

Symbiosis of Fundamental Science and Engineering Education: A Pedagogical Opportunity

Josef ROJTER
Victoria University, Melbourne, Australia
Josef.Rojter@vu.edu.au

ABSTRACT

Purpose of the work:
The objective of this exercise was to transform a fundamental science subject syllabus and pedagogy of introductory chemistry into an engineering science.

Methodology:
The evaluation of teaching of fundamental science as an engineering subject both in the traditional and problem based learning pedagogical platforms was based on the comparison of relative student pass rates to other traditional fundamental science subjects in the curriculum. Student subject rating provided an additional measure of this approach.

Findings:
The exposure to both to the scientific and engineering methods were highly appreciated by students, and despite the crowded syllabus and great demands on placed on student time, the progression rates were above average compared to other subjects and student subject satisfaction rating was high.

Conclusions:
The introduction of fundamental science subjects into engineering context has been successful. The delivery of this unit with constructivist pedagogy 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.

Value:
Fundamental sciences delivered as an extension of technical engineering problem solving had been very popular among students. Fundamental sciences lend themselves to constructivist pedagogy if placed within practical discourse.

Keywords: *Problem-based learning pedagogy, contextualizing science, constructivism.*

INTRODUCTION

A lack of cohesiveness in engineering curricula 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). In many cases engineering curricula fail reflect an integrated course of education for professional life and sometimes resemble a collection of subjects or units in search of integrated whole. This is not surprising given that curriculum designers incorporate differing knowledge streams into engineering education to produce (what is felt) the desired engineering graduate attributes outlined in figure 1.

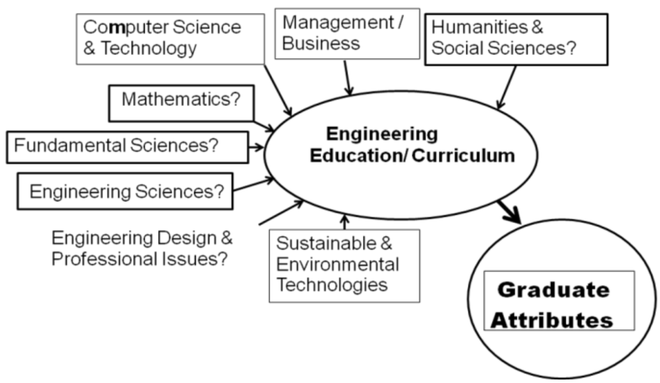

Figure1. Traditional Engineering curriculum design

The gulf between professional workplace epistemologies and educational discourse is an issue, can be attributable to the wrong mix of knowledge streams or their lack of integration. 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).

Past and well current progression rates in fundamental science subjects in engineering, at my university, are unsatisfactory. In developing fundamental science chemistry subject I decided to adopt a contextual philosophy where the subject syllabus and pedagogical design and objective were to bridge fundamental science and engineering. It was also to enhance engineering epistemic culture based on diversity of knowledge components to reflect a professional engineering discourse. This discussion focuses on an introductory chemical based subject which formed half of an omnibus subject of engineering materials in the engineering curriculum. 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.

PEDAGOGICAL APPROACHES

Background

In a traditional course design learning objectives are identified and relevant educational actions are formulated. In engineering these objectives include: Understanding and mastering of knowledge and skills of the subject matter, Understanding of the context of the subject within professional engineering discourse, 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 promoted by Derry (1996).

In designing pedagogical approaches students’ academic abilities and knowledge background were needed to be taken into account. The minimum admission to engineering at VU is at least 10 points below the minimum entry requirements to engineering at other universities in Melbourne. Year 12 chemistry is not a requirement for entry into engineering courses at VU, and only a small proportion of engineering students had an adequate preparation in this discipline prior enrolling in engineering. 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.

The Syllabus

The syllabus was designed on the basis of interrogation of epistemological questions that arise within an engineering canon and professional discourse. Bloom’s educational taxonomy provided the philosophical basis of the syllabus design (Bloom, 1956). 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, professional ethics and social responsibility provided the engineering basis for the syllabus construct outlined in figure 2 and table1.

