Demand evidence and think critically: building research excellence in tomorrow's scientists

OVERVIEW: SUMMARY OF CONTRIBUTION AND CONTEXT

"This subject opened my eyes to what being a 'research scientist' is really about."

(2013 reflection by a 2010 student after completing research honours and 2 years in a science career)

Australia faces a declining scientific workforce. Fewer science students plus poorer academic performance threaten Australia's pursuit of an innovative economy. Australia's Chief Scientist challenges us to produce future innovators by nurturing the culture of science in society[1]. Our authentic, research-based, apprenticeship framework directly addresses these challenges by fostering the development of the next generation of research scientists. The cognitive and technical leaps needed for scientific discoveries require more than a deep foundation of knowledge; they require a profound understanding of the ethos of scientific discovery, advanced critical thinking, and superior scientific communication skills. We transition students from highly scaffolded learning experiences towards independent research through the use of the Research Skills Development (RSD) framework[2] and by building discipline specific self-identity. Through these approaches we encourage excellence in the future scientific and medical workforce through the provision of research-ready Biomedical Science graduates.

Drs Lisa Chilton, Suzy Munns and Donna Rudd are actively engaged scientists, currently investigating organ transplant solutions, heart failure and lung compression. As a teaching team, we are committed to integrating research into our undergraduate teaching. Our unique combination of skills, demonstrated through various positions including academic editor of a major international research journal (*PLOS* One), national board member of Australian Institute of Medical Scientists, and North Queensland representative of Australian Association of Clinical Biochemists, profoundly influence our approach to teaching, adding authenticity and encouraging students to become engaged producers and not just passive consumers of knowledge. We are passionate about developing the autonomous research and critical thinking skills of our students and thereby building strong professional identities as graduate scientists. We embrace this approach throughout our teaching and it is best exemplified by our redevelopment of the subject *Advanced and Integrated Physiology*.

Advanced and Integrated Physiology is a 3rd year undergraduate subject exploring advanced concepts in lung, heart and skeletal muscle function. It has a diverse cohort of up to 40 students from biomedical science, medical laboratory science and science degree programs at James Cook University (JCU). Prior to redevelopment in 2009, *Advanced and Integrated Physiology* generated low student satisfaction scores and poor outcomes. We now use an authentic apprenticeship model to build discipline-related self-identity and the RSD framework[2] to produce biomedical research-savvy graduates able to enrich the scientific workforce. Our design adapts the successful transitional pedagogies typically used with First Year Experience programs[3] to students on the cusp of graduation. Not only have these strategies led to a dramatic increase in student satisfaction levels and academic outcomes, there is evidence of an increasing number of students continuing to postgraduate qualifications and scientific careers since redevelopment.

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

MODELLING AND TEACHING KEY CORE SCIENTIFIC VALUES IN A SUPPORTIVE, AUTHENTIC LEARNING ENVIRONMENT

Using a unique combination of the RSD framework[2] and an apprenticeship model, we transition students from the heavily scaffolded learning experiences of earlier years towards becoming apprentice scientists skilled in six core science research values: accuracy, precision, objectivity, testability, scepticism and open communication within three key learning activities: research, critical reflection and communication. The authentic and highly relevant nature of these activities encourages students to take ownership of their learning. We carefully develop autonomy, allowing students to actively engage in experimental design, data collection and analysis, manuscript preparation and conference presentations while gaining deep content knowledge. We foster a research scientist identity by modelling the complete research process in a low stakes environment. Personalised experiences of research science arms students with high level transferrable skills which are attractive within a traditional research laboratory and beyond. Building discipline specific student self-identity and embedding the RSD framework into curricula design have been shown previously[4], and in this subject, to increase research skills and encourage more students into

research higher degrees. Our authentic approach embraces the core tenants of the teaching-research nexus[2], deeply embedding research into classroom teaching, meets JCU's strategic intent of developing research ready graduates and directly addresses Australia's predicted future deficit in STEM (science, technology, engineering and mathematics) qualified graduates.

