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Enriching teaching through research

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Abstract: *The School of Engineering at the University of Tasmania, Australia enjoys longstanding collaborative research and training partnerships with a number of businesses and industries in Tasmania. The partnerships are designed to foster both scholarly and scientific cooperation at the undergraduate and postgraduate levels. The program has been used by the School as a pilot for research, training students and also to assist the School to address holistic course curriculum by transfer of state of the art industry best practice. This paper uses the co-operative research between the School and the Comalco Aluminium smelter at Bells Bay as an illustration of how to use such partnerships to enrich teaching and learning within a School.*

Keywords: *Research-teaching nexus; industry links.*

Introduction

> A holistic baccalaureate engineering education should emphasis the inherent connectivity and the complementary sets of elements. Tomorrow's engineers will need both abstract and experimental learning, the ability to understand certainty and to handle ambiguity, to formulate and solve problems, to work independently and in teams, and to meld engineering science with engineering practice (Bordogna, 1997).

As in most professional degree programs, engineering must address the professional development of its undergraduates, instilling within the students an understanding and appreciation of the profession into which they will graduate. The features of the Engineers Australia (EA) accreditation process are generally well known in Australia and details are readily available (EA, 1997). To familiarise the reader, EA states its primary objectives in the accreditation process to be *"the maintenance of internationally benchmarked standards, the promotion and dissemination of best practice and the stimulation of innovation and diversity in engineering education*". EA then identifies the parameters listed below as the foundation on which engineering program accreditation is founded.

- The teaching and learning environment
- The nature of the academic program
- The exposure of students to professional engineering practice
- Quality systems and processes in place

An innovative teaching and learning program that integrated professional practice within its curriculum would appear to meet many of the graduate attributes.

One feature of the accreditation process that has proven to be of great interest in the last few years is the need for the school being reviewed to demonstrate how it imbues its graduates with what has been termed desirable "graduate attributes". This need to measure and validate the attainment of attributes has stemmed from two recommendations from the Review of Engineering Education (EA, 1997) that indicated that engineering courses must have clearly stated goals and outcomes and must equip graduates for lifelong learning. Under Recommendation 3.2 of the Review, the now widely known attributes are listed (see below). It is also stated that *"engineering schools demonstrate that their graduates have the following attributes to a substantial degree".* Recommendation 3.3 sums up the present accreditation process, stating that *"that the accreditation of Bachelor of Engineering courses is based on demonstrated development of graduates with these attributes".* Thus engineering schools have trended towards a more holistic approach to teaching and learning, as their ongoing accreditation depends on meeting the EA (holistic) criteria. The reader should immediately see that the EA graduate attributes listed below should entail a holistic approach to teaching and learning.

a) Ability to apply knowledge of basic science and engineering fundamentals.
b) Ability to communicate effectively, not only with engineers but also with the community at large.
c) In depth technical competence in at least one engineering discipline.
d) Ability to understand problem identification, formulation and solution.
e) Ability to utilise a systems approach to design and operational performance.
f) Ability to function effectively as an individual and in multi-disciplinary and multi-cultural teams, with the capacity to be a leader or manager as well as an effective team member.
g) Understanding the social, cultural, global and environmental responsibilities of the professional engineer, and the need for sustainable development.
h) Understanding the principles of sustainable design and development.
i) Understanding of the professional and ethical responsibilities and a commitment to them.
j) Understanding of the need to undertake life long learning, and a capacity to do so.

The extensive components of a holistic engineering education have been listed by Bordogna (2003) and are reproduced below.

