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Integrating Fundamental Sciences into Engineering Curriculum

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BACKGROUND

Victoria University provides opportunities to a small pool of students who have not performed well in the final year of secondary education or have completed technical and trade training, and who wish to pursue studies in engineering. A large proportion of students enrolling in engineering at Victoria University (VU) have less than an adequate formal preparation in fundamental sciences and mathematics to enable them to tackle the complexities of the existing engineering curriculum. Though foundation studies summer schools assists in bridging the knowledge gap in both mathematics and fundamental sciences, there are poor progression rates in these subjects. This is a contributory factor for the relatively high attrition rates in engineering.

PURPOSE

The objective of this exercise was to transform a fundamental science subject such as introductory chemistry into an engineering context with the intention of enhancing the engineering curriculum by expanding students' scientific literacy.

DESIGN/METHOD

Chemical science, as part of engineering materials, had a distinct syllabus design and resembled an engineering science subject with a pronounced emphasis being placed on mass and energy balances in which chemical principles were introduced as key vehicles for solving technical problems in areas of general engineering, environmental engineering, fuel technology and, most important, materials engineering. The reorganization of the engineering materials subject was necessary because of the engineering curriculum changes. A loss in 17 percent in subject contact hours required a different and more imaginative pedagogical approach without compromising the subject syllabus. A more constructivist pedagogical strategy was introduced which added problem-based learning (PBL) to the existing problem focused pedagogy. The new pedagogy added studio dynamics to the passive instruction based mode of teaching and learning. Evaluations of both teaching of fundamental science in both, the traditional and problem based approaches were compared by noting student progression rates, and student subject satisfaction.

RESULTS

The integration of chemical science into engineering context worked well. It prepared students to tackle subjects in latter year where the knowledge of chemical principles were highly desirable. It also showed that previous exposure to chemistry in senior secondary levels was not a strong predictor in students' academic performance in this subject. Despite the crowded syllabus and great demands on student time, the progression rates were above most of the other subjects and student subject satisfaction was high.

CONCLUSIONS

The introduction of fundamental science subjects into engineering context has been successful with higher progression rates than other fundamental science subjects and relatively high student satisfaction. The delivery of this unit with constructivist pedagogy of problem-based learning mode accompanied by pedagogical tools such as enquiry-based learning and threshold concept learning meant that large amount of material could be covered and that previous exposure to chemistry was not necessarily an indicator to academic performance in this unit.

KEYWORDS

Problem Based Learning, constructivism, engineering curriculum.

Introduction

Current engineering curricula resemble subjects in search of a course. The lack of cohesiveness is well documented by the many inquiries held into engineering education and profession in Australia as well as in other developed nations such as the United States, Britain and Canada (Rojter, 2011). The objective of the subject syllabus and pedagogical design was essentially to integrate fundamental science into engineering context, and at the same time to develop engineering consciousness in the context of other knowledge.

This discussion focuses on an introductory materials subject that is a part of the undergraduate engineering curriculum. The one semester subject consists of two components, which are:

- Process engineering. This component focuses on the acquisition of basic chemical principles and their applications to real-life engineering problems; and
- The understanding of the principles of fundamental material science in terms of micro-structure-property relationships.

The inclusion of chemical science into the engineering curriculum in 1994 occurred as a result of the recommendations put forward by the Institution of Engineers Australia (IE Aust), in anticipating recommendations issued in 1996 by the Australian Science and Technology Council (ASTEC) and the Report into Engineering Profession (Johnson,1996).

Engineering Materials, in which chemical science was embedded, was a two semester and a part of the second undergraduate curricula for Building, Civil, Mechanical and Architectural Engineering courses. The relative higher progression rates in this subject ensured that the subject became a victim of its own success. To address the issues of low progression and high attrition rates in the first year of the course this subject was transferred in 2003 into first year and replaced by Mechanics of Solids. The return of the subject into the second year of the course in 2006 coincided with engineering courses at VU embracing Problem-Based Learning (PBL) pedagogy and Engineering Materials was nominated as a one semester subject to be delivered in PBL format. The chemical science part of the subject consisted of three contact hours per week divided into 2 hours of lectures supplemented by 1 hour tutorial, over one semester was replaced with 5 contact hours per week over half a semester. It consisted of 2 hours of lectures per week with the remaining time allocated to PBL seminars/workshops and tutorials. This represented an overall reduction of 16.7 percent of class time allocation and the reduction of 50 percent in lecture time. Such reduction of contact time meant that the choices were either to reduce subject content or retain the contact at the expense of standards. PBL pedagogy provided the creative means in which the subject syllabus and standard did not need to be diminished.

