# An International Comparison of FINAL-YEAR DESIGN PROJECT CURRICULA

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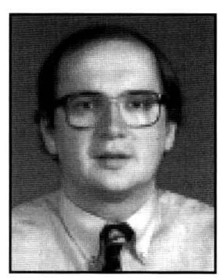
The final-year design project has been an essential part of the chemical engineering undergraduate curriculum for many decades. Some would argue that the structure of this subject has changed little.[1] As will be shown in this paper, however, there is considerable evidence of a substantial shift in the teaching of the design project to better reflect the demands of both a changing discipline and the wider expectations of future employers.

This paper reviews design project teaching at 15 chemical engineering departments across Australia, Singapore, and the United Kingdom. Information on Australian courses was obtained during a design project workshop organized by the Australian-based Education Subject Group of the Institution of Chemical Engineers, and sponsored by Aker Kvaerner Australia. The workshop was held Feb. 14–15, 2005. Information regarding the courses in Singapore and the UK was obtained during a study tour by one of the authors in July 2005.

Historically, the capstone design project was developed to draw together the design techniques developed during



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the chemical engineering course into a single, integrated project. Reference to the instructions for the 1974 Institution of Chemical Engineers design project[2] indicates that the requirements were for process selection and description, material and energy balances, process and mechanical design, and costing. There was a requirement to complete a Hazard and Operability study, but generally the emphasis on health, safety, and the environment was minimal. The learning outcomes were clearly intellectual ability and practical design skills. Transferable skills such as teamwork, oral communication, and open-ended problem-solving ability were not considered relevant. By 1991,[3] the scope of the project brief had broadened with inclusion of topics such as market assessment, energy efficiency, and environmental impact. At this stage, however, there was still no evidence of generic skill development.

More recently, emphasis within chemical engineering education has shifted to focus on learning outcomes beyond only a technical nature. Transferable skills that will assist graduates in a range of employment roles are gaining importance.[4-7] Evidence from the institutions considered here shows that the final-year design project is evolving as a crucial mechanism for developing these skills because of its position at the tail end of the course and the minimal demands for technical knowledge transfer. Indeed, the design project acts as the "exit transition" subject at most institutions, bridging the gap from university study to a real-world position.

The greater computing and word processing power available to today's students and the ready access to electronic literature resources has enabled the design project scope to expand. Larger and/or more diverse projects are being undertaken focusing on broader learning outcomes such as sustainability, process safety, and the use of design standards and regulations. Process simulation can be practiced and practical computing skills developed.

A common feature of chemical engineering courses considered here is that they are accredited by the UK-based professional body, Institution of Chemical Engineers (IChemE).[7] The IChemE promotes the concept of a design portfolio, in which a number of design exercises are completed over the curriculum. There was certainly evidence of a trend in this direction, with many institutions running product design projects in separate subjects, as well as design exercises in the earlier years of study. This paper, however, focuses in particular on the final project at the M.Eng. level, which is the fourth year of continuous study at almost all institutions (the fifth year at Scottish universities). The IChemE accreditation guide[7] indicates that at this M.Eng. level:

> *. . . the course shall include a major design exercise demonstrating that issues of complexity have been appropriately addressed. The major project is normally undertaken in the final year and is normally weighted at 20 credit points minimum (This equates to 16.6% of the final-year credit). The major project at M.Eng. level can be up to 50% of the final-year credit.*

Table 1 shows that among the departments considered, the design project had a credit range between 12.5 and 40% of the final year. In most cases, the project ran across either a single semester or the full year. Some English institutions, however, undertook the design project in the penultimate year of an M.Eng. course to accommodate B.Eng. students into a common program.

