PROBLEM BASED LEARNING IN ENGINEERING CURRICULUM: The Case of Materials Technology

Josef Rojter
School of Engineering and Science,
Victoria University, PO Box 14428 MC,
Melbourne City, VIC. 8001, Australia,
Josef.Rojter@vu.edu.au

Abstract

As part of the university re-branding program in 2005, both schools of engineering at Victoria University decided to adopt pedagogies of Problem Based Learning (PBL) as means to deliver their undergraduate courses. This action was taken for both intrinsic and extrinsic reasons, which were to increase the course attractiveness and reduce relatively high attrition rates. This would re-position engineering education at Victoria University in a languishing and a highly competitive student market by transforming engineering into an attractive course of study. Both schools of engineering agreed that 50 percent of their undergraduate engineering curricula be allocated to subjects using PBL delivery. There was little agreement between the two engineering schools concerning educational PBL frameworks. As a result I pursued a path in which the curriculum design and delivery would take note of other professional educational models and would be re-oriented from scientific to a more worldly critical approach. The course developments were based on a rudimentary philosophy of engineering which provide the basis for course construction and implementation. The underpinning of the Materials Technology was grounded in an ideological stance of engineering as a social profession which focused on sustainable application of technology. The subject was divided into three components that included asserted knowledge, empirical approaches and critical investigation. The last two required substantial student participation in small groups and focused in developing teamwork skills. The course was first trialled in 2006 and then formally introduced during both semesters in 2007. Given the complexity and intensity of the subject and the high demand it placed on student time, student response was highly positive. The negatives aspects related to poor study habits and unfamiliarity working in teams. The positives were high student satisfaction with subjects, low attrition rates and relatively high pass rates.

Key words: *Education for professions, Inductive and Problem –Based Pedagogy.*

1. Introduction

The implementation of PBL pedagogies into the engineering curriculum was a strategy to address educational problems and issues at Victoria University (VU). These were:

- Poor intake, both in terms of quality and quantity, into undergraduate engineering courses at VU; and
- Relatively high attrition and low progression rates respectively.

Though there are a number of PBL pedagogical models, there was little consensus on an initial common model selection. Without an extensive critical analysis, it suffices to say that all PBL pedagogical models are based on common goals of constructivist and student-centred learning than the traditional instructional learning models. Schmidt defined PBL in terms of knowledge processing that included learning, encoding and retrieving of knowledge when the occasion demanded [1]. Barrows (in a study of health education suggested that PBL pedagogy underpins a cyclic learning process [2]. 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.

PBL engineering education does not necessarily satisfy the professional needs in the world of engineering practice. 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 [3]. There are other implicit factors that characterize professional activities which must seriously be considered in professional education. Professional activity has been defined as one that is inherently problem solving but and its success relies in being able to identify the deviant components in messy and unpredictable situations [4], [5].

The curriculum design and implementation outlined in this paper is based on the assumption that problem based learning fosters the strategies of professional culture which seeks the deviant to explore possibilities in the quest for elegant practical solutions. Students were exposed to real-life situations as part of recognition training in future professional practice

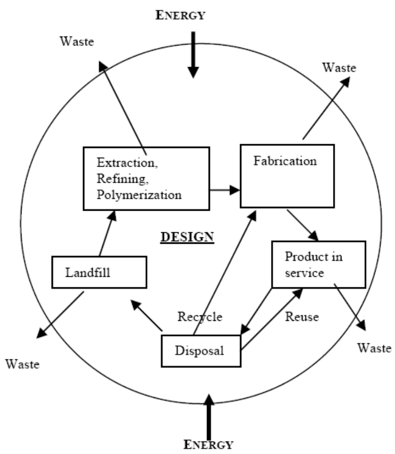
2. Subject Curriculum Design

In a PBL curriculum design it is imperative that the traditional course design learning objectives are retained and actions are formulated to meet these objectives. In engineering these objectives traditionally include:

- The understanding and mastering of knowledge and skills of the subject matter;
- The understanding the context of the subject within professional engineering discourse;
- The development of communication skills; instilling skills in teamwork;
- The development an autonomous and reflective practitioner with social awareness of the impact of engineering practice; and
- The development of skills for life-long learning [6].