This paper will first focus on the way the chemical science curriculum was developed and organized for a traditional mode of delivery and then and then its evolution into an integrated PBL subject in a challenging educational environment. It also focuses on whether the implementation of constructivist pedagogy can not only maintain subject content and standards despite the reduction of allocated time to the subject but more importantly, address the lack of students' knowledge platform in basic sciences.

Initial pedagogical approach to chemical sciences

Background

In a traditional course design learning objectives are identified and actions are formulated to meet these objectives. In engineering these traditional objectives include:

- The understanding and mastering of knowledge and skills of the subject matter;
- The understanding of the context of the subject within professional engineering discourse;
- The development of communication skills and instilling skills in teamwork;

- The development of an autonomous and reflective practitioner with social awareness of the impact of engineering practice; and
- The development of skills for life-long learning suggested by Derry (1996).

Students' academic abilities and knowledge background were taken into account when designing the subject syllabus and pedagogy to ensure that educational outcomes were of second year university standard. The minimum admission to engineering at VU is at least 10 points below the minimum entry requirements to engineering at other universities in Melbourne. Chemistry is not a requirement for entry into engineering courses which are not chemically oriented and only a small proportion of engineering students had an adequate preparation in this discipline prior enrolling in engineering at VU. Less than a third and a further 12 to 15 percent of students completed year completed years 12 and 11 chemistry respectively. Some 10 percent of students, many of them mature entrants, undertook voluntary bridging summer chemistry classes. Such lack of exposure to chemistry presented a major pedagogical challenge.

This lack of adequate chemical literacy necessitated a subject design that would capture students' interest in chemical science as a tool for solving real-world engineering problems.

The Syllabus

Engineering technology provided the backdrop for the syllabus development. The subject was introduced as an engineering science rather than as a fundamental science. It assumed minimal background in general science, outlined in table1.

Table I: Syllabus Construct

Subject principles and theory	Action and Application
Structure of atoms and atomic bonding.	Relationship between the mechanical and physical properties of solids and the nature of atomic and molecular bonding.
Stoichiometric balances of chemical reactions.	Calculations around process units involving chemical reactions such as combustion and smelting processes and introduction to production of processes such as sulphuric acid, smelting of ores, setting of cements and calculations of reactions in the environment.
Conservation of mass and energy	Calculation of mass and energy balances around process units involving recycle and by-pass streams.
Chemical equilibrium	Extent of reactions around process units. Acid-base reactions. Application to processes involving chemical equilibrium.
Rate of reactions and reaction mechanism	Examples from processes. Calculation of process units involved in the manufacture of polymers and pharmaceuticals. Illustration of reactions in atmosphere.
Thermochemistry	Heat balances around process units. Calculation of process temperatures for material selection in chemical reactors. Effect of temperature on the reversibility of reactions.
Electrochemistry	Application in the study of production of electricity with emphasis on batch and fuel batteries. Application to corrosion and corrosion protection of metals. A study in the production of aluminium.
Case studies of pollution.	Calculations involving current issues in fuel technology, manufacturing industry, agriculture and urban transport
Production of materials	Application of chemical and engineering principles to the production of steel, cement and polymers.

The syllabus narrative was designed on a platform that led to a kind of interrogation of epistemological questions that arise within an engineering canon. The subject narrative consisted of a sequence of statements that defined the subject. They were: Fundamental Science, Mass and Energy balances, Extent of Reactions, Speed, and Applications. Themes of fuel technology, sustainability, environmental land and atmospheric pollution were emphasized in this subject to meet the general objectives of the engineering curricula.

Mode of Delivery

Bloom's educational taxonomy is the core of any curriculum and syllabus design (Bloom1956). To support this, the pedagogical approach was to place the onus on students in developing the skills of "finding out". Lecturer's role was transformed to that of a guide on the side who took on the role of a mentor, coach, collaborator and facilitator in the student learning process.

