Problem Based Learning in a New Chemical Engineering Curriculum

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Abstract

The Department of Chemical Engineering, University of Sydney, has established a programme predicated on a 'problem based learning' (PBL) approach that incorporates a diversity of major projects. This program is both novel and aligned with the graduate attributes delineated by the professional accreditation bodies nationally and internationally. In the new curriculum, PBL is incorporated as a key theme spanning all four years. Thus sophomore students are initiated into the 'product/process design' mind-set through laboratory experiments and the exploration of a pilot-plant through a web-plant designed and operated within the Department. These activities are followed up through focused project work during the intermediate years of study which culminate in comprehensive (industry oriented) process/product design studies during the final year. The curriculum also includes a suite of core courses that incorporate competency based assessments and professional practice oriented courses that are graded. The building of the curricular structure required an approach that is consistent for students registered in both single and multiple degree streams. This paper presents our experiences with the design of problem based learning approach within our discipline.

Introduction

Industries face stiff competition and manufacturers search for new ways to increase production at a lower cost without compromising on quality. To address these challenges, industries need skilled personnel with good oral and written communication skills, tuned to modern technology and adept at teamwork. However, rising costs, reduced budgets, difficulties in retaining high quality students and lack of technical and laboratory resources are some of the challenges that beset universities. Further exigencies include time constraints and clashes within a flexible semester system offering multiple options. Therefore, innovative teaching methods are necessary to circumvent some of these problems.

Engineers are increasingly finding more non-traditional type employment. From a student's perspective, an essential factor in student learning is motivation. Studies [1, 2] note the limitations of traditional classroom teaching in today's changing environment. The student's desire to learn can be enhanced by involving them in the education process and by presenting the course material in an attractive format, relevant to today's needs. The curriculum designer on the other hand needs to focus on specifying the desired graduate attributes and matching course content with those attributes to be finally imparted to the learner.

Studies show that there are good reasons to shift from a content driven curriculum to a learner centred curriculum. Also there is need for reflective practitioners, engineers, whose practice is informed not only by established knowledge, but by critical reflection of the impact of their practice in relation to expectations and values of the society in which they work. Thus there are significant drivers to design an educational framework to:

- Enhance student motivation;
- Adopt a student-centred approach;
- Optimise educational costs;
- Provide knowledge construction and integration;
- Allow flexible learning.

To facilitate curriculum design, the following sets of steps were initiated:

- Identify a set of graduate attributes that could be applied to all engineering courses.
- Restructure courses and conceptualise them into key categories.
- Develop mechanisms for monitoring the attainment of graduate attributes by using student surveys and informal interactions with students by staff.
- Establish a curriculum review process so that each subject could be reviewed for its content, approaches, and assessments, against the course aims.

Figure 1 shows the various elements at work in our curriculum design process. Inputs from various sources were sought including the university, the faculty and the professional bodies. It is important to note that feedback from the stakeholders, including the students, staff and industry, were sought prior to finalizing the contents. In view of the above, we first focused on the formulation of graduate attributes and how they are to be imparted.

Graduate Attributes

The key attribute is learning, which is a process that culminates in the ability:

- to acquire information and evaluate,
- to integrate knowledge from various sources,
- to define relevant problems,
- to critically investigate and solve problems,
- to make choices among available alternatives,
- to communicate to others,
- to apply to new situations.

The first step for us was to identify the desired graduate attributes, which align with those recommended by the University and the professional body [3]. These graduate attributes are briefly summarised below:

- Knowledge skills
  - have a body of knowledge in the discipline;
  - be able to apply theory to practice
  - be able to identify, access, organise and communicate knowledge in both written and oral format;
- Thinking Skills
  - be able to exercise critical judgement;
  - be capable of rigorous and independent thinking;
  - be able to account for their decisions;
  - be realistic self-evaluators;
  - adopt a problem solving approach; and

  - be creative and imaginative thinkers.
- Personal skills
  - the capacity for and a commitment to life-long learning;
  - the ability to plan and achieve goals in both the personal and the
  - professional sphere; and
  - the ability to work with others.
- Personal attributes
  - strive for tolerance and integrity; and
  - acknowledge their personal responsibility for their own judgements, and their ethical behaviour towards others.
- Practical skills
  - collect, correlate, display, analyse and report observations;
  - apply experimentally obtained results to new situations;
  - test hypotheses experimentally; and
  - apply technical skills appropriate to the discipline.

