AC 2009-2413: A REVIEW OF PROBLEM-BASED APPROACHES TO ENGINEERING EDUCATION

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A Review of Problem-Based (PBL) Pedagogy Approaches to Engineering Education

ABSTRACT

The introduction, in 2006, of problem-based pedagogy into undergraduate courses within the School of Architectural, Civil and Mechanical Engineering (ACME), and the School of Electrical Engineering (EE) constituted a significant paradigm shift in engineering education at Victoria University (VU). Educational marketing notwithstanding, the underlying reason for the introduction of PBL pedagogy was to address deficiencies in professional engineering education and reduce the relatively high attrition rates. Given the short time since its introduction, it is difficult to gauge whether the implementation of the PBL teaching methodology has been successful. Anecdotal evidence, to this stage, suggests mixed educational outcomes. This paper challenges the notions of whether a single PBL model to engineering education produces desirable educational outcomes that meet the needs of the profession. It suggests that PBL educational approaches cannot be based on definitive educational theories, and that there are many multi-variant models that define PBL pedagogy. Implementation of PBL into an engineering curriculum needs to be placed in a context and must be developed with careful consideration of the social, economic and ethnic diversity of the student population and the university academic culture. It is argued that the PBL model in engineering education ought to evolve, with a gradual and well considered introduction.
***I**ndexTerms* **–** *Problem Based Learning, constructivism, engineering curriculum*

Introduction

The re-branding of Victoria University in 2005 as the New School of Thought was a part of the institutional re-positioning in the highly competitive national and, increasingly, global higher education market. The emphasis on student-centred learning and a constructivist educational approach was to be the new eclectic image the university was presenting in the community. The university sponsored report into engineering education at VU recommended the implementation of Problem-Based Learning (PBL) pedagogy into all engineering courses at VU. The underpinning rationale for the adoption of this recommendation was that the implementation of PBL would:

- Enhance student engagement within their course of study, and, as a consequence, reduce the prevailing high attrition rates;
- Provide senior secondary students, who are considering going on to university, an attractive option as a course study; and
- Address the skill and knowledge deficit of engineering graduates.

The faculty of Health, Engineering and Science decided to implement this recommendation on a sequential basis, starting with the first year engineering undergraduate intake in 2006. The university assisted the development and the implementation of PBL into undergraduate engineering education through the provision of funds for the development of specifically designated PBL educational teaching and learning spaces equipped with state of the art audio-visual and computing facilities. Faculty discussions on PBL pedagogies paid scant attention to the epistemological issues of the engineering profession but concentrated on the epistemology of engineering education. The following discussion introduces the epistemological dimension of the profession to provide a context for the review of PBL pedagogy.

Education for Professions

The implementation of a new teaching approach and curriculum in engineering education needs to be seen in the context of education for the professions and for professional discourses.

Unlike purely academic education, the preparation for professional life requires both academic and vocational educational elements. The evolution of most major professions was derived from crafts and trades[1]. Workplace training was combined with formal, but not necessarily university, education. Many engineers in the United States qualified within large corporations such as Westinghouse, General Electric and Edison which functioned as professional engineering corporate academies [2].

Professional work in the nineteenth century became increasingly multi-disciplinary. Engineers, increasingly, became reliant on mathematics, physical sciences and management techniques in their practice. The wider context of professional knowledge required the participation of institutions of technical and higher education. However, since many of the reflective practices that characterise professional discourses were acquired through knowledge in action, the inclusion of professional education into the universities has been, somewhat, detrimental to professional knowledge. The rhetoric of the university replaced the vocational elements of professional knowledge and a kind of knowledge schism between the university and professional practice has developed. The new knowledge acquired through university research was at odds with the real world of professional practice. In a study of professions, Eraut claimed that nearly all new practical knowledge in professions such as medicine and engineering, is created in the field of practice [3].

The introduction of PBL as means of merging the worlds of the academy and professional practice was initially introduced into medical courses at the University of Maastricht in Belgium and MacMaster University in Canada and this acted as an impetus (though not a snow-slide) for its introduction into other universities. The driving philosophy for its introduction was to:

- Expose students to the open-endedness of professional judgments;
- Bridge the vocational and theoretical elements of professional knowledge;
- Improve communication and team-working skills;
- Extend the appreciation of a wider social, cultural and environmental context of professional knowledge; and
- Produce life-long learners.

