Achieving target skills in increments using PBL courses in Chemical Engineering Program at RMIT University

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Abstract*: Graduating Chemical Engineering students are expected to have acquired a number of technical and generic skills that include design, project management, communication and team work. In the new Chemical Engineering program at RMIT University, students are offered opportunities to develop these skills in stages through project-based learning (PBL) courses. Each semester has a PBL course which integrates horizontally the scientific and engineering concepts taught in other courses in that semester. The PBL courses in senior years, however, aim to achieve not only the horizontal integration of concepts from that semester but also vertical integration of concepts taught in previous years. In all PBL courses (eight in total), the development of generic skills is given equal opportunity. However the development of design skills are achieved in stages and it occurs mainly in six of the PBL courses. This incremental progression of design skill development prepares the students to face the final year capstone design project with confidence and excitement. The high satisfaction level in the design project as indicated by a high good teaching score (GTS) of 82% in 2008 shows that the progressive development of technical and generic skills using PBL courses is an effective means of preparing work-ready graduates.*

Introduction

All chemical engineering students graduating from four year engineering programs are expected to have developed a number of skills which can be broadly grouped under transferable and technical skills. The transferable skills that are considered to be important are team work, problem solving, analysis, self-assessment, communication, time management, change management, and life-long learning skills (Woods et al. 2000, Nopiah et al. 2009). Development of these skills in engineering programs are strongly emphasised by accreditation bodies such as Engineers Australia (EA), the Institution of Chemical Engineers (IChemE) and the Accreditation Board for Engineering and Technology (ABET). Among the technical skills, design skills are considered to be important for chemical engineering graduates.

The previous program in Chemical Engineering at RMIT University involved a major design project that was carried out by teams of final year students in the final semester of the program. The course was worth one fourth of the credit points for the year and involved a long list of design tasks. The majority of the students who undertook the design project had no prior experience either in team or design projects. They were not familiar with the tasks involved and the techniques required in carrying out large projects successfully. Therefore, the design project proved to be a very stressful experience for the under prepared students. As a consequence, the satisfaction levels of the students completing the project were low which reflected in the low CEQ scores obtained by the overall program.

To redress this issue, a new program structure was designed in 2004. Recognising the importance of project-based learning (PBL) in developing technical and transferable skills, the new program incorporated a number of PBL courses. The program was designed in a way that the design skills are developed progressively in various courses starting from the first semester. This paper elaborates the incremental progression of the design skills achieved by means of six PBL courses spread over the four years of the program. Conventional problem-based learning courses focus on open-ended real-world problems which might require completing a number of small projects. However, the focus of these project-based courses is completing engineering projects with clearly defined outcomes. During the course of these projects, students could face open-ended or ill-defined technical problems for which they have to find solutions using the knowledge that they have built in prior courses in the program. In this way they also develop competence in critical analysis and skills in problem definition.

Design Project

One of the important requirements for the chemical engineering students graduating from Australian Universities is to carry out a process design project in the final year. This capstone project is a team project and involves the design of a process for converting raw materials into a marketable product. The project could also be on dealing with a waste management problem in a process industry or on revamping an existing equipment to accommodate new technology or environmental and safety requirements. The project involves quite a significant number of design tasks which are summarised in Table 1. Design teams are required to prepare a feasibility report and a final detailed design report. The final report contains the individual designs carried out by each member of the design team. At the end of the course, the design team is required to make an oral presentation to an audience consisting of academic staff, fellow students, and industry consultants.

Table 1. Tasks involved in the final year process design project

- Literature review, market analysis and business review
- Evaluation of alternative processes
- Process selection using triple bottom line criteria
- Plant location and capacity determination
- Preparing a process flow diagram and detailed process description
- Mass and energy balance calculations for the overall process and each major process equipment
- Computer simulation of the process using spreadsheet and commercial flowsheeting software
- Process optimisation
- Process design of all major process equipment
- Sizing of minor and fluid moving equipment
- Preparing process control schemes and piping & instrumentation diagram
- Safety analysis including Hazop and Hazan studies for the plant
- Environmental impact analysis and pollution control
- Plant cost estimation and economic analysis to determine the financial viability of the process
- Sustainability analysis including completing IChemE sustainability metrics

In the old chemical engineering program, there were not many team projects in the earlier years and the design project in the final year was the first major project the students faced. Because of that the students felt the design project was onerous. The majority of the students felt that they were unprepared for the project and lacking in a number of key skills such as team work, project management, and communication.