Curriculum Design and Implementation

In the first major redesign of its curriculum, the Department of Chemical Engineering, University of Sydney, has established a programme predicated on a '*problem based learning*' (PBL) approach [4-7] that incorporates a diversity of major projects. This program is both novel and aligned with the graduate attributes delineated by the professional accreditation bodies nationally and overseas. The curriculum design has received positive reviews from both the Institute of Engineers Australia (IEAust) and the Institute of Chemical Engineers (IChemE, UK) accreditation panels in terms of its innovation and intended service as a teaching support tool [8].

Following extensive consultation within the Department and externally, we developed our curriculum based on the following four categories (see):
(A) core subjects providing the concepts;
(B) enabling technology subjects to help solve problems;
(C) engineering practice subjects (based on PBL) to provide the context in learning occurs;
(D) elective subjects.

Figure 2 shows the curriculum schematic from 2nd to 4th year, while the 1st year is common across the Faculty with the course Introduction to Chemical Engineering offered to students committed to the discipline. Some of the key reasons for the placements of courses are:

- to allow students to study the common core and enabling technology subjects and then proceed to develop their practical skills in practice-oriented subjects;
- to enable students to develop their skills in specialist areas via the elective subjects;
- to permit horizontal and vertical integration of the curriculum.

In our new curriculum, PBL is incorporated as a key theme spanning all four years. Thus sophomore students are initiated into the 'product/process design' through laboratory experiments and the exploration of a pilot-plant designed and operated within the Department. These activities are followed up through focused PBL work during the intermediate years of study which culminate in comprehensive (industry oriented) process/product design studies during the final year. The changes introduced in the courses involved a deviation from the usual teacher-centred environment in the regular didactic University classes. The introduction of PBL in the two courses is not part of an institutional initiative. Rather this is a lecturer-initiated effort to focus the learners on the relevance of the courses to, real life situations.

This new learning environment embodies a suite of principles known to improve learning: active, cooperative, provision of prompt feedback, together with matching a student's learning preference with student empowerment and accountability. The process is designed to help students learn key principles of a subject in the context of using them to solve relevant problems. Thus PBL with the associated suite of projects (including those built around a web-plant) will form the scaffolding on which our teaching/learning will be delivered throughout the entire curriculum.

Our Department already has a strong base on teaching courses in the areas of core concepts, enabling technologies and a variety of electives. In order to provide the skills to pursue with life-long learning, to carry out team-work, to formulate problems and to find appropriate solutions to real-life problems in an integrated framework, we decided to include within the contextualized engineering practice course. Figure 3 shows our approach to PBL. The main effort is centred on solving the problems with assistance through lectures, tutorials and consultations.

Problem-based learning is a pedagogical strategy for posing significant, contextualized, real world situations, and providing resources, guidance, and instruction to learners as they develop content knowledge and problem-solving skills [6]. The learning is student-centered and carried out in small groups with the teacher as guide. Problems provide a focus and motivation for learning, developing problem-solving skills is a desired component, and students identify the need for new information and then obtain it. In addition to the technical knowledge acquired by motivated learners, the outcomes include skills for problem solving, teamwork and life-long learning [7].

Problem Solving

The generic strategies we recommend our students to solve problems include:

- Explore the problem, identify issues, think critically, generate and test hypotheses;
- Identify what you do not know and what you need to know (because your lack of knowledge is impeding progress);
- Self-study and preparation;
- For a group, share the new knowledge effectively;
- Apply your knowledge to solve the problem;
- Evaluate the solution in your judgment;
- Give yourself feedback by assessing the new knowledge, the problem solution, and the effectiveness of the process;
- Reflect; remember.