The pedagogical design of the curriculum reflected the multi-disciplinary nature of the subject Materials and Manufacture. The subject represents an intersection of engineering sciences, manufacturing technology, environmental technologies, ethics, engineering design, business, and sustainability. For example, the end-point of a mechanical design is an artefact composed of solid materials. These materials need to be selected on their merits which include mechanical properties such as strength, stiffness, fatigue resistance and material toughness, durability and reliability, economic properties such as availability and cost of materials and maintenance costs, physical properties of materials, which include colour, thermal and electrical conductivities, resistance to corrosion, opacity and density, environmental properties such as embedded energies in materials, recyclability of materials and the material impact on occupational health and safety. All these material merits need to be combined with issues of manufacturability which determine whether new tooling needs to be made for a selected material. Obviously, the disciplines of solid mechanics, fluid mechanics, thermodynamics and heat transfer, physics and chemistry, corrosion technology, environmental technology as well as business and ethics constitute the core ingredients of this subject.

Courses in creative arts and their respective pedagogies in disciplines such as music and drama acted as a basis and inspiration in developing the new “PBL” curriculum. The mainstay of student education experience was to mimic professional practice and experience that reflect its messiness and instability. This was best tackled by acknowledging the two mode knowledge model where modes 1 and 2 of knowledge are representations of intra and interdisciplinary discourses. Though formal teaching dipped mostly into the mode 1 of knowledge and learning, all other student activities such as laboratory exercises, and major assignments were anchored in the mode 2 of knowledge. This mode bypasses disciplinary boundaries and is highly contextual [7]. The subject was to be a journey of cognitive struggle in which students were to understand that there is a 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.



outline of student’s the subject complexity.

The underlying unifying themes of the subject contents were engineering design and sustainability. The onus was placed on students developing the skills of "finding out". These components (mainly) were to support Bloom's cognitive domains of application, synthesis and evaluation [8]. The lecturer's role as the sage on the stage was transformed to that of a guide on the side who took on the role of a coach, collaborator and facilitator in the student learning process.

3. Organization of the Subject Delivery

The pedagogical scaffolding consisted of three major components shown in figure 2, and these were:

- Instructional delivery;
- Experimentation and observation; and
- Open ended research and discovery

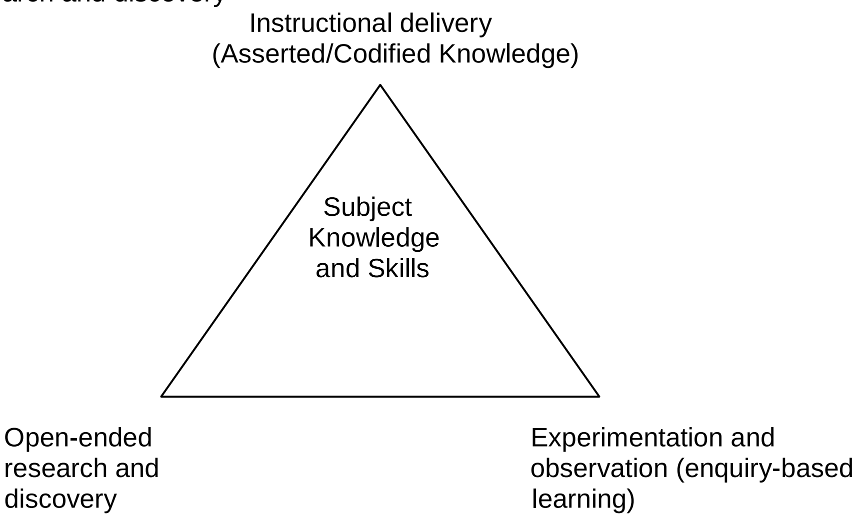


Figure2.The three subject scaffolding components

The instructional delivery consisted of 2 hour lectures each week throughout the semester. For the purpose of individual work in PBL workshops, with the allocation of 2 hours per week, students were organized into two groups of no more than 30 participants in each group. Each group was further partitioned into teams containing with each team consisting of no more than 6 members. Each team was assigned a specific open-ended research and discovery project as well as laboratory exercises that also included a specific experimental proposal, and its possible realisation. The laboratory/ tutorial sessions for each team were allocated 2 hours per fortnight per semester. Each student was also required to keep and maintain a confidential reflective journal in which the student assessed other team members, kept a diary of team meetings, interrogated subject issues and answered tutorial questions. The reflective journals were submitted at the end of the semester for evaluation and their quality played a role in determining student grade for this subject.

Inductive student learning was highly encouraged in which theories, case studies and data could be used in other (engineering) contexts. This was supported by a mix of pedagogical tools case based learning, enquiry-based learning, problem-based learning and just-in –time teaching. In the latter case team members who felt that their knowledge platform was inadequate to tackle their project would be allocated a teaching session.The distribution of the mix of pedagogies is shown in table 1.

