Teaching Fundamental Science in Undergraduate Engineering Course

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Abstract - In a response to recommendations from Engineers Australia (E A), the Department of Mechanical Engineering at Victoria University of Technology (VUT) decided to incorporate chemical sciences into its undergraduate curriculum. This was achieved by replacing first semester materials topics, in the second year two-semester Materials Technology subject, with topics dealing with chemical sciences and technology. The new revised subject eventually became an integral part of `Architectural, Building and Civil engineering curricula. Though almost all undergraduate engineering students at VUT had sound grounding in the fundamental sciences of Mathematics and Physics, less than half of these students had exposure to Chemical Sciences beyond what was offered as part of General Science curriculum at junior levels in secondary schools and colleges. The course was constructed in a way that fore-grounded Process Engineering and Technology as a vehicle for the discovery of relevance of chemistry in engineering discourses.. Subject evaluation has shown student satisfaction with the syllabus, comparatively higher pass rates than in other engineering science and fundamental science subjects and, interestingly, it also showed that Chemistry, for engineers, can be successfully introduced in a (engineering) contextual way.

Index terms - education research, innovative curricula, teaching and learning

INTRODUCTION

Over many years there has been a growing concern that engineering education has not been meeting the demands placed on the engineering profession. Engineering curricula tend to be too narrow, too specific, too technical and lacking connectivity. Engineering educational providers have not adequately responded to the changing needs, though it is possible to effect curriculum changes through tinkering of subject syllabi.

The transformation of professional engineering workplace discourse from one of highly positivist technical in nature to one of social practice has been predicted as an evolutionary process of the professionalization project. Verblen [2] saw that the rise of technocracy will lead to the engineering profession becoming the guardian of community. Galbraith [3] observed that, since 1945, large scale technological developments imposed a new form of power and decision-making in private and public organizations, and gave rise to four major power and decision-making estates: scientists, professions, administrators and politicians. Professions replaced entrepreneurs and professionalism assumed the role of post industrial ideology where it emphasized the essential component of technocracy which involved the translation of knowledge into applied practices, and stressed social service through responsibility to both clients and society.

Galbraith's view implicitly implied that the professionalization project must be accompanied by an acquisition of skills and knowledge of social sciences and humanities as well as the awareness of social and environmental impacts emanating from professional practices. Fawcett and Roberts [4] commented that without such knowledge engineering professions will be invisible and marginalized in the public domain if they continue on the only path of celebrants of technology.

Yet despite the continual rhetoric, in engineering schools, departments and faculties, of meeting needs of industry, there is disquiet [5],[6],concerning skills and knowledge of engineering graduates from Australian universities. The trend towards softer skills can be gauged through job advertisements [7],[8], for professional engineers. Since the 1970's the demand for engineering skills has undergone a major paradigm shift from one requiring high technical competence to one requiring social and environmental awareness, good oral and written communication as well as teamwork skills. It is understood that the nature of engineering practice is a multi-disciplinary one. It is world-wise and its context is people.

The Australian Science, Technology and Engineering Council identified [5], the changing landscape of engineering practice. The forces responsible for the change were:

1. Global Integration. The homogenization of productive activity had meant that engineers had to move their gaze from local perspective to a world-view;
2. Applied Information and Communication Technologies. Professional engineering discourses were now separated by time-zones not time of travel;

3. Environmental Sustainability. Increasing international accountability for sustainable practices meant that professional engineers needed to possess global environmental sensitivities; and
4. Advances in Biological Technologies. Engineering graduates needed broader scientific literacy.

The same report [5] on the future of professional engineering work identified four major roles for professional engineers in world of work. These are:

- Engineering/technical managers;
- Technical specialists. Professional engineers key roles in research, technical innovations and as experts;
- System engineers. Professional engineers in these roles are experts in system specification and, in the course of their work, have the ability to integrate the technical and non-technical knowledge domains; and
- Generalist Engineers with broad based technical knowledge enabling them to work across specialist (engineering) boundaries.