Practitioners recommend that students be consciously involved in developing desired process skills. Students need to be made aware of the benefits of the course beyond factual knowledge. They need to be informed about how their learning will occur so that they can develop the ability to assess their own progress. Self-assessment results from reflecting on:

- what am I going to do;
- how to do it;
- did it work;

- what follows next.

A critical component is an integrated web-plant consisting of two main structural elements: (1) a 'hands-on' facility designed as a flexible and versatile process and product engineering toolkit, consisting of reactors, separators, mixers, pumps, valves, piping and instruments; and (2) a web-enabled interactive control system which allows both virtual experiments as well as designing/controlling processes in addition to studying their dynamics and scale-up. The Web Plant has been designed with safety in mind, pumping water only in a closed circuit using steam and cooling water for both heating and cooling requirements. Modelling is used to provide a set of reactions that interact with real plant data, giving the impression that the reaction is occurring in the experimental rig.

For a first year course, "Introduction to Engineering Discipline", students select the reaction module for Saponification (Soap Making) and run experiments to optimise the production of the end product, in this case, soap. Students are introduced to a manufacturing process with all the associated sounds and visual stimulation that come from a pilot plant but without the danger. This approach opens the way for remote or distance delivery over the internet.

Human Machine Interfaces (HMI) have been developed has part of this program to provide students access to the Web Plant both locally (at the laboratory) and over a network using a web browser. The local interface is a commercial product, the network interface has been developed in house, using java applet as the communications engine. This interface open the way for delivering learning modules over the internet.

The facility is being expanded to include advanced years and its key features are:

- Simulated reaction modules are selected to study reaction engineering, process modelling, energy and momentum conservation, heat and mass transfer, process optimisation and process control. The pilot scale plant can be physically configured to operate under a variety of configurations.
- The facility is supported by instrumentation and control hardware, similar to the ones found in industry.
- The modular construction allows extensions and re-configuration with evolving ideas and curriculum needs.
- The Department will have the capacity to offer learning modules as accredited industrial courses that may be combined with selected offerings for inter-disciplinary access and collaboration.

Outcomes

The process helps students to learn key principles of the subject in the context of using them to solve relevant problems. Thus PBL with the associated suite of projects form the scaffolding on which all our teaching/learning are supported throughout the curriculum [4-7]. The key outcomes that are facilitated include:

- Pose problems prior to learning for student motivation.
- Involve engineering projects that are more than a synthesis of previously learned knowledge.

- Students acquire skills at their own pace within a problem solving environment.
- Learning takes place in a student-centred cooperative environment (with opportunities for self-directed learning).
- The experience help develop both research and interpersonal group skills from the *first to final year learning experience.*

A number of projects [9-10] were completed over the last few years to harness the resources to undertake the projects desired. The overall plan is closely aligned with the key recommendations of the Academic Board. In particular, the project directly address issues on improvement of quality of teaching and learning, access and equity in student learning experience, acquire skills towards excellence in research, facilitate engagement with industry and the professions and help institute effective management of sustainable learning tools.

Conclusions

The Department of Chemical Engineering has incorporated an integrated framework for teaching core concepts, enabling technologies and engineering practice courses. Initially, the desired graduate attributes were determined, followed by the design of mechanisms to impart them to the graduating students. The engineering practice segment was established with a program predicated on a PBL approach, which incorporates a diversity of major projects. The new curriculum has been introduced since 2004 in stages from the first year onwards. The language of the attributes was a major difficulty for the staff; time and continued debate are needed to develop a shared understanding and ownership of the graduate attributes. Motivating staff to get involved in unfamiliar territory has been a challenge, but team teaching has helped to provide a sense of peer-support.

