Inductive-based Pedagogy in Engineering ScienceSubject

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Abstract

As part of Victoria University's re-branding, in 2005, both schools of engineering at the university decided to adopt Problem Based Learning (PBL) pedagogies in their undergraduate courses. The pedagogical approach to Engineering Materials was uniquely based on inductive-based teaching and learning methodology in which PBL constituted one of the pedagogical tools. Yet, despite greater teaching intensity and subject complexity combined with a high demand placed on time management as part of student participation in developing teamwork skills, both pass and student subject satisfaction rates remained comparatively high. The negative aspects related to poor study habits and unfamiliarity with working in teams.

Introduction

The underlying reason for the adoption of PBL pedagogies in undergraduate engineering curricula at Victoria University was based on the belief that such action would increase engineering course attractiveness, produce better educational outcomes and reduce attrition rates. Without consensus on a PBL model, both engineering schools agreed to allocate 50 percent of each semester course to PBL delivery.

Without an extensive critical analysis of PBL pedagogical models, it suffices to say that their focus is more constructivist and student-centred than the traditional instructional learning models. Schmidt (1983) defined PBL in terms of knowledge processing that included learning, encoding and retrieving of knowledge when the occasion demanded. Students were exposed to real-life situations as part of recognition training in future professional practice. Northwood, Northwood and Northwood (2003), in a critical analysis of educational outcomes between traditional and PBL graduates, found very little difference with the exception of Aalborg University where the PBL engineering programs had significantly lower attrition rates than other engineering education providers in Denmark. However there are other implicit factors that characterize professional activities which must seriously be considered in professional education. Fenwick (1997) and Scheman (1993) define professional activity as one that is inherently problem solving and its success relies in being able to identify the deviant components in messy and unpredictable situations. Problem based learning thus fosters the culture of seeking the deviant and exploring possibilities.

Barrows (1984) in a study of health education suggested that PBL pedagogy underpins a cyclic learning process. Such process consists of the following phases:

- Students first encounter problems before theory;
- Students develop professional reasoning with the assistance of the academic staff;
- Students identify the information and knowledge needed to address the problem and acquire such knowledge through self directed study;
- Students apply their newly gained knowledge to the problem; and
- Students evaluate the solution(s) to the problem.

Full PBL subjects cannot be introduced where students are required to acquire new knowledge and concepts. This has been recognized be McKenna and Yalvac (2007) who point out that a PBL subject requires a platform of prior knowledge on which students build on. This pedagogical model was used as a template by the School of Electrical Engineering (EE) at VU in introducing its PBL program.

The School of Architectural, Civil and Mechanical Engineering (ACME), to avoid the perceived complexities and student equity issues associated with the Aalborg University type of PBL delivery, adopted by the School of Electrical Engineering, opted for a different model. The School of ACME designated two of the four semester subjects in the re-designed course as PBL subjects. As there was no general consensus on PBL methodology, the subject coordinators were given a free reign in designing appropriate PBL delivery. Second and third year materials subjects were designated by the School of ACME as PBL subjects.

The course design of the two-semester materials science subject, a common second year subject in Architectural, Building, Civil and Mechanical Engineering courses, presented two particular challenges, which were:
Reduction in contact hours. The original two semester subject consisted of 2 hours of lectures and 1 hour of tutorial/ laboratory classes per week. The new PBL subject was condensed to one semester duration of 2 hours of lectures plus 2 hours of PBL workshops/seminars and 1 hour of tutorials/laboratory per week. The overall reduction in time allocation was 16.7 percent and the accredited subject syllabus had to be covered with a 50 percent reduction in lecture time; and
Reorganization of the curriculum. The original two semester subject was basically an omnibus-type subject which consisted of two components. The first semester component was concerned with the development of chemical literacy and converged with the recommendations issued by ASTEC (1996) and the Report into Engineering Profession and Education edited by Johnson (1996). The second component related to fundamental material science. The challenge was to develop a combined space for both components addressing a common theme.

