Designing Excellence: Empowering mechanical engineers through an intentional industry-driven curriculum that assures professional readiness in highly employable graduates

OVERVIEW: SUMMARY OF CONTRIBUTION AND CONTEXT

Our company has been fortunate to employ graduates from JCU that Dr Holmes has lectured in preparation for their future careers as professional engineers. Dr Holmes provides exceptional engineering skills to JCU's young cohorts of students embarking on a career in industry. His efforts to engage with our representative stakeholders makes him a stand-out lecturer who is very well respected amongst his peers, students and colleagues. (Industry Testimonial, Mr Timothy Reynolds, CEO of Rockfield Technologies Australia, 2013)

The capacity to design and to apply design thinking is the most important characteristic of an engineer. I first developed a passion for design during my mechanical engineering degree at James Cook University (JCU). However, it was when I took up a post-doctoral position at the Massachusetts Institute of Technology (MIT) that I observed a very different form of engineering education. Examples of active learning were everywhere and this was especially evident in the engineering first year where students spent as much time in the workshop building things as they did in the theory class room. Given the level of student engagement and the quality of MIT engineering graduates, the active learning approach was clearly effective. I recognised that engineering education, design education especially, is most effective when learning mirrors authentic professional experiences.

Upon my return to JCU in 2010, my goal was to use active and authentic learning to re-invigorate the mechanical engineering design syllabus. My **six-year endeavour** has seen me redesign the curricula of four mechanical engineering core subjects: *Machine Element Design* (2nd year), *Finite Element Analysis* and *Mechanical Design* (both 3rd year), and more recently, *Engineering 1*, a foundation to the design process for all engineering disciplines. To revitalize the design pathway and provide authenticity and flexibility, I have partnered with industry to develop an array of real-world projects and active and blended learning techniques. I have shaped a series of scaffolded and related learning experiences so that students' design competence and confidence is progressively and coherently developed across the subject suite. The enhanced design capabilities of students are exemplified in the high quality work produced in culminating subjects.

There are now very high levels of student satisfaction across the suite. **In *Engineering 1*, for example, the overall satisfaction mean score, at 2.72 out of 5 prior to the implementation of real world contexts and hands-on active learning approaches, jumped to 4.5 and 4.37 in the two subsequent years.** The feedback from industry regarding our graduates is consistently excellent. The Good Universities Guide (2014) rated JCU Engineering number 1 in Australia for job outcomes (93% employed after 4 months). I draw then upon wide recognition from students, colleagues and industry **to reflect a command of the field in the development of curricula that produce graduates who will excel as design engineers in practice.**

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

1. Promoting job readiness through industry partnerships and intentional whole-of-program design

The JCU engineering program has a uniquely broad curriculum focus to service the breadth of engineering roles in tropical and northern Australia and beyond. Graduates are equipped to work within the full spectrum of engineering roles from maintenance in a remote mine, to pure design or research in a metropolitan consultancy firm. In order to prepare graduates for such diverse contexts, I have developed strategic partnerships with industry stakeholders, purposefully collaborating with them in curriculum review and enhancement. One industry partner is the highly regarded company Rockfield Technologies Australia, which delivers engineering design and analysis solutions for industry problems that are, in many cases, too complex or bespoke in nature for other consultancy firms. Given their experience, specialty, and business connections, it has been an invaluable partnership to leverage. Their input into subject design ensures curriculum benchmarking with recognised best practice worldwide. For example, all teaching, learning and assessment components of *Finite Element Analysis* have been reviewed and endorsed by Rockfield engineers, guaranteeing authenticity and graduate employability skills. With this and other industry partnerships, I have been able to incorporate industry focussed content, projects, and a range of guest lectures in curricula across multiple year levels.

To further enhance job readiness and drive cohesion within the mechanical engineering program, I have designed and implemented a novel **curriculum mapping system**. The powerful software provides a user-friendly platform for Subject Coordinators to map subject outcomes and assessment to the professional accreditation standard for engineering (Engineers Australia Stage 1 Competency Standard). By using the mapping output to inform whole-of-program design, it has been possible to progressively build key professional competence across the mechanical engineering program and ensure that assessment tasks focus on authentic professional applications across diverse settings. My mapping system has subsequently been adopted across all engineering, science, and nursing programs at JCU, and other engineering programs around Australia on the recommendation of Dr Peter Hoffmann, then National Manager of the Engineers Australia Accreditation Board, who reviewed and endorsed the approach.

