AC 2009-2414: DEVELOPMENT AND IMPLEMENTATION OF PBL AND OTHER INDUCTIVE PEDAGOGIES IN ENGINEERING SCIENCE: WORK IN PROGRESS

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Development of Problem-Based Learning (PBL) and Other Inductive Learning Pedagogies in Introductory Fundamental Engineering Science and Science Subjects: Work in Progress

ABSTRACT

Poor knowledge platform in fundamental sciences of a significant proportion of incoming students into undergraduate courses of architectural, building, civil, and mechanical engineering has meant that first and second year fundamental science and engineering science subjects, which usually relied on sound preparation at the senior levels of high schools, had to be taught in a different way. In this case, the hybrid subject of chemical/material science was designed and delivered as primarily engineering science with the focus on environmental, design and manufacturing issues. These narratives were further expanded by the inclusion of communication and team working skills when the subject was designated, in 2006, as a Problem Based Learning (PBL) subject with its accompanying pedagogy and curriculum design. The initial pedagogical approach of just-in-time teaching worked well with relatively high pass rates and generally independent of students' previous exposure to chemistry. The introduction of PBL curriculum cannot be, as yet, properly evaluated. Nevertheless, despite the subject complexity and the intense demands of the subjects, student response was highly positive. The negative aspects related to poor study habits and unfamiliarity with working in teams. The positives were high student satisfaction with subjects, low attrition rates and relatively high pass rates.
IndexTerms – Innovative curricula, education research ,teaching and learning

INTRODUCTION

This paper focuses on the introductory materials subject - a two semester subject split into two one semester components, which were:

- Introductory chemical science; and
- Fundamental material science.

The inclusion of chemical science into the engineering curriculum was the result of recommendations of course accrediting processes. The inclusion of chemical sciences in the curriculum was far-sighted because it seemed to anticipate recommendationsof the Australian Science and Technology Council (ASTEC) [1] and the Report into Engineering Profession and Education chaired by Professor Johnson[2] .

The two semester-long materials science subject was taught to second year undergraduates in Building, Civil and Mechanical Engineering courses. The relative high pass and low attrition rates in this subject ensured its victim-hood subject when it was swapped in 2003 in the course curricula with a less performing first year subject. In 2006 the subject became Problem-based learning (PBL) designated and was transferred back to the second year level. PBL designation significantly altered the course delivery. Initially the subject organization which consisted of 2 hours of lectures for 2semesters supplemented by 1 hour tutorial per week in the first semester and a 2 hour laboratory session per fortnight in the second semester. In PBL organization the subject was compressed into one semester with an allocation of 2 hours of lectures and three hours of seminars and laboratory sessions per week. Effectively, this represented a 16.7 percent reduction in total contact time and 50 percent reduction in lectures. This paper is focusing 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.

SUBJECT DEVELOPMENT- INTRODUCTION OF CHEMICAL SCIENCES INTO ENGINEERING CURRICULUM

The philosophy of this subject development was guided by the knowledge constraints of students enrolled in the course. The incoming students had not only poor grounding in basic sciences and mathematics, but also a significant proportion of students had little or no exposure to chemical sciences beyond year 10 general science high school level. Only a minority of engineering students at VU undertook chemistry subjects in their last two years of high school. Between 29 and 34 percent of students completed year 12 and a further 12 to 15 percent completed year 11 chemistry in high schools. Some 10 percent of students, many of them mature entrants, undertook voluntary bridging summer chemistry classes. This lack of exposure to chemistry presented a major pedagogical challenge.

Yet, despite general poor background in fundamental sciences, students were willing to undertake a course which is traditionally perceived to be guided by the application of sciences. In constructing both the subject curriculum and the teaching pedagogy I assumed that students had no previous knowledge of chemical sciences. This allowed me to start with a fresh page, so to speak, and to bring the students disciplinary knowledge and appreciation of chemical sciences to a university level. The lack of students' general knowledge of chemistry in necessitated a subject design that would capture students' interest as a tool for solving engineering problems. It was hoped that by using chemical principles as a vehicle for solving engineering problems, students would acquire a deeper understanding of the subject and its role in engineering. The approach was of just-in –time learning not differing much from ideas explored by John Coates elsewhere [3].

The subject development, specifically in chemical sciences, is outlined in two parts; prior and after the introduction of PBL.

