Demonstrating leadership and expertise in the development of design tools and curricula that facilitate the successful embedding of sustainability into undergraduate engineering programs.

OVERVIEW: SUMMARY OF CONTRIBUTION AND CONTEXT

Sustainability is widely acknowledged to be essential to creating a more equitable future and is a key feature of James Cook University's (JCU's) Strategic Intent. Engineering educators and leaders have begun to recognise that engineering graduates should be aware of sustainability and be able to incorporate sustainability into their engineering designs. Professional accreditation bodies such as the *Engineers Australia* (EA) expect that universities will demonstrate sustainability-aligned graduate competencies from 2014. Although the attainment of sustainability attributes is widely encouraged, there has actually been only minor progress made to modernise engineering training to embed sustainability as *context* within engineering education (Desha and Hargroves, 2013). Embedding sustainability is a challenging task for engineering educators; one that requires merging the narratives of course quality and accreditation with the imperative to think and act sustainably.

As a chemical engineer with a strong personal commitment to sustainability, I responded to this imperative and in 2008 embarked on what would become a process of leading whole-scale curriculum reform to embed sustainability throughout the JCU undergraduate Engineering program. The reform process has seen me contribute professional expertise in sustainability curriculum across four undergraduate engineering degree programs (chemical, mechanical, electrical and civil engineering). I have provided leadership in the sourcing of funds, developed innovative curricula, and provided professional development opportunities to facilitate and encourage other staff to engage in whole-scale curriculum reform. Along with creation of my own coherent and imaginative curriculum, over the past six years I have supported more than 12 academic staff members and postgraduate students to design and implement new curriculum in 1st, 2nd, 3rd and 4th year engineering subjects, enriching the overall student experience.

Since sector-wide progress in embedding sustainability had been limited, it was necessary to devise and lead collaborative research-led approaches in order to map and design new curriculum. Clear overall course learning objectives for sustainability were collaboratively developed as well as new sequenced curricula including clear expectations for student learning. I developed constructive relationships with industry, academics from other institutions, and the broader university community through forums, seminars, online learning communities, publications and mentoring. These cumulative efforts have been highly commended at the institutional and national level and have positioned James Cook University at the forefront of progress in embedding sustainability throughout engineering curricula. Such is the depth of embedding that in 2014 sustainability will be offered to all JCU engineering students as a new engineering "minor".

CRITERION 2: DEVELOPMENT OF CURRICULA, RESOURCES AND SERVICES THAT REFLECT A COMMAND OF THE FIELD

Capacity building

The whole-scale curriculum reform began in 2008 when I updated my 2nd year chemical engineering subject (Process Analysis ~ 30 students) to include sustainability content (the first within the engineering program), detailing elements such as life cycle analysis and environmental ethics. This trial, reinforced by reflective practice and replicated across a range of my subjects, has culminated in the design of new and authentic learning experiences: group based reflective work activities; ethical role plays; and local industry site visits. After six years of development work JCU Engineering has made very significant progress in embedding sustainability throughout the engineering degree program. At least 15 different subject offerings across the engineering program have been modified and updated and new curriculum embedded. Subject enhancements have occurred in large (>160 students) common first year engineering subjects (Process Engineering and Engineering 1) and all the way through to full year capstone subjects for final year engineering students (Chemical Engineering Design and Engineering Thesis). As noted in both a recent external review of the engineering school's progress in embedding sustainability and in a 2012 Engineers Australia JCU Accreditation report:

> "*From a survey of the literature, the progress made by these authors would appear to be well advanced compared to many engineering disciplines in other universities* " (Prof Skamp, 2012).
>
> "*Recent focus on sustainability is commendable*" (Engineers Australia, 2012).

Although the *broad* requirements for developing student's understanding and awareness of sustainability are well-described in the literature (Desha and Hargroves, 2013), there is less specific information to guide academics in developing new engineering curriculum. In order to develop the required up-to-date knowledge and expertise I have undertaken visits to other higher education institutions and external sustainability experts (Uni SA, Monash, Uni QLD, Uni WA, JCU-Cairns, Griffith Uni, MIT). I attended a three day course (MIT-Boston, 2012) on advanced sustainability and life cycle assessment delivered by leaders in the field. Following consultation with individual lecturers and modification to suit local circumstances, imaginative resources from these visits are now being utilised across the engineering program in many subjects. To extend capacity I initiated and funded a professional development scheme specifically linked to sustainability curriculum development. This scheme saw recipients in chemical, electrical, civil and mechanical engineering improve their knowledge domain in the area and update their courses and curricula. The learning experiences and other curriculum resources I have developed over the course of the reform process are hosted on a collaborative online repository which serves as a resource for ideas and techniques. The academic staff uptake of these resources is clear from the following examples.