Vertical in-depth thinking	Engineering science	*Research*
Abstract learning	Lateral (functional) thinking	*Solve problems*
Reductionism-fractionisation	Experiential learning	*Design*
Develop Order	Integration of parts	*Process*
Understand certainty	Correlate chaos	*Manufacture*
Analysis	Handle ambiguity	*Formulate problems*
Develop ideas	Synthesis	*Implement ideas*
Independence	Societal context	*Teamwork*
Technology-scientific base	Functional core	

Although the word holistic does not appear anywhere in the EA accreditation guidelines, such an approach is inherent in the process and the Canadian Academy of Engineering (CAE) includes under Recommendation 4 of their report on Engineering Education in Canadian

Universities (CAE 1997) that: *"Engineering faculties should ensure that undergraduate engineering programs are broadly based and holistic in scope .."*

The CAE statement is very similar to those provided by engineering accreditation bodies such as Engineers Australia (EA) and the Accreditation Board for Engineering and Technology, Inc. in the USA (ABET, 2004). The components listed in the last column (Bordogna's list) in italics are those that lend themselves to development via industry based case studies as do the EA graduate attributes described under points d,e,f and j .

Accepting that the professional body does lean towards a holistic approach to engineering education, it then devolves to the teaching institution(s) to be able to demonstrate how their engineering programs imbue students with those desired attributes. This is a complex process but engineering schools with strong links to industry are able to use those links to assist the development of professional skills in their teaching (and research programs) via incorporation of case studies and state of the art industry practice. Thus research enriches the teaching program.

The School recognised that case studies involving the development of a new process could be used to illustrate to undergraduate students how a problem can be identified, a solution formulated via teamwork and the outcomes implemented to provide a responsible and sustainable new process. The fact that students can relate to a local industry partner, who they are familiar with, makes both the problem and the solution relevant to their learning experience.

The linking of graduate attributes with learning outcomes allows the school to illustrate how it develops professional attributes within its program. This linking process can be extended across the unit to map how a range of graduate attributes is addressed. Thus a matrix for each unit and the full program can be produced. A bonus is that the linking of assessment methods with learning outcomes throughout the program allows teaching institutions to market the strengths of their graduates. For example the use of case studies during undergraduate learning could mean that the institution could claim something like "our graduates have an understanding of the real needs of industry".

To obtain good case studies for inclusion in teaching a school needs industry partners. The School has many links with a number of industries and some are indicated in Table 1. This paper uses the teaching and research links between the mechanical engineering discipline and Comalco (shown in bold in Table 1) to illustrate the process of transferring research into teaching.

The teaching-research nexus

Much has been written about the nexus between teaching and research in universities (Brew, 2003) and how both contribute towards scholarship. Simplistically, academics generate or create knowledge and then transfer it to students via the teaching process. Although Boyer (1990) frames scholarship into the four areas of scholarship of discovery, scholarship of integration, scholarship of application and scholarship of teaching in this paper the authors restrict themselves to teaching and research. The more simple view taken in engineering is that scholarship encompasses academic excellence in both teaching and research. Discovery and application is bundled into research, while integration and teaching is bundled into teaching.

Pragmatically, academics in Australia who are entrants in the promotion/tenure stakes find it wise to have a portfolio that can show outstanding performance in both teaching and research. It quickly becomes very apparent to young academics that no resource should be wasted and that any relevant research outcome should be used as a teaching resource where and when possible and also that undergraduates can contribute to research. This fits well with Brew's comments (2003) that, *"the implications of bringing research and teaching together within academic communities of practice mean that students would be treated as the adult people that they are, with something valuable to contribute as well as to learn".*

Table 1: Links between industry and the School

Industry Partner	Activity	Discipline Link	Outcomes
Cadbury	Chocolate and confectionary	Mechatronics Computer Systems	a,b,c c
Aurora	Electricity sales	Power	a,b,c
Hydro	Electricity generation infrastructure	Mechanical Power Computer Systems	a,b,c,d,e,f a,b,d,e a
Norske Skog	Paper mill	Environmental (Civil)	b
Councils Public Utilities	Public works	Environmental (Civil) Electronic	a,b,f c,d
Civil Construction Corporation	Civil works	Civil Electrical	a,b,d,f a,b,c
State Government	Civil works	Environmental (Civil)	a,c
Comalco	Aluminium production	Mechanical Mechatronics Electrical	a,b,c,d,e a,b,c a,e
INCAT	Ship builders	Mechanical	c,d,e,f
SKM	Civil consultants	Civil	c,d,f
Furntech	Furniture research	Mechanical	b,f
Zentel	Medical software development	Mechatronics	f
Pasminco Co	Smelting	Mechanical	c,f
Rolls Royce	Turbines	Mechanical	a,b,c,d,f