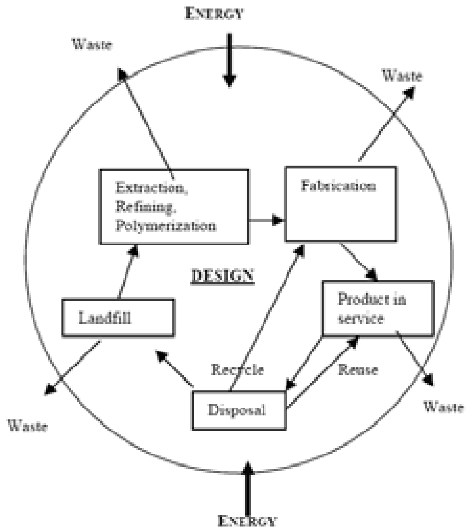
Subject Curriculum

The approach to the original two semester subject was one as an engineering science. The first semester component, with the full understanding that more than 40 percent of students have not done any chemistry since year 10 of high school, assumed no previous chemistry background. The subject was problem focused where concepts of conservation of mass and energy were used to tackle real life problems encountered in industry, environmental engineering, fuel technology, innovation and process engineering. Chemistry principles were introduced on a need to know basis to address particular problems. This instruction method of teaching fundamental sciences to engineering students, proposed by Coates (1997), was shown by Rojter (2006) to be highly effective. This approach in introducing fundamental science in the contexts of engineering problems was retained in the new curriculum.

Integrating the two components meant that there was a need to develop a unifying theme. Curriculum model derived from courses in creative arts such as music and drama were used to develop the new "PBL" curriculum. The mainstay of student education experience was to mimic professional practice and experience its messiness and instability. The emphasis was thus on what Giddons and Hellstrom (2000) describe as mode 2 knowledge which bypasses disciplinary boundaries and is highly contextual. The subject was to be a journey of cognitive struggle in which students were to understand that there are plethora of solutions to an engineering problem and an application of a solution often raises new questions and sometimes produces new engineering problems. The subject was to represent a reflective journey described by figure 1. The underlying unifying themes of the subject contents were engineering design and sustainability.

- First Cycle. It deals with both the introduction to and extension of students' chemical literacy. The students' appreciation of the role chemistry plays in the technical elements of professional engineering practice is conducted through case studies in process engineering such as: fuel evaluation; production of nitric acid, ammonia, foodstuff etc; greenhouse phenomena and global warming; evaluation of energy storage; chemical and electrochemical deterioration of materials; and production of cements, aluminium, steel, copper and plastics.
- Second Cycle. It is concerned with the microstructure- property relationship in solid materials. Though some attention is paid to ceramic and polymeric materials, most of the course emphasis is focused on the strengthening mechanism of metals and the role phase precipitations play on microstructures and properties of carbon steels and cast irons.

Figure 1. Schematic view of educational journey in the subject.



Subject Delivery and Assessment

Though designated as a PBL subject, the subject mode of delivery was multivariant in which PBL constituted just one of the pedagogical tools. An exclusive reliance on PBL as the only mode of subject delivery has many drawbacks. Boud and Feletti (1997) and, Perrenet, Bouhuijs and Smits (2000) suggest that PBL that is only focused on self-directed learning may not always lead to constructing the right knowledge and may bypass student fundamental misconceptions that hinder students' understanding of critical engineering concepts. These could affect graduates' abilities in tackling novel problems in a professional setting. This has been reinforced by Mills and Treagust (2003) findings of PBL graduate attributes. Thus in order to present a broader professional picture of engineering practice, combined with the fact that knowledge in engineering science has a hierarchical scaffolding, the mode of subject delivery was multi-fold that included both instructional and various types of inductive learning, discussed in greater detail by Prince (2004), Prince and Felder (2006) and Felder and Prince (2007).

Modes of Delivery

The subject consisted of three learning components, one of which focused on instructional activity and two on student centred learning. These were:

1. Instructional Delivery. Formalised or asserted knowledge was introduced in lectures. Topic principles were introduced and reinforced through real-life case studies. Case-based learning (CBL) formed the inductive learning approach. Lundeberg, Levin and Harrington (1999) have shown the Case-based learning approach to produce graduates, with skills of higher order thinking in Bloom's taxonomy, with better abilities to identify relevant issues and recognize multiple perspectives, and with improved problem solving skills. Kaitsikitis, Hay, Barrett and Wade (2005) compared CBL to PBL and found no significant differences in relation to performance and knowledge acquisition.
2. Open-Ended Research and Discovery. This was a part of student-centred activities for the whole semester and largely focused on PBL. Tutorial groups of 24-30 students were randomly divided into subject teams of 4- 6 students. Each team was allocated a particular problem, outlined in table 1, to be completed at the end of the semester.

Table1. Problems allocated to students

	Project title
1	Energy and Environmental Audit and Assessment of various fuel mixtures consisting of s Methanol, Ethanol, Methane, Propane, Butane and Octane at combustion efficiencies varying between 80-98 percent and excess air varying between 5 and 250 percent.
2	An environmental assessment and LCA (life cycle assessment) of three selected bio-degradable polymers
3	Examination of the feasibility of production of ethanol, methanol and diesels from sustainable sources.
4	Production of paper from garden waste.
5	Environmental feasibility of production of diesel and petrol from coal and natural gas.
6	Environmental and life-cycle analysis of 1litre milk containers produced from: - Polyethylene coated cardboard container (single trip); - PET bottle (single and 5 trips); - HDPE bottle (single and 5 trips); - Poly carbonate bottle (minimum of 30 trips); and - Glass bottle (1 and 6 trips).

