ENGINEERING EDUCATION FOR THE ENGINEERING PROFESSION

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Abstract

The on-going debate concerning traditional pedagogy versus problem-based learning (PBL) in engineering education has, by and large, been settled, within my faculty, in favour of the latter. The underpinning decisions were based on the new university branding and beliefs that the implementation of PBL pedagogy was a key element in addressing the issues of engineering education sustainability as well as assisting in bridging projected short falls of professional engineers in Australia. It was also hoped that the introduction of a new pedagogy would attract higher academic achievers to engineering courses at Victoria University (VU), reduce the current high attrition rates, produce better educational outcomes, expand educational demand for engineering courses, and address the gender imbalance in engineering professions. This paper suggests that the pedagogical debate of PBL versus traditional educational delivery detracts from the larger picture of engineering education, the engineering profession, and professional engineering practice. It is argued that the current engineering curricula at Australian universities are obsolescent because these were derived from the late eighteenth century period of the enlightenment and reinforced by the empiricism and positivism of the Vienna School, which embraced the narrative of scientism. The paper will argue that the shedding of scientism as the basis for the engineering curriculum is an essential step in designing a curriculum that is oriented to contemporary and future professional engineering practice. A curriculum based on social practice will not only meet technical professional needs but spark the curiosity and imagination of girls and boys at senior secondary schools to choose engineering as their course of study.

Key words: *Innovative curricula, education research, teaching and learning, professional issues.*

1. Introduction

The re-branding of Victoria University (VU) 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. An emphasis on student-centred learning formed a framework for a pedagogical paradigm change, as a consequence a commissioned report recommended the implementation of Problem-Based Learning (PBL) pedagogy into all engineering courses at VU. If adopted it was to:

- Engage students in their course and as a consequence reduce the prevailing high attrition rates;
- Provide an attractive option for senior secondary students of engineering as a course of study; and
- Address skill and knowledge deficit of engineering graduates.

The faculty decided to implement this recommendation on a sequential basis, starting with the first year of undergraduate courses in 2006. The university assisted this paradigm shift in engineering education by providing funds for the development of specifically designated PBL educational spaces equipped with, state of the art, audio-visual and computing facilities. The paper discusses ramifications of the new pedagogies.

2. EDUCATION FOR PROFESSIONS

The evolution of most professions in Australia, like in Britain, 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]. As professional work, in the nineteenth century, became increasingly multi-disciplinary, the knowledge needed to inform professional work could no longer be transmitted within the employing organisations or through an apprenticeship. Engineers, increasingly, became reliant on mathematics, physical sciences and management techniques in their practice. The wider context of professional knowledge demanded institutional complicity of formal education.

In many ways, the embodiment of professional education into the university has been, somewhat, detrimental to professional knowledge. The rhetoric of university replaced the vocational elements of professional knowledge and a kind of knowledge schism between university and professional practice has developed. 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]. Introduction of PBL into medical courses first at the University of Maastricht in Belgium and MacMaster University in Canada provided an impetus (though not a snow-slide) for other universities as means 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.

There is a widespread agreement with the regard to deficiencies of engineering graduates in Australia. There is a well-documented evidence of various observers and inquiries that state [4-13] that engineering graduates have too narrow technical focus, poor communication skills, inability to work in teams and possessing poor appreciation of social, economic, political and environmental issues {4]- [13]. This is surprising given that such attributes have generally been associated as a generic product of Newman's and Von Humboldt's notions of university education [14]. Guthrie[15], in a survey of Australian employers, identified the following concerns with the attributes of university graduates [15]:

- Graduates possessed poor to very poor skills in written and oral communication;
- Graduates had great difficulty in relating to workers from different disciplines and work fields;
- Graduates showed lack of empathy towards employees at lower levels of the work hierarchy;
- Graduates possessed poor skills in logical and clear thinking; and
- Graduates displayed poor leadership qualities in areas of managing facilities and employees.