New program structure

Following a program review process in 2004 to address the issue of low CEQ scores for the chemical engineering program, a new program was designed in 2005. The structure of the new program is shown in Figure 1. According to the structure, there are four courses (12 credit points each) in each semester and there are eight semesters for the BEng program. One interesting feature of this program structure is the project stream shown in the first column. In each semester of the program, one course will be a project-based learning (PBL) course. All the PBL courses involve team projects with the main focus on developing the technical skills (such as problem solving, analytical and design skills) as well as transferable skills. The program structure has been designed in a way that students will learn the main concepts and theories of chemical engineering in the course-work based courses in a given semester and will apply them in the PBL course. This structure was created to achieve the horizontal integration of courses in each semester. It should be noted that, in addition to the eight PBL courses, the program involves an individual research project in the seventh semester.

Among the eight team-based PBL courses, six of them focus on process design. They are: Sustainability Engineering (Semester 1), Chemical Engineering Design (Semester 2), Process Principles (Semester 3), Process System Design (Semester 6), Process System Integration (Semester 7) and Design Project (Semester 8). The other two PBL courses, namely Data Collection & Analysis (semester 4) and Engineering Experimental Investigations (Semester 5), focus on developing the student's laboratory and engineering skills.

The contents of the six PBL courses based on process design were designed so that the students can build their design and transferable skills progressively in stages right from the first semester onwards. Table 2 maps out the key technical and transferable skills that are developed in each of these courses. Opportunities for developing main transferable skills such as team work, project management, and communication are made available to the students in all of these courses. This enables them to achieve significant levels of expertise in all of these skills before they graduate from the program. On the other hand, activities for developing design skills are added progressively. The following section discusses the details of each of the PBL courses and how it helps students to develop their design skills in stages.

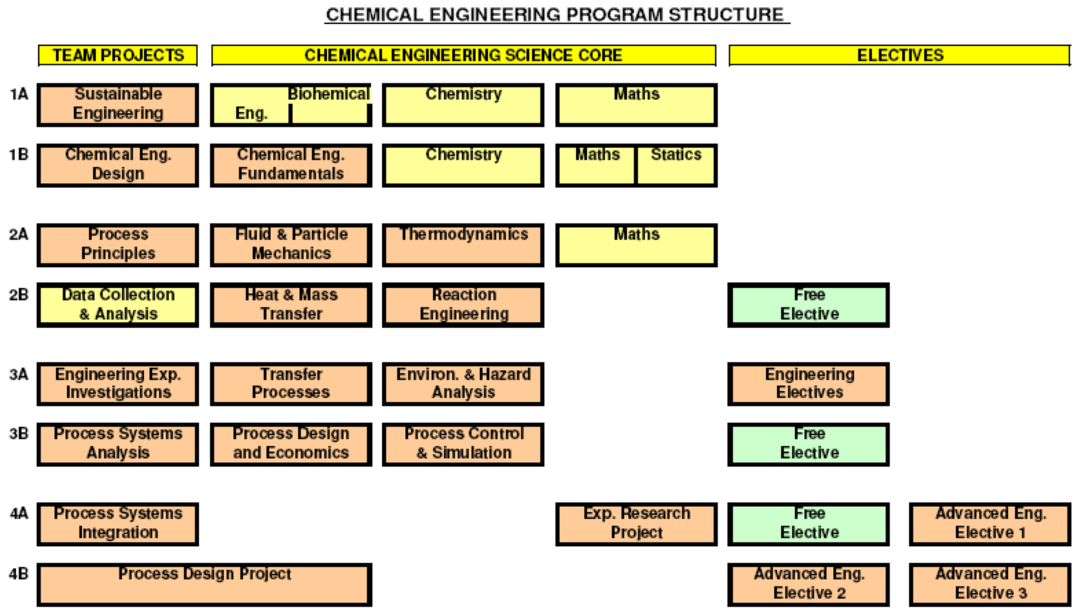

Figure 1. The Chemical Engineering Program Structure

Sustainable Engineering: This course is delivered in Semester 1in the first year of the program. The main focus of this course is to introduce the key engineering skills such as project management, team work, literature review, engineering ethics, computing, oral presentation and engineering drawing. Teams of 5 to 6 students are assigned a project which focuses on evaluating alternative processes for producing a process industry product using economic, environmental and safety considerations (triple bottom line). Learning activities include participating in tutorials and workshops, attending lectures delivered by lectures and guest lectures, field visits, self-learning activities such as researching and maintaining design files. Assessments for this course include oral and poster presentations, briefing papers and group reports. In addition to developing the above mentioned transferable skills, fundamental engineering skills such as flowsheeting are also introduced in this course. This course basically lays the foundation required for the subsequent PBL courses.