The introduction of PBL pedagogy into engineering education needs to be made with great care because of the unique nature of the engineering profession. The engineering profession is not a monolithic occupational group but consists of many tribes that often exhibit little disciplinary commonality. Unlike the major professions such as law and medicine, which are underpinned by the occupational ideology of justice and health respectively, the engineering professions are yet to find their unifying occupational ideology. This is a particularly salient point which needs to be considered when constructing both an engineering curriculum and the teaching pedagogy. The shortcomings of engineering education are well known and there is ample documentation concerning the attribute deficiencies of engineering graduates in Australia. There is a well-founded perception that engineering graduates have a too narrow technical focus, poor communication skills, inability to work in teams and a poor appreciation of social, economic, political and environmental issues [4-13]. This is despite the fact that these that attributes have been associated, by Ashby, as a generic product of Newman's and Von Humboldt's notions of university education [14]. It can be argued that the failure of engineering education is part and parcel of the shortcomings of university education in general. This has been demonstrated by Guthrie[15] in a survey of Australian employers and Yorke[16] and Harvey[17] et al in a similar survey in Britain.

However, placing the blame on university education is of cold comfort if engineering education cannot meet professional needs. There is an evident and obvious need for the re-appraisal of engineering education and its fitness within the university institutional setting. The values of different pedagogical approaches are discussed below.

Curriculum for Engineering Education

Construction of a professional educational curriculum without the understanding of the professional contextual epistemology, and without of a professional ideology and philosophy presents a major problem for engineering. One commentator suggests that there is no universally accepted characterization of engineering knowledge[18]. Professional engineering courses are not based on one curriculum but are composed of many disciplinary subjects which form, hopefully, a network of epistemic elements constructed to unify professional knowledge. In reality, professional engineering courses can be often seen as a collection of subjects in search of a unifying objective.

Grunert[19] distinguishes curricula in terms of style of delivery rather than knowledge contexts. He identifies 5 principle curriculum planning models outlined in table 1. Content-led, Rational and Assessment-led models largely represent a linear view of knowledge. Though, in style, the PBL curriculum model, like the Rational and Assessment-led models, is outwardly outcome driven, nevertheless like the Fuzzy model it can also construct the non-linear world of knowledge. It can thus reflect more closely the professional reality.

Table 1. Five curriculum planning models

MODEL	BRIEF DESCRIPTION	ISSUES
Content-led	Content (knowledge) to be taught is identified and sliced-up into smaller components.	Lacks flexibility
Rational	Learner needs are identified and learning outcomes (LO) are selected accordingly.	This is a rigid and systemic model with resource implications.
Assessment-led	It is similar to Rational model and implementation process is evaluation driven.	It assumes that the learning outcomes can be precisely measured.
Fuzzy	Based on implicit view of epistemological worthiness at present time.	Almost impossible to evaluate the subject content with its published description and outline in a handbook.
Problem based learning (PBL)	Learning outcomes are selected and topics which cover these outcomes are identified. The content is then presented in terms of sequences of problems.	It is difficult to devise problems which cover epistemic professional discourses.

PBL Pedagogies

The acronym PBL, unfortunately, encompasses both project and problem-based learning pedagogies. In order to avoid confusion it is important to distinguish between these two learning approaches. Project-based learning is concerned with the application of existing knowledge to new situations which leads to the acquisition of practical skills. Problem-based learning requires the acquisition of knowledge to address a particular problem. In reality there is an overlap between both project and problem based learning.

Both PBL approaches have some commonality because they both focus on student-centred constructivist learning in which students construct their own knowledge and skills realities. The blurring of subjective and objective domain boundaries is the essence of PBL pedagogy. There are a number of ways this can be achieved. Figure 1 demonstrates that by combining Piaget's, Anderson's or Skinner's behavioural learning pathways, it is possible to establish at least 72 different PBL models . In their study of PBL education, Woods et al[20] concluded that there were many approaches to PBL and identified as many differences between them as commonalities.