It should be noted that within the UK system, a degree of uniformity between departments is provided by the use of external examiners. All design project briefs, assessments, and samples of final project submissions are reviewed by a senior academic from another institution. Within Australia, a

**TABLE 1**
**Chemical Engineering Departments Considered in this Study and the Format of Their Capstone Design Projects**

| | Country | Percent of Final-Year Credit | Timing of Project | No. of Written Submissions |
|---|---|---|---|---|
| Curtin University | Australia | 25.0 | Final Semester | 12 |
| James Cook University | Australia | 25.0 | Full Final Year | 5 |
| Monash University | Australia | 25.0 | Final Semester | 1 |
| RMIT University | Australia | 25.0 | Final Semester | 4 |
| University of Adelaide | Australia | 25.0 | Final Semester | 1 |
| University of Melbourne | Australia | 18.75 | Final Semester | 2 |
| University of New South Wales | Australia | 18.75 | Penultimate Semester | 7 |
| University of Newcastle | Australia | 25.0 | Full Final Year | 3 |
| University of Queensland | Australia | 25.0 | Final Semester | 5 |
| University of Sydney | Australia | 33.3 | Full Final Year | 5 |
| National University of Singapore | Singapore | 12.5 | Final Semester | 3 |
| University College London | UK | 37.5 | Full Third Year | 8 |
| University of Birmingham | UK | 40.0 | Full Third Year | 8 |
| University of Nottingham | UK | 42.0 | Full Year | 1 |
| University of Edinburgh | UK | 33.0 | Full Year | 1 |

similar degree of uniformity is engendered by the availability of an Australia-wide design project student prize (the Aker Kvaerner award) and several regional prizes. For example, the Aker Kvaerner Prize guidelines currently restrict assessment components for safety and environmental considerations to between 10 and 20% of the final grade and process economics to five to 10% of the total grade.

## PROJECT STRUCTURE

Five of the 15 institutions offered only a single project topic per year, arguing this reduced staff workload. Others offered a range of project topics. In the "variations on a theme" approach, a single process was considered, but variations in things such as raw material purity or plant location were used to differentiate team projects. This approach was used by three institutions in order to reduce the opportunity for collusion between classmates, while also limiting staff workload. Only at the University of Melbourne was plagiarism software implemented as a tool for monitoring both collusion and plagiarism from the Internet. When introduced in 2004, this proved very effective. Substantial plagiarism was detected in one student's work, and appropriate action was taken.

At virtually all institutions, the students were initially presented with a design brief of between one and three pages outlining the design problem. This brief often contained basic technical and/or costing data. In most cases, the students were first expected to use this information to complete a feasibility study; that is, to assess alternate process routes and develop a process flowsheet to determine market demand and optimum plant capacity, and to identify potential environmental and safety issues. This was followed by more detailed equipment design work, the development of process control strategies, and a process and instrumentation diagram. At the feasibility study stage or at the conclusion of more detailed work, an assessment of the process economics was required. In most cases, students were expected to argue a business case to "management" as to whether the facility should proceed.

In all cases, project work was supported by a lecture program that provided instruction in design methodology. This lecture program was often structured to cover subject material missed in other areas. Thus, for example, it was recognized that the design of process utilities such as steam and cooling water systems needed to be covered within this program.

The number of assessable written reports required from each student or team varied significantly (see Table 1), from a single submission at the end of a yearlong project to weekly submissions for a 12-week program.

## TEAMWORK AND PEER ASSESSMENT

The design project was conducted as a team exercise at all institutions. Generally, broader process issues such as economics, environmental impact, and health and safety were assessed as team-based tasks, with process design remaining an individual activity. It was common for the individual-based tasks to equate to slightly more than 50% of the total grade.

As shown in Table 2, the size of the teams varied, with typically four or five students on a team. In institutions with larger class sizes, students were allowed to select their own team members. This was generally because of the logistics involved in a central team-selection process when the number of students is large. A significant proportion of design project coordinators with smaller class sizes, however, spent considerable effort to develop team membership. Interestingly, there was a range of ways to do this. Some selected students of common academic ability to be in the same team, while others deliberately placed students of varying academic