Conclusions reached by the committee chaired by Professor Peter Johnson [5] suggest that there is room in Australia for engineering education providers to provide within each engineering discipline a diversity of courses. This is a large project and beyond the scope of this paper. However, it is possible, somewhat, to shape engineering curricula through subject syllabi. This paper is concerned with the development of a subject syllabus in Chemistry and Materials Technology with an emphasis on, what Felder and Brent[1] refer to as, independent and contextual knowing in which students are exposed to the attitude that a significant proportion of engineering knowledge is uncertain and tools of critical thinking and ethical attitudes are required in the decision-making process. This is convergent with a development of constructivist, student-centred learning delivery approach culminating in the introduction of PBL (problem-based learning) pedagogies for this subject in the first semester 2007.

BACKGROUND

Designing a course syllabus is, at best, a very complex exercise. Bloom's [9] hierarchical knowledge taxonomy had to be adapted in non-linear and non-hierarchical way in which the components of learnt knowledge, comprehension, application, synthesis and evaluation are not sequential but introduced in a convergent way. This was determined by the nature of the subject which shared the same space between disciplines of chemistry and materials science. The objective of the course design was not to produce a seamless transition between these disciplines but to instil a professional way of thinking.

The mix of students entering engineering courses at Victoria University not only presented a challenge but offered a new opportunity for a course design. The minimum admission to engineering at VU, as measured by the ENTER score, on the scale between 10 and 99.95, is around 60. In comparison the ENTER requirements to engineering courses at the more prestigious Melbourne and Monash universities is between low to high 90's. The lack of attractiveness of engineering as a course of study combined with the difficulty of attracting high performing secondary school graduates into my university has meant that the entry criteria into engineering at Victoria University (VU) are somewhat relaxed. As a result of diluting the entrance requirements only a minority, between 29 and 34 percent of students, entering engineering courses within the school have completed year 12 chemistry with further 12 to 15 percent of students have only completed year 11 chemistry in their secondary education. Some 10 percent of students, many mature students, undertake preparatory or bridging summer chemistry classes which unlike similar classes in mathematics and physics are not compulsory because it is not a prerequisite entry subject.

THE CURRICULUM

This subject was organized as a replacement for two second year subjects, each of duration of one 12 week semester. In the case of mechanical engineering one semester materials subject was replaced by a subject dealing with chemistry/process engineering. The new subject retained 3 hours class contact per week.

The development of a new subject provided an opportunity to introduce a philosophy of the syllabus design which was to form a bridge between the academic and the practice-oriented engineering discourses. This subject is derived from two major engineering disciplines; chemical engineering and materials engineering. It seeks to develop both knowers, who remember information and can systematically repeat skills, and learners who can create, apply, modify and adapt concepts. The main thrust of this subject is a meta-cognitive one where consciousness of knowledge about knowledge plays a key pedagogical role. In this subject

- Students will be encouraged to think critically and monitor their understanding; and
- Students will reflect not only on *what* they know, but on *how* they know it

The course did not need to resemble other courses in content or teaching style since there is no acknowledged universal engineering knowledge [10], or pedagogical approach [11]. In addition to attributes of the traditional syllabus, new attributes were added (table I).

The syllabus content, of the first part of the subject, was designed on the assumption that students possessed mid-level high school chemical knowledge derived from the general science curriculum. This subject was to be delivered in a distinct narrative style which linked theory and principles to material technology and, more importantly, a worldview of engineering discourse. A minor objective of this subject was an epistemic one; to make students aware of scientific limitations and distinguish between the scientific and engineering methods. This two-pronged course design is shown in table II.