The reduction in lecture contact hours necessitated a more thematic delivery without compromising the knowledge canon and the educational standard in chemical and material science discipline. Subject principles were introduced early in the lecture course and were followed by case studies involving the participation of students. Often the basic principles in the topics were augmented by student questions, and new material was introduced on need to know basis during tutorial and seminar sessions, an educational approach proposed elsewhere (Prawat, 1996).

Much of the student learning was centred on problem solving in tutorials and consultations held outside the official timetabled class times. The tutorial problems were carefully designed and based on case studies of energy, environmental and product design issues. Active learning became the centre-piece of the pedagogy. Lectures were delivered in narrative style which ensured that students were exposed to learning modes 1 and 2 of intra and interdisciplinary discourses respectively (Gibbons et al, 1994). Mode 2 of learning was a key approach to expose students to the multi-variant nature of engineering problem solving and "engineering" solutions. Reflective thought on the multi-faceted nature of engineering solutions became an essential ingredient of the pedagogy and encompassed economics, environmental and health and safety issues. This approach was based by ideas on the need multi-disciplinary approach to engineering education postulated proposed by Coates (1997).

The two hour per week PBL seminars/workshops were dedicated to a mix of things. Some of the time was dedicated to the human aspects of engineering discourses as well as oral and written communication. However, the bulk of the time was set aside to student team meetings on an assigned team assignment. The team meetings provided an opportunity for team consultations with the subject supervisor. During such consultations questions, concerning the assigned problems, were raised and students' misconceptions of knowledge were addressed. Laboratory reports also required students to use data obtained in t experiments and apply them to real-life problems of engineering design (see Table2).

Table2: Inductive teaching methods in various components of the subject

Inductive teaching and learning methods	Lectures	Tutorials	Laboratory Classes	PBL Sessions
Case-based learning	X	X		
Inquiry based learning		X	X	
Just in time teaching		X		X
Problem based learning				X

Validation

Engineering Materials was delivered in two semesters at second year level in years 1998-2001 in a mix of traditional instructional and enquiry based modes. Between 2002 and 2005 the subject was transferred to first year. In 2006 the subject was once again moved to second year level but as a single semester unit in line with the new emerging educational paradigm, the subject delivery and assessment was based on largely PBL mode pedagogy. Chemical science composed 50 percent of the subject syllabus.

Student subject satisfaction surveys combined with progression rates provided a simple (though not extensive) analysis of the subject design and delivery.

A simple Hildebrand's questionnaire was used to assess students' satisfaction with the subject on a Likert scale of 1 to 5, with 1 representing highly dis-satisfied and 5 being highly satisfied response (Hiderbrand, 1973). The sample size varied from 85 to 159 students and the average results are shown in Table 3. A parallel Student Educational Satisfaction (SES) survey, conducted by the University during the period 2005-2010, rated this subject as 4.0-4.2 on a 5 point Likert scale. Generally the student response, shown in Table3, was fairly positive. In years 2003 and 2004 student satisfaction dipped slightly when the subject was transferred to first year. The larger number of students competing for attention may have been responsible. In 2006, this subject was the first to be delivered in PBL mode, though the subsequent introduction of PBL subjects in first year resulted in students' more positive responses.

Table3: Subject Assessment

Statement	Year of Student Assessment							
	98	**00**	**01**	**03**	**04**	**06**	**08**	**10**
The lecturer has a good command of the subject	4.3	4.6	4.5	4.7	4.4	4.4	4.4	4.5
The subject objectives are clear.	3.9	4.1	3.8	4.4	4.0	3.5	4.2	4.3
Lecturer interacts well with the class	3.8	4.3	4.3	4.1	4.1	3.7	4.3	4.3
Lecturer is accessible for individual consultations	3.9	4.1	4.0	3.8	3.9	3.9	4.0	4.6
Lecturer arouses curiosity in the subject	3.8	4.1	4.0	3.6	4.0	4.0	4.4	4.6
The subject widens the scope of engineering knowledge	3.9	4.3	4.1	3.9	4.5	4.5	4.5	4.6
The subject is satisfying and would recommend to others.	4.2	4.0	4.3	4.0	4.2	3.8	4.0	4.1

The relationship between previous student exposure to chemical sciences and student performances in this subject are shown in Table 4. It shows that students with little prior exposure to chemistry did not perform as well as their peers when the subject was introduced at first year level. However, as students became exposed to PBL pedagogy earlier in the course, prior exposure to chemistry had only a small impact on student performance with pass rates exceeding those of mathematics and other engineering science subjects offered at second year level. The relatively good pass rates for the student group who undertook bridging courses are distorted its small sample size and the high proportion of mature students in this group.