a. General coursework content, b. Case studies within coursework
c. Honours projects (unfunded), d. Honours projects (funded)
e. Research Higher Degree projects (unfunded)
f. Research funds (including scholarships and consultancies)

A schematic representation of how research and teaching could be linked is shown in Figure 1. Project and honours students have special significance, as the groups often form the crucial link between the undergraduate and postgraduate student bodies. The authors feel that postgraduate students are the essential element of the nexus. Clustering and sequencing projects around a common research theme accelerates research development, especially in the absence of postgraduate students. Sequencing projects is to run a series of very similar projects over a number of years, each year gradually building on the foundation of the previous. Sequencing typically only lasts for around three years after which the work tends to become outdated and stale.

Clustering projects involves more than one group of students working on different aspects of the same project. This can create a synergy among groups, as all groups can access the combined body of work, while still restricting their research and reports to their own selective subset of the total project (Bullen et al., 2001). This approach is useful with industry partners who can provide an ongoing source of undergraduate projects that may lead into larger scale research. This process was successful with the industry partner referenced in this paper (Comalco) with several honours and research projects being completed within the School with the second author during the life of the partnership.

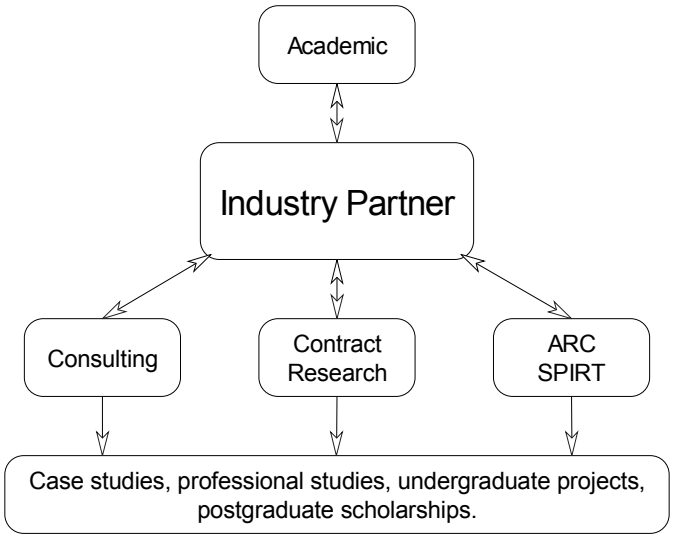

Figure 1: A research-industry-teaching nexus

The industry partner

The collaborating industry partner, Comalco is an aluminium producer with three major smelters based in Queensland, Tasmania and Invercargill in New Zealand. The strength of aluminium can be substantially increased through alloying and controlled heat treatment also leads to aluminium being an extremely competitive metal for applications where steel was predominantly used. Furthermore, aluminium is easily machined and fabricated compared to other materials due to its high malleability and can be cast by all foundry processes. Aluminium has excellent electrical and thermal conductivities, is highly reflective to radiant energy-visible light, radiant heat and electromagnetic waves and is non-ferromagnetic. This range of properties makes aluminium particularly useful to mechanical engineers and its manufacture is very applicable as a case study for engineers in the mechanical and manufacturing disciplines.