TABLE I. ATTRIBUTES OF THE NEW SYLLABUS

ATTRIBUTES OF TRADITIONAL CURRICULUM /SYLLABUS	ATTRIBUTES OF THE NEW SYLLABUS
Knowing that	Knowing that and knowing how
Personal skills	Personal and inter-personal skills
Disciplinary skills	Disciplinary and inter-disciplinary skills
Intellectual orientation	Intellectual orientation towards practice
Knowledge as a process	Knowledge as a process and as a product
Concept based	Issue oriented
Proposition based learning	Proposition and experiential based learning

TABLE II. SYLLABUS CONSTRUCT

SUBJECT PRINCIPLES AND THEORY	ACTION AND APPLICATION
Conservation of mass and energy	Calculation of mass and energy balances around process units involving recycle and by-pass streams.
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.
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.
Studies of atmospheric and land pollution.	Calculations involving current issues in fuel technology, manufacturing industry, agriculture and urban transport.
Production of steel	Full material and energy balances in production of steels.

The chemistry component was introduced in terms of issues, as process engineering, involving energy and mass balances. The material science component was less problematic and though delivered in a traditional way, it required students to participate, in small teams, in both laboratory and library investigative projects.

In 2005, with a prevailing school's stance towards PBL (Problem-based learning) course delivery, there was an opportunity to further fine-tune phenomenological approaches in engineering education. The combined process engineering/materials course, with an allocation of 5 hours per week, was introduced in 2007. It further integrated experiential knowledge with social and technological discourses. Greater onus on self learning is to be placed on students working in teams with lecture material providing the theoretical framework. Student team projects provided the key theme of the education process with an emphasis on multi-disciplinary knowledge integration based on a 7 step strategy proposed by Moust, Van Berkel and Schmidt [12].

The course is divided into 2 parts, which are:

A. Part I. This section deals with both introduction and extension of students' chemical literacy. The objectives of this part are multi-fold. Their purpose is to exposes the students to the key roles the mass and energy balances play in the analysis of technical problems. It intends to extend students' problem solving skills without reliance on given equations. The students' appreciation of process engineering is conducted through case studies such as:

   1. Fuel evaluation;
   2. Production of nitric acid, ammonia, foodstuff etc;
   3. Greenhouse phenomena and global warming;
   4. Evaluation of energy storage;
   5. Chemical and electro-chemical deterioration of materials; and
   6. Production of cements, aluminium, steel, copper and plastics

B. Part II. This section is concerned with the microstructure- property relationship in solid materials. Though some attention is paid to ceramic and polymeric materials, most of the course emphasis is focused on strengthening mechanism of metals and the role phase precipitation play on microstructures and properties of carbon steels and cast irons.

Since, in this subject, new knowledge and skills are introduced, a more traditional lectures and tutorials with formalised/structured knowledge provide the intellectual resource for student projects. The educational components of Open-ended Research, Discovery, Experimentation, and Observation emphasize student-centred learning (table III) and are constructivist in the approach. In this component students build their own internal frameworks of knowledge upon which they "attach" new ideas; and use cognitive conflict as a stimulus for learning.

The assessment of the subject will consist of three components, these being:

1. Written skills assessment tasks based on lecture and tutorial materials;

2. Open –ended Research and Discovery Projects and the assessment will include:
    - Written team report;
    - Oral presentations; and
    - Individual reflective journals on investigative work underpinning the reports as a part of student's portfolio.

Experimentation and Observation exercises which will be assessed on the basis of:

- Team reports which include the treatment of experimental data and assignment work;
- Individual reflective journals on investigative work underpinning these reports as a part of student's portfolio. The journal may be requested for review by the academic supervisor at any time.

VALIDATION

The revised course is still at the work-in progress stage and has not as yet been evaluated. However the past course has been evaluated by both students and academic staff.

The students' perspective of the subject is an interesting one. In a survey conducted of 8 subjects, by one of my colleagues, on subject quality between 1996-1998 indicated that students rated this subject as among two of the most demanding and difficult subjects though interestingly students also rated the subject as the most interesting and most satisfying. In an informal Student Educational Satisfaction (SES) survey, conducted in 2005, the two questions concerning work demands placed on the student and satisfaction and enthusiasm aroused by the subject gave scores of 4.0 and 4.1 on the Likert scale ranging from 1-5.