Dr Ling was helped to embed sustainability into her 2nd year and 4th year mechanical engineering subjects (Materials Science & Engineering and Asset Management, Maintenance & Reliability):

> "*Madoc's leadership and example has inspired me to embed sustainability into my courses*".

Dr Tuladhar (Associate Dean — Engineering), embedded sustainability into his 3rd year civil engineering subject (Concrete Engineering):

> "*Through the professional development opportunities that Dr Sheehan made available and through the inspiring discussions with him, I personally have been able to develop and deliver lecture materials on sustainability*".

In 2011 I led a multidisciplinary team involving 5 students and 4 academics in the full-year capstone subject (Engineering Thesis Project). The team tackled quantification of sustainability in tropical housing and included a sustainability professional development course that attracted more than 60 attendees across the University. This project was the first of its kind in the Engineering and Physical Sciences School and was commended by *Engineers Australia* in their 2012 Accreditation report on JCU Engineering:

> "*The panel wishes to specifically congratulate the Faculty on the following aspects of the professional engineering programs: The developing trend to offer multi-disciplinary capstone thesis projects, such as sustainable housing for tropical environments".*

I have developed and helped facilitate the development of curriculum that embeds authentic learning experiences within the degree program, particularly by engaging with local industry. Guest lectures on sustainability topics are given by experts and local industry representatives in a range of subjects, and engineering students now visit exemplar sites of best practice in sustainability. In the full-year capstone chemical engineering subject I coordinate (Chemical Engineering Design), students engage with highly topical and regionally important sustainability projects, funded by local industries. Engineering students now report on how sustainability relates to their compulsory industry vacation work practice and social sustainability is addressed in a Work Integrated Learning (WIL) project in the 3rd year subject: Engineering Project Management.

<u>Curriculum design</u>

A systematic, research-led process began via a funded collaboration (JCU curriculum refresh grant) between Dr Schneider, myself and *Griffith University's Sustainability Think Tank* (TNEP). Activities included collaborative staff and industry forums and whole-staff curriculum design workshops. The workshops were used to develop five common attributes that defined a JCU student's "awareness of sustainability". The attributes formed a solid framework to use to begin progress toward whole-scale program mapping and curricula design. The scaffolded nature of the attributes, such as a student needing Attribute 1 (knowledge) before addressing Attribute 2 (quantify), made them useful for the development work that followed. In an innovative approach described in Sheehan et al (2012a), a "first pass" mapping of subjects against attributes was undertaken to brainstorm possible curricula (using broad terms such as water and energy).

The mapping was used to identify the subject sequence in which attributes would be broadly (i.e. across the entire program) addressed and scaffolded. Using support from the expertise and capacity building initiatives, a period of initial curriculum development was undertaken in which many subjects introduced new curriculum aligned with sustainability.

A finer-scale design tool was developed (described in Sheehan et al, 2012b) in order to review the previously developed curricula and also to facilitate extension and design of new curricula. For example, well-developed sustainability curricula in subjects from the early years of the degree (such as the 2nd year subject Process Analysis) were described using specific subject learning outcomes. These specific subject learning outcomes were mapped to a modified form of Bloom's taxonomy (Nightingale et al, 2007) which described the depth and type of student learning as well as identifying the supporting assessment. New curriculum in a latter subject (with broad scaffolded attributes identified using the first pass map) was designed by extending both the depth and type of learning of the prior subjects outcomes, with minor and predictable changes in terminology and application.

INFLUENCE ON STUDENT LEARNING

The extent to which sustainability has been embedded has significantly enhanced the student experience. Academic staff have observed how the curriculum reform has enhanced student learning and experience. For example civil engineering lecturer Dr Tuladhar (Assoc. Dean Engineering) wrote of his 3rd year students:

> *"Since Dr Sheehan started incorporating sustainability in the first and second year engineering subjects; I personally have witnessed a remarkable improvement in students understanding and perspective on sustainability".*

Evidence indicates that the student experience is enriched by the introduction of this content.

