For using Problem Centred Learning (PCL) pedagogy to achieve high level engagement, enthusiasm and exceptional learning outcomes for diverse students in mathematics based engineering subjects

OVERVIEW: SUMMARY OF CONTRIBUTION AND CONTEXT

> "*Education in Science, Technology, Engineering and Mathematics (STEM) must provide Australia with both expert practitioners and a knowledgeable and receptive community… But the value of the investment in STEM will be diminished if practitioners operate without due regard for society and its wants, needs, aspirations and concerns"* (Office of the Chief Scientist, 2013, p3).

Australian higher education practitioners in engineering have been challenged with the diverse level of skills and knowledge in mathematics mastered by students – the foundation for effective learning in engineering. This is particularly challenging for the Bachelor of Engineering programs at James Cook University (JCU) as our students have diverse academic, cultural, geographical and socio-economic backgrounds, and typically have very different levels of mathematics skills. Helping students develop and sustain high level of interest in the mathematics based subjects is the key to achieving successful learning outcomes and equipping future engineers with the professional competence and confidence to solve society's engineering problems.

To meet the challenge, I have implemented Problem Centred Learning (PCL) in a range of engineering subjects in the second year and above, in particular two multidisciplinary core subjects in fluid mechanics, a third-year core subject (*Fluid Mechanics*) with an average enrolment of 75 students over 2011-2014, and a fourth-year core subject (*Advanced Fluid Mechanics*) with average student numbers of 60 in Chemical, Civil and Mechanical Engineering of the Bachelor of Engineering programs at JCU. Due to the heavily mathematics based, theoretical nature of the subject content, engineering students in general lack enthusiasm and often find these two subjects challenging and 'dry'. My passion for creating a student-centred and interactive teaching-learning relationship prompted me to review the subject material and pedagogical approaches for these two core subjects. In finding new ways to instill critical thinking and problem-solving skills in engineering students, I realised that the main barrier is that it is inherently difficult for students to connect the heavily mathematics based subject material to real-life engineering situations, and appreciate the relevance of the subject content to future professional practice. To cater for the needs of students with a great range of experiences, interests and abilities in mathematics, I identified that Problem Centred Learning (PCL) would be a suitable pedagogical approach with which to deliver these two subjects, as it would help the students to relate theoretical subject content to interesting real life engineering situations, a crucial aspect to keep students interested and motivated.

CRITERION 1: APPROACHES TO TEACHING AND THE SUPPORT OF LEARNING THAT INFLUENCE, MOTIVATE AND INSPIRE STUDENTS TO LEARN

Problem Based Learning (PBL) is a commonly used pedagogical approach (Webb, Mennin & Schwartz, 2001). Problem Centred Learning (PCL) is a micro variant of PBL that emphasises the practical side of theory and promotes learning independence, making PCL better suited to situations where content is heavily mathematical, or where students are yet to fully develop independent learning skills (Potvin et al., 2010). Since I joined JCU in 2006 and became the Head of Discipline of Mechanical Engineering in 2010, I have led by example to implement PCL as best practice pedagogy. This approach has proved to be exceptionally effective in helping engineering students develop and sustain interest in theoretical and foundational subjects with a heavy mathematics component. My leadership has resulted in stronger student interest in fluid mechanics, outstanding institutional student evaluations and multiple teaching awards received by our Discipline in recent years. **The sustained positive impact PCL has on student learning has markedly contributed to JCU engineering graduates achieving the highest job outcomes (93% after 4 months) for engineering graduates in Australia (The Good Universities Guide, 2014).**

Since 2008, I have developed and implemented three distinctive strategies to embed PCL, inspire and motivate students. These strategies are operationalised through the whole teaching and learning process.

1. Purposeful, research informed subject content design with authentic and practical professional problems

To foster students' intellectual curiosity and interest in foundation subjects, I have re-designed the subject content to embed PCL into the two subjects. Teaching materials have been purposefully structured in order to facilitate better student understanding of core concepts using meaningful links to real-world problems that are authentic, interdisciplinary and thought provoking, mirroring those found in their future careers. The aim in providing practical and problem-oriented subject materials is to demonstrate the relevance of the theoretical content, increase student interest in foundation mathematics and to further exercise and improve their critical thinking and problem solving skills required for professional engineering competences. I utilise my expertise in the subject areas as a leading researcher in the field, as evidenced by the fact that I have undertaken six ARC Discovery Projects in this field in the past 10 years, to ensure that the problems selected are well informed by current and advanced research and innovative and meaningful solutions. My outstanding command of this subject field and the sustained impact of the purposeful, problem inspired subject design is clearly evident by the fact that a great number of students have subsequently chosen research topics in fluid mechanics as research projects and have achieved outstanding academic excellence, research capability and intellectual confidence. A selection of these achievements over 2011-2014 include:

