By integrating the core subject matter of the discipline into topic-centered pillar courses arranged in the curriculum according to block-schedul-