Table1.Inductive teaching methods in various components of the subject

Inductive teaching and learning methods	**Lectures**	**Tutorials**	**Lab Classes**	**PBL Workshops**
Case-based learning	**X**	**X**		
Enquiry based learning		**X**	**X**	
Just in time teaching	**X**			**X**
Problem based learning				**X**

3.1 Instructional Delivery

This component comprises of the traditional lecture, tutorial and consultation format. It is a key process for the delivery and learning of the canon of subject (asserted) knowledge and skills. It is also a tool by which students' educational attributes can be achieved to, at least, the third level of Bloom's knowledge taxonomy level [8].

The teaching of the subject matter is presented in a grand narrative or a "big picture" form and students are expected to undertake further reading of recommended and referenced texts. The fundamental principles of the relationship between structure and properties of materials, fabrication processes, environmental and health and occupational issues are teased out with case studies of manufacturing processes and failures of manufactured products, as shown in table 2. Students are required to respond to questions concerning classical engineering failures, material substitution, environmental and social impact of product design, and on materials used in the school's undergraduate and research laboratories.

Table2. The narrative in instructional delivery

Subject principles and theory	Action and Application
Introduction to Ferrous and Non-Ferrous Alloys	Application of phases and phase diagram in selecting appropriate treatments to modify material properties and assess their weldabilities and fabricabilities.
Diffusion Mechanism in Solids	Numerical application in assessing industrial surface treatments with the intention of process optimization.
Manufacturing Technologies and Processes	Application of numerical solutions to optimize manufacturing processes for a specific product design.

Instructional knowledge forms a platform for further inquiry.

3.2. Open-ended Research and Discovery

This component constitutes a major team assignment. Each team is assigned a specific project in the first week of the semester. At its inaugural meeting, during PBL workshop, each team decides on team members' labour Division, and also chooses the team coordinator whose function is to coordinate and set agenda of the team meetings. The coordinator also generally acts as the editor of the team report with the responsibility of writing the overall report introduction, summary and conclusion. Each team member contributes individual chapter to the report and the editor has the responsibility that all chapters are discreet with their own introduction, summary and conclusion and with little overlap. There are two oral presentations. The first one is in the third week of the semester where each team identifies project issues and presents their proposal on their project of how it is going to be done and which team member is going to be doing it. The final and assessed oral presentation is held in the last week of the semester. In this presentation each student submits and discusses their findings and conclusions. Students in audience take active role in assessing their peers' presentations.

The PBL workshops are essentially times for team meetings. Each team has an allocated space and are free to invite the academic staff to participate in the team's discussions and suggest possible lines of enquiry. 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. The team coordinator can also invite the lecturer/ PBL facilitator to explain or elaborate on knowledge and skills that are missing but required to tackle a particular project. Such lecturettes were part of the inductive learning process to and constitute just in time teaching (JTT) [9]. The workshop time is also used for introducing mini-seminars on oral presentation and written report writing.

A full written team report was submitted in week 13. This was a highly structured document which sign-posts team members' individual contributions. The report is required consider a particular assignment 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. Though instructional delivery provided the conceptual base for many of the problems, students are required to seek out relevant databases, information and knowledge required.

3.3. Experimentation and Observation

In a traditional schema this component is normally referred to as a laboratory class. The traditional laboratory is aimed at developing students' observation and experimental skills, evaluation and processing of experimental data skills, and written communication skills through laboratory reports. However, in addition to the aforementioned, the objective of this component is also to develop students' analysis skills which represent the fourth stage in Bloom's knowledge taxonomy level [8]. Enquiry- based learning (EBL) is a particular feature of this component. This component comprises of two sub-components; three set experiments, experimental project proposal.

3.3.1 Set Experiments

These are set experiments which are performed by students in teams. The end product is a team report for each experiment. The enquiry based activity takes on a form of questions which must be answered in the report. These questions are loosely based on knowledge and the theoretical underpinnings of the laboratory experiments but emanate from the real world of industry, sport, medicine, engineering design and architecture. Though the lecture material provides a starting point for tackling these questions, students are required to refer to texts and other academic literature in order to undertake further inquiry.

3.3.2 Laboratory Projects

These are performed in teams. Students are required to undertake a specific problem needing laboratory investigation. Each team must submit a laboratory or experimental proposal report which also takes into account occupational health and safety issues. Students are thus exposed to grounded-type investigation whisch needs to be accompanied with an extensive literature research. Typical investigative problems are:

- Determination of activation energy in curing of cements;
- Determination of residual stresses in polymer;
- Characterization of visco-elastic properties of polymers;
- Environmental stress fracture of materials;
- Formability of aluminium alloys;
- Corrosion of steels in various environments;
- Activation energy in polymer melt viscosities;
- Permeability of water vapour in polymer films;
- Activation of precipitation hardening in metal alloys.