- Two students received the highest rank and High Distinction grade in their honours thesis.
- Two students were selected to compete in the prestigious annual CN Barton Medal competition.
- One student was invited to give a presentation at the 19th Australasian Fluid Mechanics Conference (Melbourne, 2014) as the *only* undergraduate student among 210 student participants.
- One student co-authored a journal paper that was recently submitted to the *Journal of Fluid Mechanics*, the most prestigious journal in fluid mechanics.
- Over 2011-2013, four other students have achieved High Distinction grades for their honours theses in fluid mechanics.
- One student had his research work published in the *International Journal of Green Energy* (DOI: 10.1080/15435075.2013.858045) and another co-authored a journal paper that was published in the *International Journal of Heat and Mass Transfer* (V86, 957-972, 2015)
- Outstanding academic excellence led one student to establish a career in fluid mechanics by doing a PhD in the area with an APA scholarship

2. Student focused teaching approach with deliberate connection to real life engineering problems

My practice with PCL is to introduce each topic in class by first considering an engineering problem, examining the physical processes involved, and only then moving to the mathematical model, followed by well-worked examples closely related to real-life situations. Through this deliberation, the students better appreciate the relevancy and necessity of having basic skills and fundamental knowledge to solve practical problems. To stimulate and sustain students' interest and enthusiasm in learning theoretical component, I make sure the lectures are well structured and paced, and my explanations are detailed. Institutional student surveys indicate this problem- and student-centred approach has been very effective (see Figure 1). The success is also evident in positive student evaluation responses such as ***"Speaks at the perfect pace, goes through everything with enough detail to easily understand"*** (Student evaluation, 2013), ***"He communicates the subject material extremely well, as indicated by class attendance"*** (Student evaluation, 2013), ***"His delivery of the subject was good and got students engaged"*** (Student evaluation, 2014), and ***"Makes the subject interesting and easy to understand"*** (Student evaluation, 2011).

Each week, immediately after the delivery of the topic theories, I use at least one lecture session to exclusively work through, step-by-step, two to three practical problem examples with gradually increasing difficulty. The students are shown how to effectively relate the relevant theories and knowledge to specific

practical problems and how to solve the problems by following the correct steps, significantly enhancing their enthusiasm in learning and effectively instilling their critical thinking and problem-solving skills. This strategy has been particularly appreciated by the students, with positive student evaluation responses such as ***"Learning the content and then demonstrating it through the use of examples is a very effective teaching method"*** (Student evaluation, 2013), ***"I benefited a lot from the in class examples"*** (Student evaluation, 2013), *and* ***"It is really useful the way Wenxian uses examples throughout his lectures to explain the concepts"*** (Student evaluation, 2014).

3. Close monitoring of student progress and needs-based support approaches

The cohorts of both subjects are multidisciplinary, with very diverse academic capability. Increasingly, a notable proportion of the students enter the subjects demonstrating limited previous achievement in mathematics foundations. As the subjects are strongly mathematics based, I have dedicated time, both in and out of class, to patiently and passionately help struggling students to catch up. Tutorials provide the best opportunities to examine firsthand the students' learning progress so appropriate improvements and adjustments can be made in a timely manner. More importantly, tutorials allow individual students to directly interact with me when working through tutorial and review problems. This has been particularly welcomed by both the high achieving and struggling students alike, as they can engage based on their personal abilities. The effectiveness of this strategy is clearly demonstrated by numerous positive student evaluation responses, such as ***"He spends a solid lecture introducing new content, gives at least two examples for each new topic, and holds the tutorials himself being the most knowledgeable person on tutorial content. It's great!"*** (Student evaluation, 2013), ***"Tutorials are set to reinforce our learning, which works effectively"*** (Student evaluation, 2011), and ***"Providing the tutorial problems as well as the additional review problems for each section is very useful for study"*** (Student evaluation, 2013).

When a student has a question I focus on the needs of the individual student when deciding the level of detail required to explain a theoretical component. I also operate an open-door policy to provide support to students when they need it. This needs-focused support strategy has been very effective which has been demonstrated by the high student evaluation scores to the question "*Lecturer's teaching methods inspired me to learn*" (Figure 1b). These strategies have also been endorsed by my peers, such as ***"Relevant example problems were done after explaining the theoretical concepts which was helpful to reinforce the understanding of the topic"*** (Peer Review, Dr R. Tuladhar, 2014), and ***"Wenxian's style is such, students from all demographic groups will find it easy to engage and participate"*** (Peer Review, A/Prof N. Sivakugan, 2014). They have also been highly appreciated by the students, with comments such as ***"Very well taught by a lecturer who has a sincere interest in the subject matter. Always a pleasure attending lectures and tutorials"*** (Student evaluation, 2010), ***"The open door policy meant we could ask him for assistance with tutes and preparation for the final exam, outside of scheduled class time, which is very useful"*** (Student evaluation, 2014), and ***"Provided plenty of contact hours as well as being available for help during office hours"*** (Student evaluation, 2014).