2. Developing engineering design skills through integrated active learning

Design skills are developed in the mechanical engineering design curriculum through use of extensive industry-based active and authentic learning tasks. The underlying principal of an active, 'student-centred' learning approach is that learning activities allow students to actively interact and engage with the subject matter in order to stimulate learning (de Graaff, 2004). Authors such as Prince (2004) and Freeman et al. (2014), have found a direct correlation between the introduction of active learning approaches and improved student outcomes in engineering. Their findings relate to higher pass rates and skill retention, but also note significant improvements in student engagement. The curricula I have developed for the subjects in the mechanical design stream involve a variety of specific active learning techniques, including:

a) **Practice problem tasks:** *Machine Element Design* uses extensive practice and extension problem tasks to engage students with the analysis theories taught by solving complex real-world design problems. Students find that frequently applying the theory to tangible design problems greatly enhances their learning: *"Comparison and questions to do with real scenarios makes learning interesting as we can see how different factors effect different situations"* (Student Evaluation, 2012); *"Many real world practical examples were used to explain some of the material which made learning a much better experience and equipped students with a deeper understanding on how things work"* (Student Evaluation, 2013); *"I loved the way this subject was taught, and how practical it was"* (Student Evaluation, 2015).

b) **Design analysis projects:** *Machine Element Design* and *Finite Element Analysis* each incorporate two real-world projects, wherein students apply analysis techniques to complex machine components. The projects are designed to consolidate and extend on the theory and initiate a substantial amount of independent student learning to achieve intended outcomes: *"The modelling software and projects were informative and very much enjoyable"* (Student Evaluation, 2013).

c) **Screencast led active skill development:** In *Finite Element Analysis* students learn the theory and practice of computer modelling by both coding their own software, and implementing commercial software packages to complete real-world design analysis. Students complete these tasks in computer workshop sessions where the instruction is carried out via screencast videos, which students follow while using the software. They then complete extension exercises to consolidate their conceptual understanding. A single lecture per week provides context and supplements theory as necessary. The blended approach to the subject is appreciated by the students: *"All of the components of the subject (lectures, labs and projects) worked well together to cement learned information, and to provide an overview of how computational modelling is used in the overall workflow"* (Student Evaluation, 2013); *"The recorded video screencasts/tutorials were extremely helpful and well organised by the lecturer"* (Student Evaluation, 2013). The focus I have placed on skill development and the practical use of computational software has been identified as a strong point by industry: *"Dr Holmes has introduced opportunities for students to work on 'live' design and analysis problems in this module drawn from a variety of industries, together with a specialist focus on elements of the Motorsports program. His subject content development has afforded reality to the learning environment, establishing skills in analysis, results interpretation, accuracy and responsibility for the physical design and analysis outcomes"* (Industry Testimonial, Mr Timothy Reynolds, then CEO of Rockfield Technologies Australia, 2013).

d) **Project Based Learning:** *Mechanical Design* represents a wholly project-based curriculum where students work in teams to design, analyse, and specify manufacture for a portion of a race car. The designs are then manufactured for inclusion in the JCU Motorsports car, which competes at Melbourne's international Formula Society for Automotive Engineering (Formula SAE) race event. By integrating part of the car's design into the *Mechanical Design* curriculum, students get exposure to real mechanical engineering design and gain key skills in the actual manufacture and testing of a design, which students really enjoy: *"The interesting real engineering problems provided an excellent opportunity to develop the necessary skills for an engineer"* (Student Evaluation, 2012); *"The subject as a whole is great because it allows you to solve, by design and bringing to fabrication, a real engineering problem"* (Student Evaluation, 2011).