Concerns about such lack of work-related attributes among university graduates were not restricted to Australia. Yorke , Harvey et al, show that in Britain employers wanted, but were unable to recruit, graduates who were [16], [17]:

(a) Competent in written and oral communication skills;
(b) Able to work effectively in teams;
(c) Able to take initiative in the workplace and organize their work and time effectively; and
(d) Were highly motivated enthusiastic and interested in their work and the workplace.

3. Curriculum for Engineering Education

Professional engineering curricula are often composed of many disciplinary subjects in where the subject syllabi are constructed to unify professional knowledge. Grunert distinguishes curricula in terms of style of delivery rather than knowledge contexts [18]. He identified 5 principle curriculum planning models outlined in table 1. In style the PBL curriculum model, like the Rational and Assessment-led models, is learning outcome driven.

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 on 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.

3.1 PBL Pedagogies

It is unfortunate that the acronym PBL 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. The pedagogical framework for both PBL approaches is common. The framework focuses on student-centred constructivist learning in which students construct own realities from the knowledge and skills they have acquired during the construction of these realities. Constructivist knowledge – a kind of situation knowledge- which blurs boundaries of subjective and objective domains forms the kernel of PBL pedagogy. This can be achieved through various paths or combination of paths, shown in figure 1, which combined with Piaget's, Anderson's or Skinner's behavioural learning pathways suggest a multitude of PBL pedagogies. In their study of PBL education, Woods et al concluded that there were many approaches to PBL and identified as many differences between them as commonalities [19].

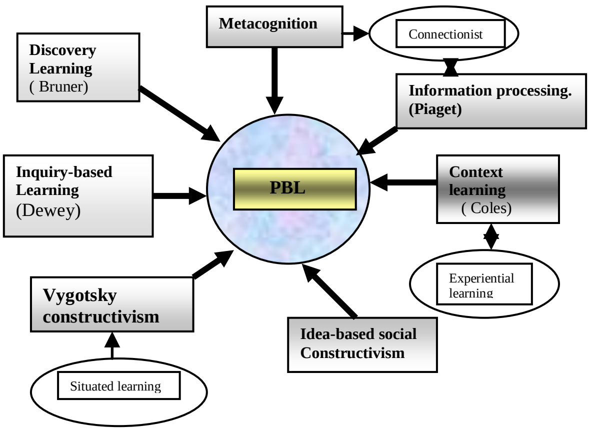

Figure1. Paths towards PBL education

3.2 Case for PBL in Professional Engineering Education

Theories of professions, professional discourses and education provide a narrative for examination of educating for the engineering profession. Many social thinkers and scholars of professions see professions in terms of their rhetoric drawn from their social and knowledge dimensions [20], [21]. Schumpeter observed professional rhetoric as one of management of change [22]. However, the academic rhetoric of professional engineering education seems to be a conservative one, manifesting in resistance to change. Grose points to resistance of professoriate to inclusion of non-technical elements into engineering curricula [23]. Moesby reflects on resistance from the professoriate to the introduction of Project Based Learning programs in the faculty of engineering at Aalborg University [24] . The Review into Engineering Education in Australia implied that the crisis of engineering education in Australia can be attributed to the failure of implementation of recommendations suggested by the Williams Committee [5]. Thus the implementation of PBL programs could thus provide a mechanism to effect educational change in engineering curricula. It can be viewed as an opportunistic vehicle for the incorporation of integrative knowledge through constructivist pedagogies. PBL programs can also be viewed in terms of evolutionary educational developments necessary because of a number of factors. These are:

- <u>Meeting market needs.</u> Development of higher education curricula geared towards labour markets has been a feature of universities. In such climate the orientation towards what Lyotard[26]calls performative knowledge is an evolutionary process in universities focus. It is a paradigm shift from "is it true?' to "is it useful"? It also reflects the educational paradigm shift from what is taught to what is learned.
  - <u>Necessity for flexible engineering graduates .</u> There is a need for fopr producing graduates who are learners rather than knowers. Learners can create, apply, modify and adapt concepts to given situations as opposed to knowers who are trained to systematically repeat taught skills [26]. Schmidt defined PBL in terms of knowledge processing that includes learning, encoding and retrieving knowledge when the occasion arises [8].