RECOGNITION AND SUSTAINED IMPACT ON STUDENT LEARNING

Using these three key strategies, PCL pedagogy has proved to be highly successful in improving the student learning experience and outcomes. This is demonstrated in substantially improved student achievement rates since I took over the subjects. For example, the average percentage of the students who obtained a Credit grade or better has considerably increased since I took over *Fluid Mechanics* in 2010 and *Advanced Fluid Mechanics* in 2008, from previously 46% and 42% to 59% and 54%, respectively. Student evaluation scores for the two subjects (Figure 1) have similarly been consistently excellent, clearly demonstrating the sustained impact on student learning of my application of the PCL approach.

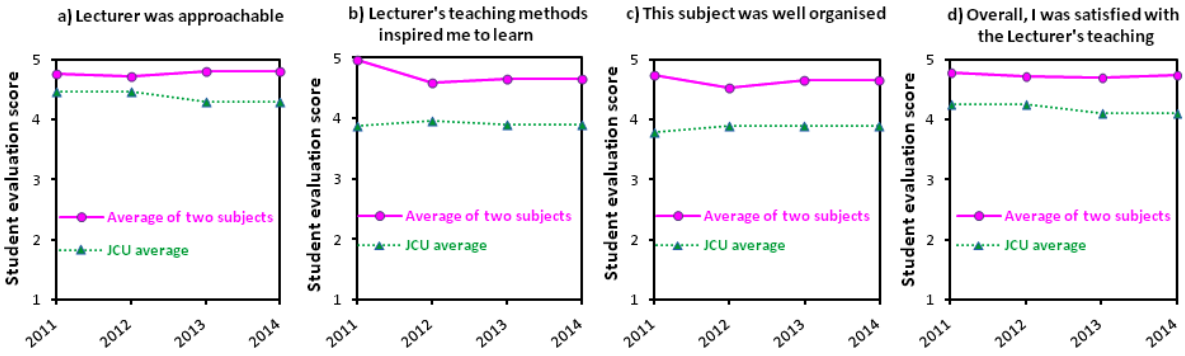

Figure 1: Average institutional student evaluation scores of *Fluid Mechanics* and *Advanced Fluid Mechanics* over 2011-2014. Score scale: 1 = strongly disagree, 2 = disagree, 3 = neither disagree or agree, 4 = agree, 5 = strongly agree.

The student-centred and needs-based teaching and support strategies centred on problem solving have been particularly successful in encouraging active student engagement and motivating students to learn theoretical subject content, and build the students' confidence to achieve their best. The numerous positive student responses received during the institutional student evaluation process reflect the impact on student learning: **"He is a great lecturer who makes me enthusiastic about a topic I was not previously interested in"** (Student evaluation, 2011), **"He was always enthusiastic when teaching and made the subject an enjoyable experience"** (Student evaluation, 2013), **"Couldn't ask for a better lecturer! It is a credit to JCU & I recommend to students to select Mechanical as their discipline purely for him"** (Student evaluation, 2011). In 2015, I was awarded a *JCU Citation for Outstanding Contribution to Student Learning* as institutional recognition of teaching excellence.

To conclude, I note recognition from professional peers and employers that attests to the relevance and success of the PCL approach in teaching subjects that are theoretical in nature and heavily mathematics based: ***"Being an outstanding researcher in his field with several postgraduates and ARC grants,… [Wenxian] brings in the latest development and state-of-the-art mechanics and hydraulics into his teaching practice. This is even more evident in the final year honours projects he supervises where the students get to use the latest techniques such as Particle Image Velocimetry, and carry out some cutting edge research and present their work in international conferences… I have seen for years that the students learn better and quicker when they see… real-life applications. There were plenty of these in Wenxian's lectures, which were nicely interwoven with the theory… The focus has been always in the big picture, which is what that matters at the end. Wenxian's style is such, students from all demographic groups will find it easy to engage and participate"*** (A/Prof N. Sivakugan, 2014), and ***"Over the years, we have employed a number of bright JCU Mechanical Engineering graduates at Rockfield. Our engineers have a very high regard to Wenxian's teaching methodologies, given the profound impact this has had on their ability to solve complex problems… His passion and dedication in continuously improving the subject contents and delivery to ensure their industry relevance have been refreshing… Wenxian's lecture delivery style embraces the philosophy of engineers in the workplace, in that the difficult core concepts are simplified first, and complexities are gradually introduced… He is very approachable and has an open door policy and always has time for his students. This is a very direct teaching method that makes the difficult content of fluid mechanics easier to absorb from a student perspective… I believe he deserves the highest possible recognition for his contribution to the industry through his outstanding undergraduate teaching"*** (Dr Govinda Pandey, CEO, Rockfield Technologies Australia Pty Ltd, industry employer, 2015).

REFERENCES: **Potvin, P., M. Riopel, S. Masson, and F. Fournier** (2010). PCL vs. teaching-centred learning in science at the secondary level. *J of App Research on Learning*, V3, A5; **Office of the Chief Scientist** (2013). *STEM in the national interest,* Aust. Gov.; **Webb, G., S. Mennin, and P. Schwartz** (2001). *PBL: case studies, experience and practice*. Taylor & Francis.