The use of extensive active approaches to learning throughout the mechanical engineering design sequence has greatly enhanced the design abilities of the students. This is especially showcased in JCU's extracurricular Formula SAE race car design team which I coordinate. Formula SAE is an international engineering design competition and following JCU's first ever entry in 2014, the competition organisers wrote:

> *"…we implore you and your faculty to join us in the commendation of your students' efforts and achievements, and to continue your support of this project at James Cook University" (FSAE Design Feedback, Mr Luke Morrow, Design Event Captain, and Mr Adrian Feeney, SAE-A President, 2014)*.

In 2015, to better expose the students to manufacturing practices and enhance the long-term sustainability of the team, I invited Tec-NQ, a local trade training school, to partner with JCU and field a joint Formula SAE team to the 2015 competition. We are the only university in the country to have done this and the benefits that both the engineers and trades apprentices have attained from working together on the design project (exactly as is done in industry) have been significant. *"All students have benefitted from the process including involvement in the entire process, manufacturing individual parts, compliance, and the competition. Work completed by the students is valuable evidence for the completion of their trade qualifications"* (Mr John Edwards, Trades Facilitator Tec-NQ 2016). At the 2015 competition, out of 30 universities from around the world, the JCU/Tec-NQ car was placed 22nd for autocross (timed lap) and equal 15th for endurance (22km race), which were excellent results for a very young team and reflective of the design quality. The joint collaboration continues and the completed design for the 2016 car is expected to be highly competitive.

3. Transforming the first year curriculum to contextualise learning in disciplinary practice for the tropics

Engineering 1 was almost wholly based on traditional theory lectures and often identified as students' least favoured subject of the first year. As an introduction to design for all engineering disciplines, it became clear that a transformation was needed so as to inspire a love of design in the students and motivate them to want to be engineers. To achieve this, I designed a range of meaningful activities based on engineering 'grand challenges', which are often centred in the tropics and introduced from the very first lecture (National Academy of Engineering's Grand Challenges report, 2008). This approach sees students purposefully immersed in real-life problems. To maximise their engagement, I often use images and examples from my own long term engagement with the challenges of tropical regions. For instance, to develop understanding about ethical and sustainable practice in diverse community settings, students critically engage with case studies from my experience in the Solomon Islands. To build skills in design thinking (Dym et al., 2005), students complete three interrelated group projects wherein they design components of a water supply for a village in a developing county. Each component is then manufactured and students enthusiastically compete for the best performing design. Active engagement with each learning experience is key and staged feedback and reflection, particularly throughout the three design projects, helps nurture both understanding of the core engineering concepts, as well as development of generic skills such as written communication. Explicit development of students' communication skills is especially important given the range of university preparedness within the JCU cohort (ATAR scores ranging from 60 to 99 in 2014-2015, average 84, and 11% of students commencing with no ATAR score in that period). Through my active approach to the subject curriculum, students learn fundamental design skills that they will build on in later subjects and gain an authentic sense of purpose and orientation to the discipline.

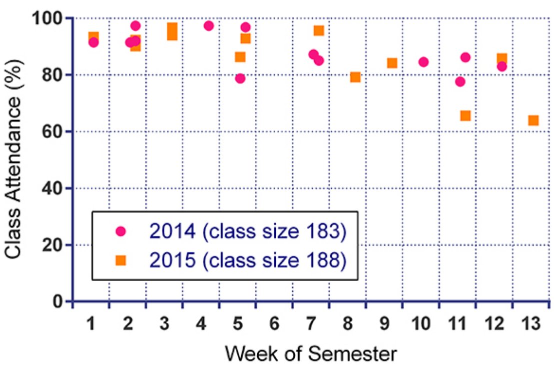

Figure 1: Engineering 1 class attendance. Numbers 2014-2015

My redesign of *Engineering 1* has positively impacted student engagement, as demonstrated by class attendance figures during semester (Fig. 1). As an extra-large first year subject (>150 students), and with all lectures being video recorded and released to YouTube reducing the need to attend classes in person, class attendance at or above 80% for the majority of the semester indicates the students' level of engagement; figures below 50% were common before the redevelopment.