SUBJECT DEVELOPMENT PRIOR TO PBL INTRODUCTION

The subject design had to meet some of the objectives which are common to education for professions. These objectives included:

- The understanding and mastering of knowledge and skills of the subject matter;
- The understanding the context of the subject within professional engineering discourse;
- The development of communication skills; instilling skills in teamwork;
- The development an autonomous and reflective practitioner with social awareness of the impact of engineering practice; and
- The development of skills for life-long learning[3].

The subject design was developed in the context of engineering technology. It was taught not as fundamental science but an engineering science based on the fundamental engineering principles of conservation of mass and energy. The subject syllabus design was to, hopefully, embody the kind of epistemological questions that arise within a discipline of knowledge. These were transformed into a sequence of statements that defined the subject (see table 1 They were:

- Fundamental Science. Fundamental chemical principles were introduced in the first two-three hours of lectures. They included basic atomic structure, periodic table, and atomic and molecular bonding and their effect on solid properties;
- Mass and Energy balances. These basic engineering principles were extended to stoichiometry, thermochemistry and electrochemistry of chemical reactions encountered in the world of engineering;

- Extent of Reactions. Ideas of yields and equilibrium constants were introduced;
- Speed. Rates of reactions were examined including functions of catalyst and the applications of Arrhenius constants in the world of engineering;
- Applications. Provided an interface to the real world of engineering and process technology, and included such issues as degradation of materials (corrosion), energy storage, as well as manufacture of materials such as cement, polymers, aluminium and steel.

TABLE 1. 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.

Problem-solving focused tutorials provided the context for much of the student learning. Academic consultations, outside timetabled classes, provided further context for student learning. Tutorial problems were generally based on case studies such as fuel comparisons in terms of economics, energy intensities and carbon footprint, or glass bottles design for the fermentation of sparkling wines. Other problems were derived from topics on health, waste water treatment, mineral and food industries. Areas of knowledge, both in fundamental sciences and engineering sciences, not covered in lectures were introduced on need to know basis [4]. The subject was delivered in a narrative style that focused on learning modes 1 and 2 as representations of intra and interdisciplinary discourses respectively [5]. Student active learning underpinned the subject delivery.

Subject Evaluation

Students' subject evaluation surveys were based on a simple Hildebrand's questionnaire[6]. The surveys pointed, in table 2, to a general satisfaction with this subject.

Table 2 Student evaluation of the subject

Statement	**Year of Assessment and average score**				
	1998	2000	2001	2003	2004
The lecturer has a good command of the subject	4.3	4.6	4.5	4.7	4.4
The subject objectives are clear.	3.9	4.1	3.8	4.4	4.0
Lecturer interacts well with the class	3.8	4.3	4.3	4.1	4.1
Lecturer is accessible for individual consultations	3.9	3.8	4.0	3.8	3.9
Lecturer arouses curiosity in the subject	3.8	4.1	4.0	3.6	4.0
The subject widens the scope of engineering knowledge	3.9	4.3	4.1	3.9	4.5
The subject is satisfying and would recommend to others.	4.2	4.0	4.3	4.0	4.2

Students rated this subject amongst the two most demanding and difficult subjects. Yet, they also rated this subject as the most interesting and most satisfying. A Student Educational Satisfaction survey, in 2005, rated this subject as 4.1 on a 5 point Likert scale. Further evaluation of the subject was undertaken to observe whether previous exposure to chemistry in high schools determined students' academic performance. Student academic performances in the subject studied at second and first year levels are shown in tables 3 and 4 respectively.

Table 3. Comparisons of second year students' performance in the subject

Subject Preparation Level	Year of study	GRADES (% of student population)						Av. Score (%)
		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	10.1	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 summer course	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

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

Table 4. Comparisons of year students' performance in the subject

Subject Preparation Level	Year of study	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	61.2
Year 11	2003	8.8	7.2	8.6	22.8	13.2	41.0	49.1
	2004	10.5	7.2	11.2	26.3	19.0	27.5	53.2
	2005	13.6	0.0	10.5	31.6	26.3	21.1	54.5
Bridging summer course	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%

Not surprisingly, the pass rates and the proportion of students attaining honours marks of credit and above were higher when the subject was taught at second year level. The results in tables 3 and 4 are summarized in table 5. When the subject was offered at the second year level of the course there was little difference in students' academic performance between those who studied chemistry at the senior levels in high school and those students who didn't. This is very likely due to two factors which are:

- Student maturity. Student learning methodology improves with length of exposure to university courses; and
- Higher quality of students. Poor performing students in the first year have been "weeded out".