I have, as well as for other subjects, encouraged students' evaluation of teaching and subject content using a simple Hildebrand's model [13] with two extended statements. Students' evaluation used Likert's scale ranging from strongly agree (5 points) to strongly disagree (1 point). The average scores are shown in table IV.

The first 5 statements, in table IV, evaluate lecturer's performance and what is interesting is that the response to the last two statements, in table IV, students were very positive about this subject in terms of enhanced engineering

Unlike engineering sciences and fundamental sciences such as physics and mathematics, this subject did not, like engineering design, assume prior high school chemistry knowledge. It represented new knowledge, and an introduction to a different way of thinking inclusive of open-ended problems and solutions. However unlike engineering design, this subject was also concerned in establishing new directions of information processing, particularly with concept attainment and synectics [14], [15]. The effect on student academic performances as a function of previous exposure to chemistry is shown in tables V and VI. Table V is concerned when the subject was offered at the second

TABLE III. STRUCTURE OF THE COURSE DELIVERY

FORMALISED AND STRUCTURED KNOWLEDGE (LECTURES)	
PART A: SKILLS ASSESSMENT TASK (1.5 HOURS)	PART B: SKILLS ASSESSMENT TASK (1.5 HOURS)
INDIVIDUAL PORTFOLIOS INCLUDING REFLECTIVE JOURNAL AND TUTORIAL TASKS	
PART A: STUDENT - CENTRED ACTIVITIES	PART B: STUDENT - CENTRED ACTIVITIES
Open-ended Research and Discovery • Team Report • Oral Presentation Reflection on Ethical, Social and Environmental Issues • Other Issues	Experimentation and Observation • Experimental Techniques and Data Analysis • Literature Research • Oral Presentation • Written Communication • Teamwork •

TABLE IV. SUBJECT ASSESSMENT

STUDY LEVEL OF CHEM.	YEAR	GRADES (% OF STUDENT POPULATION)						AV. (%)
		HD	D	C	P	N1	N2	
Year 12	2000	12.8	13.1	19.6	26.1	7.5	20.9	60.0
	2001	13.2	15.2	18.9	26.1	8.1	18.5	61.2
	2002	13.1	14.9	24.1	29.2	8.1	10.6	63.2
Year 11	2000	0.1	12.8	19.9	27.1	7.9	21.4	57.8
	2001	13.1	12.8	21.6	27.6	7.9	16.9	59.5
	2002	13.6	14.1	22.4	26.9	8.1	14.9	60.5
Bridging	2000	8.4	14.0	23.1	32.1	5.9	16.5	58.0
	2001	10.7	13.6	23.6	31.8	9.5	10.8	58.1
	2002	10.7	12.9	23.1	30.9	8.6	13.8	58.0
None	2000	9.9	10.0	26.1	33.0	8.0	13.0	57.6
	2001	11.1	10.0	24.3	31.8	8.6	14.2	57.7
	2002	10.0	9.9	24.3	32.1	9.9	13.5	56.7

year level of the course, whilst table VI deals with the data collected when the subject was shifted into first year. Table V shows little difference in the subject performance between students who have or have not studied chemistry in secondary schools at the highest levels. The pass rates, in this subject, matched and exceeded pass rates of other subjects at second year level.

The transfer of the course into first year has not proved to be a positive thing. A variation of performance in the subject between students who have completed year 12 chemistry and those who have studied less or no chemistry in secondary schools is observed in table VI. These results of students who undertook bridging courses are distorted by the small population of students and the mix of students. Some students who enrolled in the summer bridging course had completed year 11 chemistry, others have not done chemistry before and these included many mature students who, by-and-large, were responsible for the relatively high proportion of high distinctions. Though tables V and VI indicate that a level of maturity was required to tackle this subject, it also shows that students without prior knowledge but willingness to study can successfully complete this subject. In fact the overall pass rate for this subject was

TABLE V. COMPARISONS OF STUDENT PERFORMANCE WHEN THE SUBJECT IS INTRODUCED IN THE SECOND YEAR.