4. Subject Assessment

The overall pass mark is set at 50 percent. Students were required to obtain a minimum of 40 percent for each component to qualify for a pass or higher grade.

The Instructional Delivery component was assessed through a 3 hour examination that in addition to material covered in lectures and tutorial, it included general laboratory questions as a quality assurance that students participated in the writing of the laboratory reports. This component accounted for 45 percent of the subject assessment.

The Open-Ended Research and Discovery component, including student assessment of oral presentations accounted for 40 percent of the subject assessment. The evaluation of the report was divided into two equal parts; overall report quality and individual contributions. The reflective journal also provided a qualitative feedback on the subject and its delivery. The Experimentation and Observation component accounted for the remainder of the subject assessment.

5. Subject Evaluation

One way of evaluating success or failure of new pedagogical paradigms is to compare student performance and educational perceptions prior and after their introduction. Prior to 2004, the mechanical engineering curriculum had a greater allocation to engineering materials. It was composed of a second semester and second year introductory engineering subject followed by a two-semester third year engineering materials subject with a total lecture, tutorial and laboratory time of 108 hours. The first restructuring of the curriculum in 2004 meant that teaching of engineering materials was done in one and a half semesters in second year of the course. The total teaching face to face contact time in materials was reduced to 66 hours with the associated changes in the syllabus. The introduction of PBL pedagogy in 2006 was accompanied with further restructuring of the curriculum. Introductory topics in engineering materials were introduced in in the second half of first semester in the second year of the course and followed in by second semester Materials and Manufacture subject VAM 2062.The total teaching allocation to materials subjects was 18 hours in the first semester and 36 hours in the second semester. The second semester had a strong manufacturing technology flavour and new subject material was incorporated into the student–active learning sessions through semester student assignment. In reality, though the course was intense, much of the original subject content was retained.

Student satisfaction with the subject, despite its intensity, remained high as shown in table 3.

Table 3. Student evaluation of the subject

	Third Year Subject	Second Year Subjects					
	EMW 3110	EMW2761		VAM2062			
Year of Teaching	2003	2004	2005	2006	2007	2009	2010
Lecture organization	4.3	4.1	4.0	4.7	4.3	4.3	4.5
Clarity of lecture presentation and delivery	4.3	4.1	4.3	4.3	4.2	4.5	4.5
Lecturer's knowledge of the subject material	4.7	4.7	4.8	4.3	4.8	4.6	4.8
Effective use of teaching aids	4.3	4.7	4.6	4.8	4.8	4.5	4.8
Subject interest displayed and evoked	4.5	4.5	4.6	4.7	4.6	4.8	4.7
Assistance provided	4.5	4.1	4.3	4.5	4.1	4.5	4.7
Approachability	4.7	4.3	4.7	4.5	4.9	4.3	4.6
Teaching quality	4.7	4.2	4.3	4.6	4.7	4.6	4.6
The study of this subject is highly recommended	4.2	4.2	4.4	4.4	4.4	4.8	4.7

1-Very poor, 2-Poor, 3- Satisfactory, 4- Good, 5-Very good

Typical student comments reflected well on the student active learning approach.

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.

I have realised that engineering is not just an applied science but also art

Student progression rates were also relatively high in comparison with other subject as shown in Table 4

Table 4. Comparison of student performance

	Third Year Subject	Second Year Subjects					
	EMW 3110	EMW2761	EMW2761	VAM2062	VAM2062	VAM2062	VAM2062
Year of Teaching	2003	2004	2005	2006	2007	2009	2010
Percentage passed	90.5	67.2	77.3	80.6	85.3	80.8	86.7

The reduction in pass rates in 2004-5 could be attributed to new substantial enrolments of students who transferred from the vocational Technical and Further Education Colleges. These students had difficulties acclimatizing to a different academic culture.

6. Conclusion

There is little conclusive evidence that PBL education produces better engineering graduates. The introduction of PBL pedagogy was the result of necessity rather than intent to ensure a more effective coverage of the syllabus with the reduction of teaching time. It also provided an opportunity to re-think the way course material was delivered. As a result, the syllabus and its delivery were re-positioned towards more vocational and professional elements. The change of student culture has been observed with the change of the teaching paradigm. The introduction of PBL into engineering curricula provided 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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