Table 5. Comparisons of student academic performance in the subject when taught at first and second year levels.

Subject Preparation Level	**Average pass rates (%)**		**Proportion of students attaining honours grades (%)**	
	1st year	**2nd Year**	**1st year**	**2nd Year**
Year 12	77.9	74.8	51.5	47.6
Year 11	52.7	73.2	25.8	46.8
Bridging summer course	63.9	78.2	30.7	46.7
No prior preparation	49.0	77.2	16.9	44.9

Though table 5 indicates that student performance in chemical sciences, in first year, is proportional to the level of prior preparation in chemistry and suggests the value of the bridging course, nevertheless the table also suggests that the teaching and curriculum approach based on the assumption of no prior knowledge in chemistry works well at the second level. In this case, there is little value for students in undertaking a bridging course.

POST PBL SUBJECT DEVELOPMENT

Though it was designated to be a PBL subject at the end of 2005 and transferred back into second year in 2006, its full PBL delivery was introduced in 2007.

Chemical Sciences in PBL Format

The reduction in lecture contact hours in delivering the asserted knowledge and canon in chemical and material science discipline necessitated a more thematic delivery. Subject principles were introduced early in the lecture 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. The onus was placed on students developing the skills of "finding out". These components (mainly) were to support Bloom's cognitive domains of application[7], synthesis and evaluation. The lecturer's role as the sage on the stage was transformed to that of a guide on the side who took on the role of a coach, collaborator and facilitator in the student learning process.

The two hour per week PBL workshops, in the newly constructed PBL studios, were dedicated to mix of things. Small amount of time was dedicated to non-technical matters of oral and written communication. The bulk of the time was assigned to student team meetings concerning team problem. The team meetings provided an opportunity for team consultations with the subject supervisor. During such consultations questions, concerning particular problems, were raised and students' misconceptions of knowledge were addressed.

Laboratory sessions required students to use data obtained in the experiment and apply it to real-life problems of engineering design.

The one semester subject was divided into two component cycles. Chemical science and technology was to be covered in the first cycle of 6 weeks. The second 6 week cycle of the semester was allocated to materials science and technology. These are described below:

- First Cycle. It deals with both the introduction to and extension of students' chemical literacy. The students' appreciation of the role chemistry plays in the technical elements of professional engineering practice is conducted through case studies in process engineering 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.
- Second Cycle. It 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 the strengthening mechanism of metals and the role phase precipitations play on microstructures and properties of carbon steels and cast irons.

Under the guise of PBL, a different pedagogical tack was adopted to the subject delivery. It was an extension to previous approach with pedagogical modifications which had greater emphasis to an inductive approach to teaching [8, 9]. The pedagogical mix included problem-based learning as well as cases based learning, just in time teaching, and inquiry based learning (IBL). In the case of IBL, it was introduced in week 7 of the semester during laboratory classes. The subject organisation consisted essentially of two parts, these were:

1. Formalised and Structured Knowledge. This part is concerned with expanding students' explicit knowledge base through lectures, and developing skills in applying this knowledge during the problem-solving sessions using both theoretical and real world case problems. This part was assessed through two written tests held in weeks 7 and 12.
2. Student-centred activities**.** This part is concerned with self-directed learning and has a constructivist dimension which is explored in the laboratory, seminars and workshops. This part comprises of two components () which are:
   - *Experimentation and observation; and*
   - *Open-ended research and discovery.* Each student team was set an open-ended and ill defined problem (see table 6). A team report concerning the problem was submitted in week 12. The report clearly identified each team member's contribution and outlined sets of possible solutions from which conclusions were derived. The submission of the team major report was accompanied by the team members' individual reflective journals. This component also required student oral presentations in weeks 4 and 12.

Table 6. Problems allocated to student team

	Project title
1	Energy and Environmental Audit and Assessment of various fuels and mixture of fuels operating at various and efficiencies and excess air. Fuels in question are: Methanol; Methane; Propane; Butane; Butane-propane mixtures; and Ethanol-octane mixtures.
2	An environmental assessment and LCA (life cycle assessment) of three selected bio-degradable polymers
3	Examination of the feasibility of production of ethanol, methanol and diesels from sustainable sources.
4	Production of paper from garden waste.
5	Environmental feasibility of production of diesel and petrol from coal and natural gas.
6	Environmental and life-cycle analysis of 1litre milk containers produced from: Polyethylene coated cardboard container (single trip); PET bottle (single and 5 trips); HDPE bottle (single and 5 trips); Poly carbonate bottle (minimum of 30 trips); and Glass bottle (1 and 6 trips).