STATEMENT	YEAR OF ASSESSMENT AND AVERAGE SCORE							
	1997	1998	1999	2000	2001	2003	2004	2005
The lecturer has a good command of the subject.	4.5	4.3	4.7	4.6	4.5	4.7	4.4	4.5
The subject objectives are clear.	3.8	3.9	4.2	4.1	3.8	4.4	4.0	4.2
Lecturer interacts well with the class.	4.0	3.8	4.3	4.3	4.3	4.1	4.1	4.3
Lecturer is accessible for individual consultations.	4.1	3.9	3.9	3.8	4.0	3.8	3.9	4.0
Lecturer arouses curiosity in the subject.	4.0	3.8	4.4	4.1	4.0	3.6	4.0	4.0
The subject widens the scope of engineering knowledge.	3.8	3.9	4.2	4.3	4.1	3.9	4.5	4.1
The subject is satisfying and would recommend to others.	4.1	4.2	4.0	4.0	4.3	4.0	4.2	4.1

TABLE VI. COMPARISONS OF STUDENT PERFORMANCE IN THE FIRST YEAR.

PREPARATION	YEAR OF SURVEY	GRADES (% OF STUDENT POPULATION)						AV. SCORE (%)
		HD	D	C	P	N1	N2	
Year 12	2003	8.8	8.1	25.2	31.2	4.0	26.7	58.2
	2004	11.5	10.6	34.6	25.0	3.0	15.3	59.1
	2005	12.2	14.6	29.2	26.8	4.9	12.2	61.1
Year 11	2003	7.2	7.2	8.6	22.8	13.2	41.0	49.1
	2004	8.8	7.2	11.2	26.3	19.0	27.5	53.2
	2005	10.5	0.0	10.5	31.6	26.3	21.1	54.4
Bridging	2003	16.2	3.6	11.2	32.1	12.5	24.4	50.1
	2004	14.1	1.5	12.2	34.1	10.6	27.5	51.1
	2005	22.2	0.0	11.1	33.3	11.1	22.2	50.0
None	2003	3.5	1.8	11.5	31.6	1.6	50.3	42.2
	2004	3.6	1.8	10.7	31.6	0.0	52.3	43.1
	2005	3.9	2.0	11.8	33.3	3.9	45.1	43.7

HD (High Distinction) = 80+ %, D (Distinction) = 70%-79%, C (Credit) = 60%-69%, P (Pass) = 50%-59%, N1 (Fail) = 40%-49%, N2 (Fail) < 39%

higher than pass rates in both physics and mathematics which required year 12 equivalent preparation as a pre-requisite for the course.

CONCLUSION

Unlike other professional courses, engineering at Australian universities has been, by and large, treated as an academic discipline of science. Yet non-scientific perspective of engineering has lot to offer. In such perspective, engineering is different from science because of it is multi-disciplinary and like art it explains rather than states meanings. It owes as much to a critical theory which takes place at hidden coercions of concrete contradictions in the established worldview [16]. Like other professions, the engineering profession possesses tacit knowledge which cannot be readily converted to formal and abstract knowledge found in sciences [17].

Despite the many recommendations by formally instituted inquiries into engineering profession and education, the changes in engineering education have been sublime and not concrete because academic beliefs often shaped by disciplinary (scientific) research. It is nevertheless possible to tinker with the engineering curriculum at the subject level. The subject material was introduced in a form that confronted students' notions of knowledge as being linear and consisting of collection of facts [20]. The objective of the subject was to arouse student curiosity and therefore improve the quality of active learning. This approach, as shown by student response and evaluation of the subject, seem to be successful in enhancing student participation and active role in students absorbing new knowledge. It is hoped that further movement towards student centred learning will aid towards professionalization of the engineering curriculum.

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