Unlike other fundamental science subjects such as physics and mathematics embedded in the engineering course, this subject was designed without the reliance on senior secondary school pre-requisites. The teaching objective was one based on discovery learning was to establish amongst students new directions of information processing (Bruner 1961). This required student maturity beyond the first year stage of the course.

A major proportion of the PBL subject assessment of 45-50% was set aside to a written examination, a significant assessment of students' knowledge and application of chemical principles to engineering problems was based on their contribution to the team project and laboratory. Students had to clearly demonstrate satisfactory knowledge of chemical principles, both in their section of the team report, and in their oral presentation. Students' individual contributions to team work were further assessed by the team members in their confidential, reflective journals and in student oral presentations. The written test provided further information on whether the student had attained the desired educational outcomes.

Certainly a one semester devoted to chemical sciences and using the traditional instructional pedagogy and modes of assessment such as with written tests and examination produced better pass rates than the PBL scaffolding used in a half of a half a semester, though by 2010 a homogenisation of results is observed. Interestingly enough students who had no previous academic exposure to chemistry performed better than those who undertook the subject in year 11.

Table4: Student performance as a function of prior exposure to chemistry

Preparation level and grade achieved	Percentage of Students							
	Year of Assessment							
	2nd year-2 semester subject			1st year-2 semester subject		2nd year-1 semester subject*		
	98	00	01	03	04	06	08	10
YEAR 12								
HD	12.0	12.8	13.2	8.8	11.5	7.5	6.3	7.9
D	14.5	13.1	15.2	8.1	10.6	12.1	12.0	8.6.
C	21.1	19.6	18.9	25.2	34.6	22.1	23.3	16.1
P	24.2	26.1	26.1	31.2	25.0	28.6	32.7	39.4
Pass Rates (%)	71.8	71.6	73.4	73.3	71.7	70.3	74.3	72.0
YEAR 11								
HD	10.2	10.1	13.1	7.2	8.8	3.1	6.0	3.5
D	12.2	12.8	12.8	7.2	7.2	0.0	0.0	3.5
C	19.4	19.9	21.6	8.6	11.2	7.2	12.0	12.1
P	26.6	27.1	27.6	22.8	26.3	36.6	34.1	46.7
Pass Rates (%)	68.4	69.9	75.1	46.8	53.5	46.9	52.1	65.5
BRIDGING PROGRAM**								
HD	8.6	8.4	10.7	16.2	14.1	0.0	10.0	10.0
D	13.5	14.0	13.6	3.6	1.5	0.0	10.0	20.0
C	23.7	23.1	23.6	11.2	12.2	16.6	20.0	10.0
P	31.7	32.1	31.8	32.1	34.1	83.4	30.0	40.0
Pass Rates (%)	77.5	77.6	79.7	63.1	61.9	100	100	80.0
NO PRIOR PREPARATION								
HD	7.8	9.9	11.1	3.5	3.6	0.0	1.5	2.2
D	6.3	9.9	10.0	1.8	1.8	0.0	0.0	2.2
C	24.2	26.1	24.3	11.5	10.7	2.3	13.3	17.8
P	36.1	33.1	31.8	31.6	31.6	36.6	43.3	48.9
Pass Rates (%)	74.4	79.0	77.2	48.4	47.7	38.9	58.1	71.1

**Evaluation of Chemical Sciences in the PBL Format. ** Dealing with very small numbers<10*

Discussion

Weaving fundamental science with engineering technology with its integration of pure and practical knowledge had some resonance with the students. Though the chief aim was to improve chemical literacy of undergraduate students no attempt outside the subject assessment was made to discover how much chemistry had been learnt by the students. Nevertheless, colleagues who teach latter year subjects in areas of environmental and fuel technology that require some chemistry knowledge have reported poor student performance since this subject has been abolished. Few students were inspired to take up courses in chemical engineering at other universities.