The partnership with Comalco was initially developed under an applied research link involving maximising the life of their aluminium production cells. The overarching research project was identified as the development of new process and performance models based on neural networks and artificial intelligence. These would replace old empirical models that only had capacity to deal with a limited number of input parameters. The intent was that the research project and its outcomes could be re-packaged as case studies in the mechanical engineering discipline teaching program. The overarching research project was then split into the following sub-programs.

- Monitoring and Predicting Temperature.
- Cell degradation due to anode effects.
- Monitoring of cell conditions - cathode, potholes, tapholes.

A short description of the manufacturing process is provided for the reader who may not be familiar with the Hall-Haroult process for aluminium manufacture. The 3 sub-programs are also described in more detail.

Aluminium manufacturing and issues

The Hall-Heroult process is the only known technique for aluminium production and although continuous attempts have been made to improve the process to obtain higher production it has remained virtually unchanged in principal. The empirical models used for performance estimation and process modelling were largely inadequate due to the limited number of process parameters taken into consideration. It was apparent to School researchers that the rapidly developing field of neural networks and artificial intelligence held great potential for application to the process and could provide the School with both research projects and case studies for teaching.

Monitoring and predicting temperature

The process involves dissolving pure alumina in a bath of molten cryolite (Haupin, 1995) in large electrolytic furnaces, called reduction cells. A carbon anode suspended in the bath enables a current to be passed through the bath mixture causing metallic aluminium to be deposited on the carbon cathode at the bottom of the cell (Figure 2). Since stable cell operation is critical the amount of metal removed must balance production continuously (Grjotheim & Kvande, 1986). The bath temperature is a significant indicator of how stable and efficiently a reduction cell is operating but the corrosive nature and extreme temperature of the electrolyte causes problems with temperature measurements. Continuous measurements have not been technically or economically viable as remote sensors, such as optical pyrometers and measurements of the intensity of infrared radiation, are not practical or accurate enough (Grotheim & Welch, 1988).

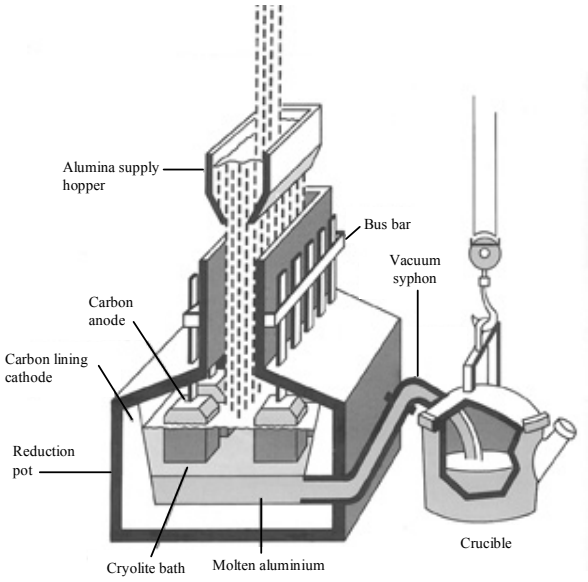

Figure 2: Aluminium reduction cell (Tomago Aluminium, 1999)

The most commonly used technique is Type K mineral insulated metal sheathed thermocouples, however these deteriorate rapidly at great expense (Madsern, 1992). School researchers recognised that a temperature prediction technique based on neural networks would largely eliminate the problems associated with manual temperature measurements. This became one of the research projects and eventually a case study in KNE453 Advanced Manufacturing.

Cell degradation due to anode effects

A significant and potentially catastrophic process parameter in aluminium smelting is the *anode effect*. The anode effect occurs when the electrolyte becomes depleted in alumina. The first sign of an anode effect is a gradual and potential rise in voltage. A very high voltage drop at the anode follows, leading to a rise in total cell voltage from 4-5 V to 15-45 V (Haupin, 1996). This results in increased energy consumption, reduced metal production, overheating of the cell and reduced cell life. This became the second research project and was used as a case study in KNE353 Manufacturing, Maintenance and Quality.