- Addressing Attrition Rates. There has been concern in addressing relatively high attrition rates in engineering at some universities. Woods showed that the introduction of PBL in engineering had a significant effect on drop-out rates at Aalborg University [28].
- 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 chooses engineering as a course of study. Tonso , 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 [29], [30]. Benjamin and Keenan showed that PBL pedagogy is open-ended, multi-tasking and process driven to provide students with a sense of empowerment and more attractive to girls [31].

3.3. Case against PBL in Professional Engineering Education

The majority of professional engineering education providers have shown little or no commitment to PBL pedagogy. This is because the investment into PBL education in terms of allocated spaces and human resources is considerable 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 that retention rates were higher at AU and that AU produced engineering graduates with better initial communication and team-working skills [32], [33]. 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 of industry showed that AU engineering graduates were more likely to meet the needs of industry reflecting better educational outcomes [24]. 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 higher commitment to teaching and learning being one of these. Woods compared educational attributes of graduates from traditional and PBL courses and found little difference [28]. Newman and Schmidt admit that the effectiveness of PBL has not really been established since there are no available tools for measurement [33]. Other studies in which differences in attitude were compared, between students undertaking PBL and those enrolled in the traditionally delivered introductory courses course, found no significant differences in most areas [34].

Others suggest that the implementation of PBL pedagogy may be actually deleterious to professional education. Aldred et al observed that PBL pedagogies in professional curricula are driven by instrumental perspectives leading to reduced capacity for critical thoughts among graduates [35]. Boud and Feletti warn that many PBL courses reduce professional practice to a perception of problematic routines tackled using existing schema [36]. Students focus on what is needed to solve a problem leading to equation learning with practical value. Fenwick condenses professional education onto the understanding the practice of framing ill-structured problems and solving them in unpredictable “messy” contexts [37]. Framing problems becomes an essential activity where normal is distinguished from the deviant. Professional practice seeks the deviant, to place the gaze on what are the possibilities. Gaze is embedded in rational mind only identifies “rational” disorder.

4. A Simplified Discourse Analysis of Engineering Education

A survey conducted in the United States among professional engineers and their supervisors found that there was need in educating graduates to equip them for challenges they were likely to encounter in the real world [38]. In particular respondents expressed desire that engineering curricula should:

- Not neglect 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 “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.

The nomenclature of problem based terminology is actually a narrow and “old” view of professions and their activities. The old notions of problem based practice which provided professions with an epistemic authority in deciding what is true and with a quest of grand narrative of emancipation in which situational ambiguities, messy dynamics were reduced to a pipeline of knowable problems needs to be discarded [39], [25]. 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 constructivism in which a kind of conversation, extraneous to any single discipline, taking place [40]. Constructivist approaches allow student exposure to notions that nothing is predictable and engineering outcomes cross boundaries of technical, scientific, social science, economic, and humanities knowledge disciplines. Effective professional engineering education must thus places constructivism as the key ideological focus of its pedagogy that is not confined to PBL.

The traditional undergraduate four year engineering, based on the nine stage intellectual developments, is an adequate vehicle for a constructivist approach [41]. This is outline in table 2. The constructivist pedagogy is partially introduced at second year level of the course, and by the fourth year, the pedagogical approach is 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 [42]. 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 of 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 identified teaching of concepts as an essential ingredient of a journey of inquiry [36];
- <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 fitness of things but how the different task representations are connected together [43] ; 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 define it as knowledge which contextualizes explicit and tacit knowledge [44]. Familiarization of 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 ground of propositional knowledge. Coles compared PBL to contextual theory learning (case studies) and found constructivist development was superior in the latter [45].

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 in 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 where 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.

5. 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:

- Characteristic, 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 PBL teaching approach is the focus on 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 practiced 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 to produce engineering graduates not only with more hands-on approach but better communication and team-working skills, there is ample evidence many other skills such as ability to work independently, think critically are sacrificed.

There is no doubt that 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 the prescriptive PBL methodology.

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