Though the teaching of chemical sciences was restricted to six weeks, students developed the ideas and concepts derived from the lecture material in chemical technology to the major team problem assignment, described in table 6, over the 12 weeks of the semester.

Subject Evaluation of Chemical Sciences in the PBL Format

Subject evaluation post PBL were similar to the results shown in table 5. Student pass rates were around 75 percent and independent of prior preparation in chemistry (see table 7). However, the proportion of students managing to attain honours grades were substantially lower in the PBL format than through the orthodox subject delivery. This could have been due:

- to greater complexity in assessment tasks;
- students reliance on teamwork submission where the quality of the assessment task dependent on the weakest link of the team;
- Time management for team meetings and
- Reduction of teaching time.

Table 7. Students' acsademic performance in chemical sciences delivered in the PBL mode.

Subject Preparation Level	**Year of study**	**GRADES (% of student population)**					
		HD	**D**	**C**	**P**	**N1**	**N2**
Year 12	2007	5.8	6.1	21.2	37.2	3.0	26.7
	2008	5.5	8.6	24.6	38.1	2.6	20.6
Year 11	2007	4.8	5.2	19.6	37.8	3.2	29.4
	2008	5.5	6.2	22.2	38.3	4.0	23.8
Bridging summer course	2007	6.2	6.6	21.2	39.1	3.5	23.4
	2008	5.1	7.5	22.2	37.7	3.6	23.9
None	2007	4.5	7.8	21.5	38.5	3.6	24.1
	2008	5.6	7.8	22.9	37.9	3.7	22.1

Students' evaluation of the subject taught in the PBL format have been, by and large, fairly positive as shown in table 8.

Table 8. Students' evaluation of the subject teaching in the PBL format

Statement	**Score**	
	2007	**2008**
The lecturer has a good command of the subject	4.4	4.6
The subject objectives are clear.	3.5	4.0
Lecturer interacts well with the class	4.3	4.4
Lecturer is accessible for individual consultations	3.6	3.9
Lecturer arouses curiosity in the subject	4.0	4.0
The subject widens the scope of engineering knowledge	4.5	4.4
The subject is satisfying and would recommend to others.	3.8	4.0

Though that there has been no significant change in pass rates with the introduction of PBL pedagogy, the improved education outcomes in student development of research and self-learning skills would suggest that the adoption of PBL in the subject was a worthwhile educational strategy. However the pass rates are based on students who were notionally enrolled in the subject. Though no statistics were collected, anecdotal evidence suggests increase in attrition rates in PBL designated subjects. The reduction in proportion of students gaining honours were due to the quality of submitted project and laboratory reports. Students had, by and large, put little thought and time into their projects. This is not surprising given the large proportion of students who were either doing subjects across years or had outside work commitments (see table 9). Timetable clashes and workplace commitments made it difficult for many team members to organize common free time for team meetings.

Table 9. 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	48

There is 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

The teaching of fundamental science such, as chemical sciences, 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 relationship between fundamental science and 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, introducing fundamental sciences in a non-linear way, discussed in this paper, relies on students' maturity and is most effective when introduced in the second year of the course.

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. The inductive approach demands intensive efforts of both students and school staff. It seems that while PBL drives student-focused learning process, it relies on collaborative student participation. Such learning synergies occur when students interact with each other when faced with common projects and problems. Such synergies improve with increased student peer contact. It is most effective when students are full-time on campus.

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 the 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.

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RESPONSE TO REVIEWER'S COMMENTS

Reviewer Comments	Action Taken
Lack of structure and organization	Connections between various sections were established. Greater signposting of sections were included.
Interpretation of data was incoherent	The interpretation of data is more emphatic to strengthen the argument that 1. Fundamental science can be introduced successfully on the need to know basis without compromising educational outcomes; and 2. Introduction of PBL, though educationally neutral needs to be considered very carefully.
Overuse of mixed tenses	Action taken
Word missing on page 2	Action taken
Space between 2005and, page 7	Action taken.