PBL as an instructional strategy moves students towards the acquisition of knowledge and skills through a staged sequence of problems presented in context, together with associated learning materials and support from teachers. The principal idea behind PBL is that the learner gets a problem, a query, or a puzzle that he/she wishes to solve with curriculum centred upon key problems in professional practice. Thus, PBL is both a curriculum and a process: a curriculum that consists of carefully selected and designed problems that demand acquisition of critical knowledge, problem solving proficiency, self-directed learning strategy, and team participation. The process involves a systemic approach to resolve a real-life situation. Our PBL approach incorporates a web-plant for hands-on experiments in conjunction with simulation work for analysis and for conducting virtual experiments to deepen the experience. The PBL approach has helped teach students to have: better and longer information retention, more highly developed critical thinking and problem solving skills, better interpersonal and communication skills, higher self-esteem and lower levels of anxiety

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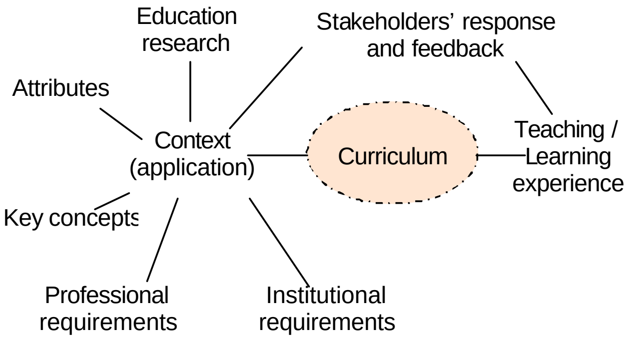

Figure 1. Curriculum design process

	(A)	(B)	(C)	(D)
Year 2 Sem 1	CHNG 2801 Conservation and Transport Processes	CHNG 2802 Applied Maths for Chemical Engineers	CHNG 2803 Analysis Practice 1 – Energy and Fluid Systems	CHEM 2 Physical Chem for ChE
Year 2 Sem 2	CHNG 2804 Chemical and Biological Systems Behaviour	CHNG 2805 Industrial Systems and Sustainability	CHNG 2806 Analysis Practice 2 – Treatment, Purification and Recovery Systems	CHEM 2 Chemistry of Biological Systems
Year 3 Sem 1	CHNG 3801 Process Design	CHNG 3802 Operation, Analysis and Improvement of Industrial Systems	CHNG 3803 Design Practice 1 – Chemical and Biological Processes	CHNG 3804 Elective
Year 3 Sem 2	CHNG 3805 Product Formulation and Design	CHNG 3806 Management of Industrial Systems	CHNG 3807 Design Practice 2 – Products and Value Chains	CHNG 3808 Elective
Year 4 Sem 1	CHNG 4801 Thesis A	CHNG 4802 Design A	CHNG 5001 Elective	CHNG 5002 Elective
Year 4 Sem 2	CHNG 4805 Thesis B	CHNG 4806 Design B	CHNG 5003 Elective	CHNG5004 Elective

Figure 2: Schematic of new curriculum structure

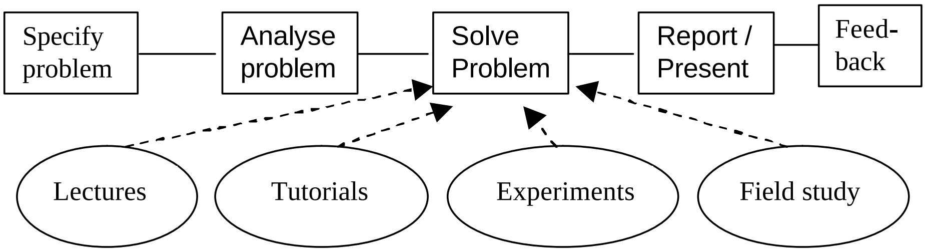

Figure 3. Problem based learning strategy

BIOGRAPHY

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Vincent Gomes is the director of Teaching and Learning and a faculty member of Chemical Engineering Department at the University of Sydney. He received the bachelor's degree from IIT and the master's and PhD degrees in Chemical Engineering from McGill University. His primary areas of interest are in educational methods and assessment, curriculum design and problem-based learning.

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