**TABLE 2**
**Basis for Team Assignments in the Capstone Design Project at the Institutions Studied**

| Class Size | Group Size | Team Allocation | Team Leaders | Peer Assessment |
|---|---|---|---|---|
| 12-25 | 5-6 | random | rotated | no |
| 25-35 | 4-5 | by project preference | elected by team | no |
| 25-40 | 2-3 and then 10-12 | random | rotated weekly | no |
| 40 | 5 | mix of abilities/gender | no | no |
| 45 | 5 | by several factors | yes | yes |
| 50 | 6 | random | | no |
| 58 | 5-6 | academic merit | no | yes |
| 60 | 4 | students can exclude others | no | no |
| 70 | 3-4 | by academic merit and project preference | no | yes |
| 60-70 | 4-5 | random | - - - | no |
| 70-80 | 4 | self-selection | rotated weekly | no |
| 80-100 | 5 | random | rotated | no |
| 100 | 6-10 | mix of abilities/ethnicity/background | no | yes |
| 80-120 | 4 | self-selection | no | yes |
| 200-300 | 7 | self-selection | elected by team | no |

ability within one team. The University of Queensland is considering the use of specific assessment of team skills from previous years as a basis for team membership in the final-year project.

Many institutions provided explicit workshops or training sessions to develop teamwork skills. For example, the University of Sydney had fortnightly sessions on team building with group leaders. University College London (UCL) had a two-day workshop on effective teamwork a year before the capstone design project, and followed up with a one-day refresher course at the project's start. Similarly, many institutions defined a formal role for team leaders. Rotating the position of team leader allowed leadership skills to be developed among the majority of students.

Some campuses had interdisciplinary teams, which is more representative of actual industrial environments. For example, both the University of Queensland and the National University of Singapore included an environmental engineering student in each team, while the University of New South Wales included industrial chemists. The University of Birmingham had an optional project that integrated civil engineers, while Sydney had a multidisciplinary project for highly academic students only that integrated civil and mechanical engineering students.

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While teamwork was clearly well established as part of the design project, it was somewhat disappointing to the authors that only a third of the institutions used this opportunity to introduce peer assessment. Between the institutions that did, a considerable range of methods was used to manage the process. In some cases, peer assessment marks were determined collaboratively by all team members in an open forum. In others, submission of peer assessment ratings was anonymous, so that students could not discover how their team members rated them. The University of New South Wales presented a relatively sophisticated peer assessment method designed to improve the consistency of assessors.[8] While this method would provide high accuracy and a lack of bias, it could be time consuming in large classes.

## INDUSTRIAL INVOLVEMENT

All institutions actively involved engineers with a design or processing background in the design project curriculum. Some institutions, notably Melbourne and Birmingham, maintained part-time adjunct professor-type positions for engineers with engineering design experience, typically one day a week. In the two cases where the design task was specified by such design engineers, the hazard analysis was considered at an earlier stage as a more integral part of the design process than in other cases. Many other institutions relied on corporate engineers to assist with setting a valid technical scenario, and in many cases personnel from these companies provided a consultant role. In most cases, the academic in charge of the project also had extensive industrial expertise.

## PROCESS SIMULATION AND COMPUTING TECHNOLOGY

All institutions incorporated the use of simulation packages such as HYSYS and ASPEN PLUS to assist in design. In most cases, their use was actively encouraged. In some cases, the design project brief was even manipulated to ensure that simulation was possible. Others, however, felt that the use of simulation packages could detract from the design exercise because proper implementation required significant time input. They also argued that there was a tendency for students to accept simulation output without question, and the educational value was therefore limited. An emphasis on proper justification of simulation output was essential, and was usually the basis for assessment. Justification by both shortcut hand calculations and reference to literature data was encouraged. The use of dynamic simulation for process control and hazard assessment by RMIT University was noteworthy.

Also of note was the extensive use of Web-based learning. A significant proportion maintained subject Web pages as a major mechanism for relaying information to students. These subject sites also often used online discussion forums as a means of bringing common questions into the open and creating inter-student debate. Electronic library resources such as Proquest, SciFinder Scholar, and Knovel were also utilized. A range of smaller, discrete computer programs was also used to support student learning, such as Microsoft Visio for engineering drawings.