Student feedback on the active approach used in *Engineering 1* has also been overwhelmingly positive with average student satisfaction scores of 4.5 and 4.4 out of 5 in 2014 and 2015 respectively (Figure 2), and comments such as: *"The hands on work and creating our own projects were some of the best parts about the whole first semester engineering. It encouraged creativity as well as freedom. Every lecture and test felt meaningful and overall everything was very engaging"* (Student Evaluation, 2014), and *"The practical components are a good way of applying the theory concepts, and the fact that practical performance is assessed inspired me to be creative* (Student Evaluation, 2015). By transforming *Engineering 1* into a platform for delivering practical design competence, the subject is now an effective foundation for the job-ready design skills developed in the subsequent mechanical engineering design stream subjects.

RECOGNITION AND SUSTAINED IMPACT ON STUDENT LEARNING

My work to introduce active and authentic learning strategies within the mechanical engineering design sequence has enhanced learning and the student experience and this is reflected in consistently high levels of student satisfaction (Table 1; Figure 2). In the last three years, 4 of the 6 subjects that I have taught have been ranked in the top 10% of all subjects at JCU in terms of students' overall satisfaction. My work in delivering a whole of curriculum reform to the mechanical engineering design stream has been recognised through a *JCU Citation for Outstanding Contribution to Student Learning* in 2013. I have subsequently presented at workshops on active learning for large class sizes, organised screencast workshops within science and engineering, and been one of four academics in the university to be featured in a Blended Learning Showcase video detailing my approach.

Table 1: Average subject feedback scores (out of 5) before and after the introduction of active learning (AL) (averaged over at least 2 years of data for each except where shown)

Subject	Before AL	After AL	Change
Engineering 1	2.72*	4.43	**+1.71**
Machine Element Design	3.55	4.53	**+0.98**
Finite Element Analysis	3.29	4.34	**+1.05**
Mechanical Design	3.58	4.41	**+0.83**

**Only 1 year of data available*

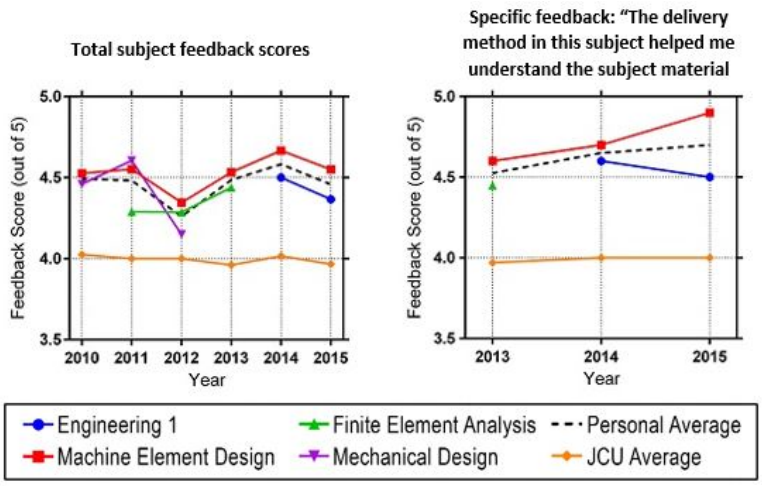

Figure 2: Total and specific subject feedback scores showing consistently high levels of student satisfaction. Response rate across all data points 28.66%; class sizes ranging from 22 to 188.

Conclusion: The necessity of assuring industry-relevant design competencies in mechanical engineering graduates drives my work in reimagining and enacting successful course curriculum design. I have implemented deliberate redesign actions across three strategic areas: partnerships with industry to create systematic alignment between real-life professional demands of engineers and institutional accreditation requirements; the integration of a cohesive and powerful suite of motivating active learning experiences across a whole course, and, finally, providing a curriculum that contextualises engineering grand challenges giving purpose to the application of design thinking. This has led to significant benefits for students, who are skilled in professional design, industry ready, and highly employable.

REFERENCES: **de Graaff, E.**, 2004. Active learning in engineering education. *In: New methods and curricula in engineerng education in a new Europe: proceedings of the International Symposium*, Valladolid 14-16 Oct 2004; **Prince, M.**, 2004. Does active learning work? A review of the research. *Journal of Engineering Education*, 93(3), 223-231; **Freeman, S., *et al.***, 2014. Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, 111(23), 8410-8415, **Dym, C., *et al.***, 2005. Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, 94(1), 103-120.