Teaching and Learning

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.

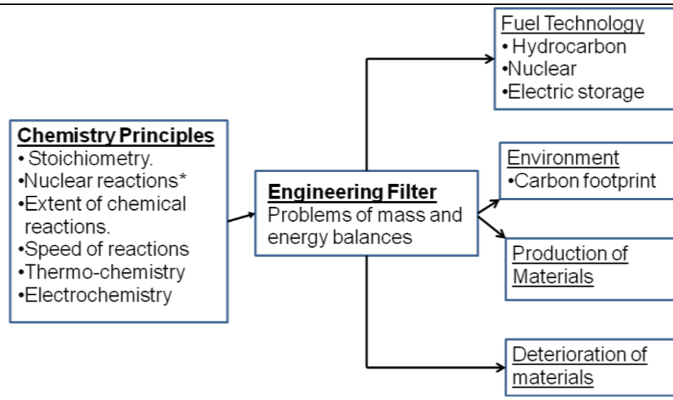

Figure 2. Snapshot picture of the course design.

Table 1: 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. 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. Application to processes involving chemical equilibrium.
Rate of reactions and reaction mechanism	Examples from processes. Illustration of atmospheric reactions.
Thermo-chemistry	Heat balances around process units.
Electrochemistry	Application in the study of production of electricity with emphasis on batch and fuel batteries. Application to corrosion and corrosion protection of metals.
Production of materials	Application of chemical and engineering principles to the production of steel, cement and polymers.

The subject was initially of one semester at second year level, and of 3contact hours per week of which 2 hours were allocated to lectures with the remaining hour to tutorials. Lecture material started with the assumption of student fundamental science knowledge platform stopped at year 10 high school level. 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. Subject principles were introduced early in the lecture course and were followed by case studies involving the participation of students. Augmentation of learning was a key pedagogical tool by actively encouraging student questions. New material was introduced on need to know basis during tutorial and seminar sessions, an educational approach proposed elsewhere (Prawat, 1996).

Professional discourses are based on problem solving and reflection on solutions, and thus problem solving was the key pedagogical approach in formal tutorials as well as outside-class time consultations. 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 others (Coates, 1997). 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.

Relatively good pass rates meant that the subject was a victim of its own success. It replaced a first year with relatively poor progression rates. Such a switch meant that the student body enrolled in the subject were not only less mature but had lower learning and motivational skills. In 2005, the subject returned to second year but was confined to half a semester of 5 contact hours per week. The reduction of contact hours necessitated the adoption of PBL pedagogy where it placed the onus on the students to seek out knowledge under a guiding hand. 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.

A major proportion of the (45-50%) subject assessment of 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.

OUTCOMES

Effect of previous student exposure to chemical sciences and student educational outcomes are shown in Table 2.

Students with little or no prior exposure to chemistry, during their secondary education, did not perform as well in comparison to their peers who studied some chemistry in senior high school 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. It must be noted that 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.

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 homogenization 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.

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. Anecdotal evidence from colleagues, who teach latter year subjects in areas of environmental and fuel technology that require some chemistry knowledge, suggests 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 even if there was no significant improvement in pass rates. 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. It needs to be also noted that the both the strength and weakness of PBL pedagogies require a high level of student commitment. Students were required to attend a weekly two hour PBL seminars but 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. 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 often 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.

Table 2: Student performance as a function of prior exposure to chemistry

Entry level and grade	Percentage of Students							
	Year of Assessment							
	2nd year-2 semester subject			1st year:2 semester subject		2nd year-1/2 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	71.8	71.6	73.4	73.3	71.7	70.3	74.3	72.0
Year11								
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	68.4	69.9	75.1	46.8	53.5	46.9	52.1	65.5
BP**								
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	77.5	77.6	79.7	63.1	61.9	100	100	80.0
None								
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	74.4	79.0	77.2	48.4	47.7	38.9	58.1	71.1

**Evaluation of Chemical Sciences in the PBL Format. ** Bridging Program (BP) dealing with very small numbers<10*

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. 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.

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