Each team was required to deliver two oral presentations. The first team presentation, in weeks 3-4, was focused on informing other students on the nature of team's topic and how the team members were going to address their problem. The second oral presentation, in weeks 11-12, informed on the team's findings. A full written team report was submitted in week 13. This was a highly structured document which sign-posted team members' individual contributions. The report was to consider the problem as a design exercise in which a number of solutions were outlined before committing to a single solution justifying the selection in the context of technological, economic, environmental, ethical and social criteria. Student team meetings were allocated 2 hours per week in PBL studios with an opportunity to consult with the facilitator and the coordinator of the subject. Though instructional delivery provided the conceptual base for many of the problems, students were required to seek out relevant databases, information and knowledge required. The facilitator's function was to suggest possible sources of information in the world of the academy, research and industry and, to act as a sounding board for student ideas. The facilitator would often, if required, through a short lecture present new knowledge relevant to the problem at hand. Such lecturettes were part of the inductive learning process to which Prince and Felder (2006) refer as just in time teaching (JTT).

3. Experimentation and Observation. Half a semester was allocated to this component. Students were required to perform three prescribed experiments and submit their findings in a team report. Answers to relevant experimental questions and the application of the experimental results to real-world problems as an essential part of the report that compelled students to review relevant literature and databases. This section concerning placing meanings to experimental data, was also an inductive learning process defined by Prince (2004) as inquiry based learning (IBL).

Assessment

Submission of individual reflective journals was a compulsory requirement for the subject assessment and allowed students to gain up to 5 percent bonus marks. Keeping a reflective journal exposed students to reflective professional practice and engaged them with the subject content. The reflective journal also provided a qualitative feedback on the subject and its delivery.

Students were required to attain a minimum of 40 percent for each component and 50 percent for the overall result to pass this subject. The Instructional Delivery component accounted for 50 percent, and The Open-Ended Research and Discovery component, including student assessment of oral presentations accounted for 38 percent, and the Experimentation and Observation accounted for the remainder of the subject assessment. The team reports were equally assessed on the basis of being a unified and coherent document and on the basis of individual contributions.

Evaluation

The approximately 70 percent pass rates, of 140 to 170 students enrolment in this subject, have not changed during the subject transformation into a designated PBL subject. This in itself is good news given the reduction of contact hours and the greater intensity of the demands placed on students.

In general, student evaluation of the subject and its teaching has not altered much as a result of its transformation to a "PBL" mode of delivery. Table 2 compares the subject evaluations in years 2003-2004 to its transformed entity for the period 2007-2008. Student opinion of the subject as being difficult but interesting remained constant. Generally students liked the narrative mode of delivery.

Table 2. Student Subject Assessment

Statement	**Year of Assessment and average score**			
	2003	**2004**	**2007**	**2008**
The lecturer has a good command of the subject	4.7	4.4	4.4	4.6
The subject objectives are clear.	4.4	4.0	3.5	3.9
Lecturer interacts well with the class	4.1	4.1	4.3	4.4
Lecturer is accessible for individual consultations	3.8	3.9	3.6	4.0
Lecturer arouses curiosity in the subject	3.6	4.0	4.0	4.2
The subject widens the scope of engineering knowledge	3.9	4.5	4.5	4.5
The subject is satisfying and would recommend to others.	4.0	4.2	3.8	4.1

Student reflective journals revealed that students gained a lot of positive experiences from this subject's method of delivery. Typical comments are shown below:

I am glad to have finished this subject as it has been stressful and frustrating in regards to team members. However, I enjoyed the subject content. I look forward to PBL subjects in the future and being allowed to choose own groups.

One major element I have benefit from is that I have made 2 really great friends who were people I would have never worked with, but came to hate some others.

Overall for the 12 weeks it went fairly well as the group worked hard as I was pushing them. In the end we got the work done but due to problems beyond our control we couldn't show it.

Conclusion

The fact that failure rates remained unchanged would suggest that PBL delivery did not produce more inspired students. But the assessment data also indicates that most of the students failed not by under-performing in the exam but also through underperforming and disengaging from other components of the subject. Though there is little conclusive evidence that PBL education produces better engineering graduates, nevertheless a change of both student and staff culture has been observed through the change of the teaching paradigm. This is very important because introduction of PBL into engineering curricula provides an opportunity for taking the control over education of the engineering professions from the academic rhetoric of the university and shifting towards the rhetoric of the engineering profession. The shift in educational paradigm is of course difficult since it challenges prevailing academic cultures.

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