Table 2. Incremental progression of technical skills in project-based courses

Course name	**Technical skills**	**Transferable skills**
Sustainable Engineering	• Units and conversion of units • Engineering drawing • Flowsheeting, Process flow diagram (PFD) • Preliminary mass balance	• Project management (preparation of Gantt chart) • Team work & engineering ethics • Literature review, computing, oral presentations & report writing
Chemical Engineering Design	• Flowsheeting • Mass and energy balance calculations • Process simulation using spreadsheet	• Team work • Literature review • Project management • Oral presentation • Report writing
Process Principles	• Market analysis • Analysis of alternative processes using triple bottomline • Process selection and description, PFD • Mass and energy balance calculations • Process simulation using spreadsheet and commercial software (Hysys) • Sizing of fluid moving equipment • Selection of material of construction • Estimation of capital cost of the plant	• Team formation using Belbin team role analysis and team work • Literature review • Design portfolio using Wiki • Project management • Oral presentations • Report writing • Critique of other teams reports
Process Systems Design	• Market analysis • Analysis of alternative processes using triple bottomline • Process selection and description, PFD • Mass and energy balance calculations • Process simulation using spreadsheet and Hysys • Process design of major process equipment • Safety and environmental analysis • Estimation of capital and operating cost estimation, Return on investment (ROI), payback period	• Team formation • Literature review • Design portfolio using Wiki • Project management • Oral presentation • Report writing
Process Systems Integration	• Market analysis • Analysis of alternative processes using triple bottomline • Process selection and description, PFD • Mass and energy balance calculations • Process simulation using spreadsheet and Hysys • Process design of major process equipment • Process control schemes and piping & instrumentation diagram (PID) • Process optimisation using pinch technology • Economic analysis involving capital and operating cost estimation, Cash flow analysis, ROI, NPV & DCFR	• Team formation using Belbin team role analysis and team work • Literature review • Design portfolio using Wiki • Project management • Oral presentations • Report writing
Design Project	• Market analysis • Triple bottomline for process selection • Process selection and description, PFD • Mass and energy balance calculations • Process simulation using spreadsheet and Hysys • Process design of major process equipment • Mechanical design of major process equipment • Selection of material of construction • Engineering datasheet	• Team work • Literature review • Design portfolio using Wiki • Project management • Oral presentations • Report writing

	• Process control schemes and PIDs • Hazop and Hazan for the process • Process optimisation using pinch technology • Environmental impact assessment of the process • Safety issues for the product, process and plant • Complete economic analysis plus sensitivity analysis • Sustainability analysis and IChemE matrix	

Chemical Engineering Design: This course is delivered in Semester 2 in the first year of the program. This course also focuses on developing key transferable skills such as project management, team work, literature review, oral presentation and design report writing. However, this course starts to build fundamental process design skills especially mass and energy balances skills. The project in this PBL course requires the students to evaluate alternative processes for producing a process industry product using triple bottom line considerations. For the selected process, the design team develops a process flow diagram and carries out mass and energy balances using manual calculations and spreadsheet simulation. It is the first opportunity for the chemical engineering students to understand the implications of mass and energy balances in a project and experience horizontal integration of scientific and technical concepts learnt in conventional courses in the same semester. Learning activities include team meetings, academic consultations, literature review and design file maintenance. Assessments include oral presentations, mid-semester tests and group reports. At the end of this course, skill levels of students are expected to progress from solving assigned problems to identifying problems within the project, constructing mathematical equations, and solving them. Students are also expected to learn the basic protocols that are to be followed in oral presentations and report writing.