It can be argued whether the introduction of PBL pedagogy was a worthwhile educational strategy if there has been no significant improvement in pass rates with its implementation. This has not been the case, though the pass rates were generally higher than for other subjects. PBL pedagogy, in this paper, is the object rather than the subject. The introduction of PBL pedagogies clearly showed that it provided the means by which new material could be introduced into the syllabus without sacrificing subject content and standards. The exercise was not about changing educational outcomes as reflected by pass rates, though anecdotal evidence has shown that colleagues teaching environmental engineering, fuel technology and design subjects in the latter years were very appreciative of knowledge and skills students gained in my subject.

It needs to be also noted that the both the strength and weakness of PBL pedagogies require a high level of student commitment. This often has led to student disengagement which had an undesirable impact on the pass rates. Students were required to attend a weekly two hour PBL seminars. Timetable clashes and workplace commitments made it difficult for many team members to organize common free time for team meetings. Many students who failed to do so and were eventually eliminated from teams by other team members. New teams were sometimes formed with different time-tables. Failure of attendance was not surprising given that engineering students at VU are generally in paid- employment of more than 20 hours per week. Outside the classroom students were encouraged to participate in consultation meetings and virtual meetings. These options were all there and, unfortunately, students failing to attend PBL seminars/workshops also did not participate in other forums. Many students had, by and large, put little thought and time into their projects and sometimes resorted to plagiarism. This is not surprising given the large proportion of surveyed students who were either doing subjects across years or had outside work commitments (Table5).

Table5: Student commitments precluding team meetings

Statement	Student numbers
Undertook less than 5 hours per week of outside work during the semester	6
Undertook between 5-10 hours per week of outside work during the semester	24
Undertook between 10-15 hours per week of outside work during the semester	38
Undertook between 15-20 hours per week of outside work during the semester	19
Undertook more than 20 hours per week of outside work during the semester	10
Not Applicable	4
Enrolled only in second year subjects (no timetable clashes)	48 (47.5%)

Economic stress has become an increasing part of university students' landscape in Australia. Given that a high proportion of students at VU come from more disadvantaged socio-economic backgrounds than students at other universities, and cannot rely on the financial support from their families the need for earning support income becomes obvious. A situation thus develops where a large number of students are enrolled in a full time course but attend the university on a part-time basis. PBL subjects rely on a synergy of learning derived from collaboration of team members. Such collaboration requires student face to face meetings and they are highly time intensive. Finding a common meeting time has been a theme of complaints about PBL subjects.

The second concern is about the shifting of the student culture from one of passive to active learning. Thus at a staff-student meeting a group of students responding to a question on their view of PBL subjects replied: " *the PBL subject is great and enjoyable, however we need more lectures and tutorials to understand the subject material. We do not have the time* to go through the prescribed texts."

CONCLUSION

Teaching of fundamental science, such as chemical science, in an engineering context has been shown to be fairly effective both in traditional and PBL deliveries. It can be introduced without assumed pre-requisites provided it arouses students' curiosity in the role fundamental sciences play in a professional engineering discourse. When a fundamental science is used as a vehicle to tackle engineering problems it can lead to a better understanding of both the fundamental science and the messiness of professional practice. However such approach relies on students' maturity and is most effective when introduced, at least, in the second year of the course.

Outside the positive student responses and lower than average attrition rates, it is difficult to evaluate whether such an integrative approach had been good or bad. The same outcomes might have been achieved if the subject was taught as two separate stand-alone subjects as it has been in the past. However the reduction of hours provided an opportunity to use PBL pedagogy to ensure that the subject content remained intact by focusing on active and action-based education.

Though the introduction of chemical sciences in a PBL/inductive teaching format was seamless and worked well. There have been issues concerning such pedagogical approaches. It is time demanding of both the students and the staff and issues of time management, workloads and research time have not been appropriately addressed. It seems that while PBL drives student-focused learning process, it relies on a campus collaborative student participation.

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