Monitoring cell condition - cathode delamination, potholes and tapholes

Cathodes should last as long as it takes the endemic erosive and corrosive forces to wear the carbon cathode lining evenly down to the level of the current collector bars. However, in practice this does not occur and reduction cells fail in a significantly shorter time and a main factor influencing the profitability of an aluminium electrolysis cell, is the life of the cell lining. When a cell failure occurs it is usually attributed to failure of the carbon cathode and is typically attributed to cathode delamination, longitudinal cracking or pothole/taphole formation. The use of process modelling to minimise these failures became the third project. It was incorporated into the undergraduate program via KNE453 Advanced Manufacturing and KNE353 Manufacturing, Maintenance and Quality.

Outcomes to enrich teaching and learning

Although this paper concentrates on the benefits obtained in the undergraduate teaching programs significant research outcomes were obtained including dissemination of the research outcomes via publications in international conferences and journals over the 3 years of active liaison (Frost & Karri, 2000, 1999). The collaboration also developed a multi-disciplinary engineering training approach for postgraduate students using the processes involved in smelter technology as examples and also provided training of research students for the industry via industry based projects. There have been 3 research higher degree completions as a result of this collaboration (Frost, 1997, 2002; Farnsworth, 1997). One major outcome of the teaching and learning activity is the initiation of the honours programs with Comalco. In the last 5 years there have been projects related to product flow, cathode designs and cell maintenance (MacKay, 2003; Walsh, 1997; Spiranovic, 2000).

Integration into the teaching program

As in most Australian universities, a university wide approach at the University of Tasmania to map graduate attributes, while under development, is yet to be realised. The School, faced with an imminent accreditation visit, opted to comprehensively map its six engineering specialisation programs. This required developing new unit outlines for all 60 plus units taught by the School and linking assessment-outcomes-graduate attributes in matrices especially developed by the School for the EA accreditation visit. Table 2 provides an example of a unit matrix, for KNE453 Advanced Manufacturing, a unit taught in the final year of the mechanical engineering specialisation. In order to create this matrix the unit

designer estimates to what extent each graduate attribute is addressed in the unit. Such an approach may be seen as being rather mechanical in nature and perhaps a somewhat imprecise measure of delivery of graduate attributes within a single unit. However, when aggregated over all 32 units in a School specialisation, a reasonable estimate of delivery of graduate attributes throughout the program is obtained. An example of such information is shown in Table 3, which provides the summary of graduate attributes addressed.

To support successful student development of the desired attributes, the School has adopted a strategy of making it explicit to students just which graduate attributes are addressed in each unit, and how they are addressed. Accordingly, every unit outline now makes explicit the relevant graduate attributes and the unit's intended learning outcomes. In particular, there is an explanation of how each assessment item in the unit will assist the student to develop specific graduate attributes. In this way, the likelihood of students completing a course without being aware of their development of the desired graduate attributes is substantially diminished. Students are able to achieve relevant learning outcomes in each unit and to track their development of graduate attributes (Bullen et al., 2004).

The mapping process for each unit, taken in the context of making graduate attributes and learning outcomes explicit, provides a good indicator of graduate attribute outcomes for all the School's engineering disciplines. It is important to note here that the School uses the overall graduate attribute data to make decisions if a program requires fine-tuning via adjustment of a few units, a minor revision within a Year or even a major course review.