> *"There was an industry visit for 1st year engineering students which pointed out the need for sustainable engineering...I found this to be beneficial and helpful"* (Anonymous, Faculty sustainability survey, 2012).

By way of specific example, in a large first year common engineering subject I teach, (Process Engineering ~ 160 students) specific focus on sustainability was trialled in 2011 and then enhanced in 2012 using the described mapping and design tools. A selection of official student survey responses in this subject over the last five years are shown below. These responses indicate consistent high scores, continuous improvement and the appreciation by students of imaginative and authentic learning experiences in this subject. A spontaneous cheering and ovation by first year students in the final lecture of this subject (2012) was taken as another encouraging sign of the students' appreciation. Typical student comments from the 2011 and 2012 surveys include:

> "*Overall, great subject and very exciting*" (Student evaluation survey, 2012).
>
> *"The best thing in this subject was that everything was clearly spelled out and we always knew what was expected from us"* (Student evaluation survey, 2012).
>
> *"I appreciated during the teaching of the theory aspects of the subject that real world examples were given. This enabled me to get a complete understanding of the material and I believe this enabled me to enjoy the subject a lot more"* (Student evaluation survey, 2012).

Table 1: Student Evaluation 2008-2012

Student evaluation question[1]	2008[2]	2010	2011	2012	JCU avg.[3]
As a result of this subject, I feel more confident about tackling unfamiliar problems	3.6	3.9	4.0	4.1	3.8
The staff made it clear right from the start what they expected from students	3.9	4.1	4.6	4.4	3.9
The teaching staff worked hard to make this subject interesting	3.8	4	4.8	4.7	4.0
Survey average across all questions	3.6	3.8	4.3	4.3	3.9

[1] Categories are out of 5 and include well-below average (1), below average(2), average (3), above average (4) and outstanding (5). [2] I was on study leave during the 2009 delivery period. [3] 2012 University (JCU) averages

Furthermore, in 2013 the proportion of 1st year transitions to 2nd year chemical engineering (Process Engineering is a feeder subject into the chemical engineering program) jumped by 80% to the highest student cohort ever. As noted in a 2011 Faculty student survey interrogating the influence of university experiences on thinking and behaving sustainably:

> *"As a chemical engineering student, all of my classes have a strong focus on sustainability as part of our development into a professional"* (Faculty sustainability survey, 2011).

EVIDENCE OF RECOGNITION

The significant progress made to embed sustainability throughout the engineering degree program has been recognised for both the extent and quality of this effort. An external JCU Teaching and Learning Fellowship review by Prof Skamp (2012) recognised that JCU's embedding of sustainability curricula has advanced beyond other Australian Engineering degree programs. In their 2012 course accreditation review, Engineers Australia commended both the overall focus on sustainability and also the multidisciplinary sustainability curricula. Furthermore, the embedding of sustainability at JCU has been documented as an important case study in the recent book: Engineering Education & Sustainable Development *'A Guide for Rapid Curriculum Renewal'* (Desha & Hargroves, 2013).

The curriculum reform process I have undertaken has been disseminated widely to support and engage the profession in this important transition. I have presented seminars at institution-wide JCU teaching and learning events in 2011 and 2012 and over the past several years have facilitated many internal discipline based workshops. In 2011 I delivered an invited seminar on attribute development and mapping at the University of Queensland, and also presented at the *Seventh International Conference on Environmental, Cultural, Economic and Social Sustainability*. I also ran a workshop session on embedding sustainability into undergraduate design courses at the Institution of Chemical Engineers (IChemE) Australasian Design Teachers Meeting (Sydney). In 2012, the JCU case study was published internationally (Sheehan et al, 2012a) and the curriculum design tools were also peer reviewed and presented nationally (Sheehan et al, 2012b). In 2012 I received the *highly commended* award in the JCU TropEco Sustainability Awards (Curriculum Category) and I have recently been awarded a *2013 JCU Citation for Outstanding Contribution to Student Learning* for embedding sustainability into undergraduate engineering programs.

In conclusion, the response to this work from students, fellow staff and peers has been exceptionally positive. The impact of this work has been demonstrated by positive student survey responses, institutional awards, expanding enrolment numbers and new industry collaborations. All are testament to the quality of this work and my command of the field. Peer recognition through high staff involvement, book, journal and conference publications, invited seminars and commendations from the profession have placed this work as an example of national significance.

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