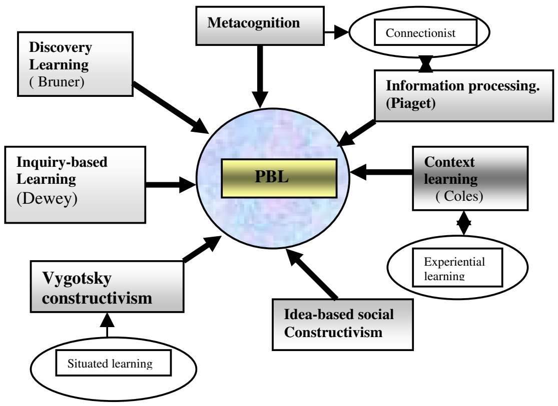

Figure 1. Paths towards PBL education

Case for PBL in Professional Engineering Education

The case is based on bridging the deficit between what professional engineers do and what professional engineers are required to do. It touches upon perceptions of professional education and perceptions of professions. One view of professions is in terms of their rhetoric, drawn from their social and knowledge dimensions[21, 22]. Others view professions in terms of their utilitarianism. Schumpeter[23] observed professional rhetoric as one of management of change.

The academic rhetoric of professional engineering education seems to be a conservative one and is reflected in resistance to change. Grose[24] points to this in cases when non-technical knowledge elements were introduced into engineering curricula. Similarly, resistance from the professoriate was observed during the introduction of Project Based Learning programs in the faculty of engineering at Aalborg University[25]. The Review into Engineering Education in Australia implies that the crisis of engineering education in Australia can be attributed to the failure of implementation of recommendations suggested earlier by the Williams Committee[5, 7].

The case for the implementation of PBL programs is largely epistemological. It would provide an opportunity to effect educational change in engineering curricula and to introduce new knowledge elements. It can be viewed as an opportunistic vehicle for the incorporation of integrative knowledge through constructivist pedagogies.

PBL programs can also be viewed as the means to introduce practicality into engineering education to address external needs rather than academic imperatives. In particular, these are:

- Meeting market needs. Development of higher education curricula geared towards labour markets has been a feature of universities. In such climate the orientation towards what Lyotard refers to as performative knowledge is an evolutionary process in the universities' focus. It is a paradigm shift from "is it true?' to "is it useful"? [26] It also reflects the educational paradigm shift from what is taught to what is learned.
- Necessity for flexible engineering graduates [27]. The rapid changes in social infrastructure and needs require graduates who are learners rather than knowers. These can create, apply, modify and adapt concepts to given situations as opposed to knowers who are trained to systematically repeat taught skills. PBL engineering education is seen in terms of knowledge processing which includes learning, encoding and retrieving knowledge when the occasion arises[8].
- Reducing Attrition Rates. Overlaying the lack of attractiveness of engineering as a course of study, there are relatively high attrition rates in engineering schools and faculties. This has an impact on engineering graduate numbers. There is a general view that the PBL curriculum makes engineering study more attractive to students. Woods[29] shows that the introduction of PBL in engineering had a significant effect on drop-out rates at Aalborg University.
- Enhancing attractiveness of engineering as a course of study. The proportion of university students in Australia undertaking engineering courses has been fairly constant over the years, varying between 5.8 to 7.5 percent. The gender imbalance is one of concern, to both engineering education and to the engineering profession, as only around 2 percent of female university students choose engineering as a course of study. Tonso[30,31], in studies of engineering students, shows that unlike their male counterparts who are task driven towards particular outcomes, the female engineering students are process-driven and are socially involved. Benjamin and Keenan[32] show that PBL pedagogy is open-ended, multi-tasking and process driven to provide students with a sense of empowerment and thus more attractive to girls.

Case against PBL in Professional Engineering Education

Despite a general agreement that PBL constitutes a valuable tool within the pedagogical toolbox in professional engineering education, very few engineering education providers have committed themselves to institute PBL as the main ideology underpinning the whole engineering curriculum. Generally the decision to implement PBL pedagogy was left to subject coordinators if it suited them to meet their educational objectives. This reluctance in incorporating PBL as the mainstay of the engineering curriculum was because of the high investment, in terms of the allocated spaces and human resources needed, and there is no decisive evidence that PBL teaching and learning produces better educational outcomes.