Table 2: Graduate attribute development in KNE453

KNE453 **Advanced Manufacturing**	a) Ability to apply knowledge of basic science and engineering fundamentals	d) Ability to undertake problem identification, formulation and solution	f) Ability to function effectively as an individual and in multi-disciplinary and multi-cultural teams, with the capacity to be a leader or manager as well as an effective team member	h) Understanding of the principles of sustainable design and development	j) Expectation of the need to undertake lifelong learning, and the capacity to do so
Estimated % Split	**30**	**20**	**20**	**20**	**10**
Ability to appraise performance predictive models for advanced conventional and unconventional machining operations.	Assignment	Assignment	Examination	case studies	Assignment
Design and evaluate operations research tools for industry cases for automation problems.	Examination	Examination	Laboratory	Examination	Assignment
Ability to plan, design and construct economics of manufacture models. Develop break-even analysis for machine tool selection, process comparison and appraisal.	Examination	Assignment	Laboratory	Case studies	Case studies
Product development and design appraisal for Formula SAE race car components.	Assignment	Assignment	Case studies	Case studies	Assignment
To gain a broader knowledge of modern manufacturing techniques such as product development, operations research and operations planning.	Examination	Examination	Laboratory	Examination	Assignment
Presentation:	Lectures, tutorials, laboratories				
Assessment:	Assignment, case studies, examination				

Returning to case studies, the need to expose students to professional engineering practice, as part of the process of developing graduate attributes requires embedding current practical examples and industry case studies into the teaching program. Case studies are an ideal means of achieving this aim and the application of neural networks for dynamics processes at Comalco have been incorporated into manufacturing units to assist the development of students in the mechanical engineering discipline. The EA graduate skills matrix for the unit KNE453 is shown in Table 2 and is apparent that the incorporation of case studies such as these assist in the development of graduate attributes.

Experience has shown that some graduate attributes (for example g,h,i) are more difficult to incorporate into teaching programs than others (for example a,c,e). In 2003 the School undertook a mapping exercise of all its teaching (> 60 units) regarding demonstration of how graduate attributes were imbued into students during their leaning experience. This exercise was partly in response to an Engineers Australia accreditation visit that took place in October 2003. The summary of the mapping exercise is provided in Table 3. The information in Table 2 for KNE453 would form a subset of the mechanical engineering discipline shown in Table3 (1 of 32 units).

The information in Table 3 provides some details of the mapping exercise carried out for all of the School's engineering disciplines. Case studies appear to be a very good resource to help develop some of the more "difficult" graduate attributes such as the attribute *Understanding the principles of sustainable design and development* (Table 2).

Table 3: Mapping the degree Programs for graduate attributes

EA Generic Graduate Attributes and Summary									
Discipline	a	b	c	d	e	f	g	h	i
Civil	30%	7%	17%	16%	4%	10%	3%	4%	2%
Comp. Systems	34%	6%	12%	19%	9%	12%	3%	3%	2%
Elec. & Comms.	33%	5%	12%	19%	9%	13%	3%	2%	2%
Elec. Power	32%	5%	13%	18%	9%	14%	3%	2%	2%
Mechanical	32%	5%	13%	18%	7%	10%	3%	5%	2%
Mechatronic	31%	6%	13%	19%	9%	12%	2%	3%	2%
Average	**32%**	**6%**	**13%**	**18%**	**8%**	**12%**	**3%**	**3%**	**2%**

Conclusions

This paper highlighted that industry links are an excellent vehicle to develop the teaching and research portfolio of an engineering school to strengthen both teaching and learning activities. The research–teaching nexus has enabled the School to develop case studies based on quantitative predictive models for aluminium smelter operation related to both process and maintenance issues.

A brief description of the smelting process was provided to highlight the inherent problems that needed attention to alleviate expensive maintenance costs. The collaboration has assisted in providing reliable quantitative predictive models for cell performance and failure criteria that greatly benefited the process. The multi-disciplinary nature of the collaboration has assisted in training high quality research higher degree students that resulted in sharing the results with wider community via international refereed publications. The research led to on-

going design and honours projects and has assisted the teaching and learning activity at the final year engineering level.

The case based learning has very significant benefits to third year and final year engineering students by helping to develop a holistic engineering education by melding engineering theory to industrial practice. The research-teaching nexus has helped the School graduate new engineers with an appreciation of important graduate attributes such as life long learning.

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