Process Principles**:** This course is delivered in Semester 1 of the second year of the program. In addition to the transferable skills developed in the first year courses, students develop further skills in literature review, team formation using Belbin team roles, design portfolio creation using Wiki, critiquing other design reports, and report writing. Weekly workshops are conducted to enhance the above mentioned skills. Further, lectures and tutorials are conducted to reinforce students' knowledge in mass and energy balances. The project involved in this course aims to integrate the students' knowledge in courses conducted not only in this semester but also from the previous year. There is a significant progression in acquiring the key design skills in this course. Students are required to carry out market analysis, analyse alternative processes, select the best process based on triple-bottom line criteria, complete mass and energy balances, carry out steady-state process simulation using spreadsheet and commercial software (Hysys), size pumps, select material of construction, and estimate capital cost. Learning activities include weekly workshops, lectures, tutorials, group work, and academic consultations. Assessments include a mid-semester test, oral presentations, and group design reports. The students' ability to self learn is by now sufficiently developed that they can draw required knowledge from other courses without being instructed to do so, and then use the knowledge to solve identified design problems.

Process Systems Design: This course is delivered in Semester 2 of the third year of the program. This course focuses on reinforcing the transferable skills acquired by students in various conventional- and project-based courses they have completed so far. The main focus of this course is to further develop the design skills, especially, in equipment and plant design. In addition to the design activities involved in the 2nd year PBL course, Process Principles, students are required to carry out the process design of all major equipment in the process. The project also requires safety, environmental and sustainability analyses followed by a preliminary economic analysis. The design tasks in this course require the integration of knowledge obtained in courses from the previous semesters (vertical integration) and the current semester (horizontal integration). Therefore the incremental progressions in design skills in this course include the equipment sizing skills and the analyses on safety, environmental, sustainability and economic aspects. Learning activities include lectures, tutorials, teamwork, design portfolio creation using Wiki, and weekly consultation with academic supervisors. Assessments include tests, oral presentations and group design project reports.

Process Systems Integration: This course is delivered in the Semester 1 of the final year of the program. As shown in Table 2, the transferable skills addressed in this course are similar to those in Process principles (2nd year) and Process Systems Design (3rd year) but they are required at higher levels. There is a significant increase in the design activities in this course. In addition to the design tasks for the Process Systems Design (3rd year), students are required to do the mechanical design of process equipment, develop piping & instrumentation diagram (PID) and process control schemes, optimise the process using energy integration, and carry out the complete economic analysis. All these tasks involve the use of design skills which are acquired in this as well as in previous courses. Learning activities in this course include lectures on specialised topics required for the project, tutorials, weekly academic consultations, teamwork, and design portfolio using Wiki. Assessments include tests, oral presentations and group design project reports.

Design Project: This is the capstone project for the program and is delivered in the final semester of the final year. This course does not usually involve any lectures or tutorials. As mentioned above and shown in Table 2, the number of design tasks required for this project is high. These tasks require both vertical and horizontal integration of knowledge obtained in various courses throughout the program. All the main transferable and design skills developed in previous PBL courses are practiced at a higher level in this course. In addition, some new design tasks are introduced. They include the preparation of hazop and hazan studies on major process equipment, engineering data sheet preparation, sustainability analysis of the process, safety and environmental analysis of the process, and sensitivity analysis in the economic evaluation. These tasks form a relatively minor portion of the overall project, but are sufficient to give students a sense of progress and challenge. Learning activities in this course include teamwork, weekly academic consultations, and design portfolio using Wiki. Assessments include oral presentations and group and individual design project reports.

It is clear from the above discussions that the majority of the capstone design project tasks have been carried out by student teams many times in their previous PBL courses. Some of these activities have been repeated in many courses, which help to reinforce the key design skills. Because of the repeated prior experience in carrying out design projects of different types, students doing final year design project in 2008 displayed confidence and excitement. The number of student queries on the design project steps has decreased significantly indicating that the students were well versed with various aspects of the project. Stress levels also seem to have come down. In 2008, students who have completed the design project expressed high satisfaction for the course which was evidenced by the Good Teaching Scale (GTS) score of 82% in the course survey. The CEQ score for this graduation year has not yet been published.

Conclusions

The renewed Chemical Engineering program at RMIT University involves 6 project-based courses which focus on developing the key transferable and design skills of Chemical Engineering students. Developing the transferable skills is emphasized in all the courses at equal levels. However the development of key design skills is achieved in increments when students obtain the core knowledge from other courses at various stages. The scope and the learning activities of the PBL courses have been designed so that the students are able to develop the design skills in stages.

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