Comparisons of PBL at Aalborg University (AU) with the traditional engineering course at the Danish Technical University (DTU) showed[33] that retention rates were higher at AU and that AU produced engineering graduates with better initial communication and team-working skills. DTU engineering graduates, on the other hand, had better fundamental engineering skills and were more capable of independent work. Both institutions produced different educational outcomes. Surveys[25] of industry showed that AU engineering graduates were more likely to meet the needs of industry on graduating. However differences between AU and DTU graduates, shown in the survey, in terms of employability were small. The lower attrition rates at AU could be attributed to factors other than PBL pedagogy, with a higher commitment to teaching and learning being one of these. Woods[29]compared the educational attributes of graduates from traditional and PBL courses and found little difference. Newman and Schmidt[34] , both exponents of PBL education, admit that the effectiveness of PBL has not really been established since there are no available tools for measurement. Other studies in which differences in attitude were compared, between students undertaking PBL and those enrolled in the traditionally delivered introductory course, found no significant differences in most areas[35]. PBL proved to be significantly positive in the area of generating interest in the technical aspects of engineering. However in traditional introductory courses the technical aspects represent the surface spectrum of learning, a mode preferred by weaker and first year engineering students[36].

PBL pedagogy may be actually deleterious to professional education. Aldred et al[37] observed that PBL pedagogies in professional curricula are driven by instrumental perspectives leading to a reduced capacity for critical thought among graduates. Boud and Feletti[38] warn that many

PBL courses reduce professional practice to a perception of problematic routines tackled using existing schema. Students focus on what is needed to solve a problem leading them to invest only equation learning with practical value. Fenwick[39] condenses professional education onto developing an understanding and the practice of framing ill-structured problems and solving them in unpredictable "messy" contexts. Framing problems becomes an essential activity where the normal is distinguished from the deviant. Professional practice seeks the deviant, to focus the gaze on what the possibilities are. The gaze embedded in the rational mind only identifies "rational" disorder.

A simplified discourse analysis of engineering education

An American survey in the world of professional engineering practice found that engineering graduates needed to be equipped for challenges they were likely to encounter in the real world[40]. In particular, the respondents of the survey, expressed desire that engineering curricula should:

- Not neglect the classic " back of the envelope" method in favour of computation. There were concerns that engineering curricula overemphasized scientism at the expense of the technical knowledge of the "fitness of things";
- Deliver courses in three dimensions in which technical, scientific, creative and the non-technical are connected;
- Induce student awareness of the multi-disciplinary nature of engineering practice;
- Develop problem framing and solving skills; and
- Teach the business of engineering.

Thus the traditional academic perception of object-based engineering practice needs to be discarded and replaced. The problem based terminology reflects the narrow and "old" view of professions and their activities. The old notions[41,26] of problem based practice, which provided professions with an epistemic authority in deciding what is true and with a quest for a grand narrative of emancipation in which situational ambiguities, messy dynamics were reduced to a pipeline of knowable problems, needs to be discarded. A constructivist approach is a more contemporary and more realistic representation of engineering professional life.

Engineering curricula have always been, by and large, problem focused rather than problem based though these distinctions often evaporate in project and design based subjects. What is important is the introduction of pedagogical constructivism in which a kind of conversation, extraneous to any single discipline, takes place[42]. Constructivist approaches allow student exposure to notions that nothing is predictable and that engineering outcomes cross the boundaries of technical, scientific, social science, economic, and humanities knowledge disciplines. Effective professional engineering education must thus positions constructivism as a key ideological focus of its pedagogy that is not confined to PBL.