## ORAL PRESENTATION

Now considered an important transferable skill, oral presentation served as an assessment component in nine of the 15 curricula. In some cases, these presentations were made directly to engineers and management of the company whose operations had formed the basis of the design task. Presentations could be individual- or team-based, and sometimes involved the use of posters to support oral commentary.

**TABLE 3**
**Bio-Based Design Project Topics Used at the Institutions Studied**

| |
|---|
| Enzymatic production of glucose and galactose from cheese whey waste |
| Lactic acid production |
| Plasmid DNA-based AIDS vaccine |
| Bio-ethanol from waste paper |
| Production of tissue plasminogen activator |
| Penicillin production |

## SUSTAINABILITY

The IChemE now prescribes that graduates must "be aware of the priorities and role of sustainable development." There was little evidence, however, that sustainability was being given a focus in the capstone design project. RMIT University was the only institution formally requiring a sustainability report as part of the project, relying on the IChemE Sustainability Metrics[9] as a template for students. No more than five other institutions discussed sustainability during the course. This is clearly an area that could be improved, and many design teaching staff indicated that they would be enhancing their approach to this crucial issue in the years to come.

## BIO-FOCUSED PROJECTS

Internationally, there is a shift within many chemical engineering undergraduate degree programs from projects based on the traditional petrochemical, chemical, and mineral industries into biomolecular and biochemical engineering fields. We are currently undergoing such a shift within the University of Melbourne with a four-year degree in chemical and biomolecular engineering commencing in February 2005. It is imperative that the design project can accommodate this shift to a "bio" focus while retaining the generic skill development discussed above.

In many respects, University College London was the leader in developing a bio-focus with the development of a biochemical stream alongside their standard course years ago. This proved so popular, however, that a separate department had to be formed. This meant that the chemical engineering department no longer had a need for a bio-based design project. Birmingham University ran three projects simultaneously, one of which was a bio-based project. This project was taken mainly by M.Sc. students, but had IChemE accreditation. They found that a design team with a mix of scientists and engineers worked well. They have found some issues with a full-year bio-based project, however, because of the limited nature of these processes, and were intending to move to a series of shorter, more intense campaigns. Some of these would be focused more on product design than process design.

Typical bio-based projects that had been undertaken at different universities are listed in Table 3. In such bio-based programs the process volume is much smaller (20kg versus 20,000 tonne per year). The downstream separation processes, however, can be more complicated, with 10-15 separation steps being usual. Detailed design tasks can include expanded bed columns and membrane filtration rigs. Production of microbiological quality steam or ultra-pure water may also be required. The regulatory environment of bioprocessing must also gain an increased focus. Students need to be exposed to relevant food and drug quality-assurance programs such as Good Manufacturing Practice (GMP),[10] as well as Hazard Analysis and Critical Control Point (HACCP).[11] Conversely, these projects will be more limited in their use of process simulation packages. There are a number of bioprocess modeling computer packages on the market (Aspen Batch Plus and Intelligen SuperPro), but these can be limited in their ability to accurately predict unit operation scale-up.[12]

## CONCLUSIONS

The design project workshop and subsequent study tour raised a number of other issues common to many institutions that cannot be covered in-depth in this analysis. These issues included the high workload required from teaching staff to provide a worthwhile design exercise, and the similarly high workload taken on by some students in completing the project. Student stress was a significant issue at a number of institutions, and it was felt that this resulted principally from the open-ended nature of the design study. Many staff members also commented on the difficulty of obtaining accurate and up-to-date equipment cost data from the public domain.

The above discussion, however, shows that institutions in the United Kingdom, Singapore, and Australia are now using the capstone design project as a major vehicle for the teaching of transferable skills such as time management, open-ended problem solving, teamwork, and oral presentation. This final-year program has a significant role in "exit transition," or preparing the student for a role in the workplace. While the curricula in most cases is very well developed, the incorporation of more peer assessment and a greater emphasis on sustainability would enhance further teaching in this subject.

## ACKNOWLEDGMENTS

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