The traditional undergraduate four year engineering course, seen through the prism of Perry's[43] nine stage intellectual developments (condensed by this author into four stages corresponding to the year levels of the course- see table 2) is an adequate vehicle for a constructivist approach. Constructivist pedagogy is introduced at the second year level of the course. In fourth year, the pedagogy is a fully constructivist in which the role of the academic is restricted to that of a facilitator. Active, collaborative and co-operative learning fulfil constructivist goals[44]. The traditional course framework, outlined in table 2, has a number of inherent advantages which enhance constructivist skills. These are:

- <u>Formal acquisition of new non-technical knowledge.</u> In a traditional PBL education it is assumed that such knowledge can be acquired in situ, in the context of the problem. In fact, knowledge from humanities and social sciences domains is very complex. Their frameworks are based on competing critical theories with historical, cultural, ethical and political dimensions. Students unaware of this complexity, at best, address the problem with superficial assumptions, and the emanating solutions are only technical in nature. Boud and Feletti[38] identified the teaching of concepts as an essential ingredient of a journey of inquiry;
- <u>Development of meta-cognitive skills.</u> Effective constructivism is based on a visualization of the "big picture" of the task ahead. It demands knowledge and the understanding not only of the fitness of things but of how the different task representations are connected together[45] ; and
- <u>Contextual knowledge.</u> It relates knowledge to reality. It involves judgemental matters such as risks, ethics, rewards, politics and environment. Hills and Tedford[46] define it as knowledge which contextualizes explicit and tacit knowledge []. Familiarization with contexts requires knowledge of contexts and therefore professional case practice. Contextual learning theory is one of reflective case studies and requires a traditional learning framework, because it covers a broad range of propositional knowledge.

Coles[47]compared PBL to contextual theory learning (case studies) and found constructivist development was superior in the latter.

Table 2. Defining the course by years and stages

Description	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
View of knowledge	All knowledge is known. Right and wrong answers exist for everything.	Most knowledge is known. All can be known if a right path can be found to provide the right answer.	Some knowledge is certain. Most situations have inadequate knowledge base	All knowledge is contextual and disconnected from absolute truth. Right and wrong answers exist only in specific contexts and are judged by values of adequacy.
Role of the student	Receive the knowledge and demonstrate having learned the right answers.	Learn how to learn to do the processes.	Learn to think for one self. Independence of thought is valued and qualitative criteria is readily acceptable.	Think in context and apply rules of adequacy. Evaluation of problem and action on the basis of critical thinking.
Role of academic in professional education.	Impart knowledge.	Show the method for seeking and finding knowledge.	Demonstrate means for obtaining supportive evidence. Encourage to challenge the existing paradigms and procedures.	Guide students within framework of adequacy rules.
Primary intellectual tasks	Learning basic information and concepts	Compare and contrast issues and solutions by which multiple perspective of issues and outcomes are illustrated	Develop critical and analytical skills. Issues, problems and outcomes are placed in multi-disciplinary context	Ability to differentiate contexts and modify and expand concepts to satisfy these contexts.

Conclusion

There are numerous PBL teaching models that can be derived from figure 1. They are all equally valid and the nature of each methodology is dependent on factors such as:

- Characteristics, shape and orientation of the engineering curriculum;
- Attitudes, skills of the academic body;
- Underpinning academic culture of teaching and learning; and
- The mix and socio-economic background of the student body.

What defines the PBL teaching approach is the focus on a constructivist pedagogy. It would be thus reasonable to expect that the learning outcomes from PBL centred engineering education would differ from the traditional "chalk and talk" passive engineering education practised at many universities. However, the production of different learning outcomes does not necessarily meet the multi-variant needs of the engineering profession. Though the general consensus is that the learning outcomes emanating from PBL centred education produce engineering graduates with not only a more hands-on approach but also better communication and team-working skills, there is ample evidence that many other skills, such as the ability to work independently and think critically are sacrificed.

There is no doubt that the constructivist approach is the right educational tool in engineering education for professional practice in the post industrial world. It is likely to re-define professional engineering discourse and the focus on the process leading to the raising of questions rather than convergent problem solving is more likely to trigger critical attitudes. However educational constructivism is certainly not limited to PBL teaching. Traditional course structures can also incorporate constructivism as their ideological masthead for all subjects. It requires continual tinkering with curricula and subject syllabi and therefore allows for greater flexibility than would be allowed by locking into a highly prescriptive PBL model.

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