BUILDING DISCIPLINE-SPECIFIC SELF-IDENTITY

As scientists we are more than the focus of our research or the content that we teach. We embody the core values that govern the development and certification of knowledge. However, the culture of science is often overlooked in favour of delivering content. Redevelopment of *Advanced and Integrated Physiology* was underpinned by the need to both teach and actively model the 6 core values described above in order to foster a 'research scientist' self-identity. Realistic research experiences were integrated into the learning environment[5], offering students deep understanding of the culture of their discipline[6]. This process is similar to an apprenticeship; exposing students to activities they will perform post graduation[7]. Students learn not just by listening, but also by doing and mimicking[5]. For science students, this requires explicit role models and experiences that go beyond skills or knowledge to explore the culture of scientific research. We offer students our personal experiences as scientists and embrace our own unrelentingly high standards to encourage students to develop a strong self-identity of 'research scientist'. High levels of discipline-related self-identity lead to the adoption of deep approaches to learning and increases the students' desire for continued engagement in the discipline[8]. As one student commented in 2013, our innovations *"played a direct role in my decision to continue pursuing a career in science."* By overtly representing core values and emphasizing the direct link between core values and scientific success, we seek to produce passionate, engaged graduates who embrace their future science and other careers with integrity and vigour.

***The Aims of Our Authentic Learning Initiatives*: Research, critical reflection, and communication.**

Research means taking risks. De-sanitised authentic research activities immerse students in the 'thrill of the chase', with all the inherent challenges, rewards, and frustrations. Respiratory physiology practicals employ the same techniques used by Dr Munns in her cutting-edge research. Muscle physiology practicals challenge students to test if the skeletal muscle changes that they measure in rats match their predictions based on human athletes. These authentic research experiences are explicitly designed to be 'real world' scientific research odysseys. The simplified protocols and perfect data of introductory laboratories have been eliminated. Instead, these experiments are rich with the potential to produce inexplicable results, challenging students in an entirely new way. Students must carefully analyse their data and methodologies and explore published research for explanations of why their results do not match the predicted ideal. Students gain intimate appreciation for core values of accuracy, precision, objectivity and testability by linking the quality of data to their own cognitive and technical skills. By allowing students to take risks, we foster ownership in experimental outcomes, increasing student engagement and inspiring development of high level analytical and technical skills. High levels of engagement are achieved by scholarly dialogue during each practical session, and by requiring students to write research papers for a mock peer-reviewed international scientific journal. Students valued the teaching approach in sustained ways after engaging in the subject, as reflected in comments such as *"this was my first taste of real scientific writing and really helped me when it came to producing my thesis in the following years"* (2010 student, received via email in 2013 after the student completed honours). These authentic research activities build essential skills that underpin not only the most common form of scientific communication but also the most professionally valued.

Critical reflection ensures the integrity of knowledge. Scientists offer more than a toolbox of techniques and a body of knowledge. We make complex decisions about the interpretation of data and critically evaluate published research articles, the mainstay of scientific communication. We believe that rapidly expanding content knowledge necessitates explicit student training in how to identify and evaluate credible sources of information. Critical analysis requires skills drawn from both intellectual training and personal experience. Our students learn from class discussion and personal experience that knowledge is provisional and that conflicting interpretations are a valuable resource in the advancement of science. We challenge our students to critique a selection of recent research papers in oral and written formats. We foster a sense of ownership and enable students to explore their own areas of interest by allowing them to create their own shortlist of cutting edge research papers to critique in journal club. Students then improve their critical reflection skills by discussing the research papers, explaining the aims and findings, and placing the results

in the context of current research. We explicitly train students to critique the work of others as a stepping stone to critically evaluating their own mock research papers prior to submission.

Much to our delight, students surpassed all our expectations in this authentic scientific endeavour. Many performed to post-graduate standard, demonstrating superior understanding and innovative thinking in presenting and leading discussions on their chosen papers; in 2013, 58% of the class earned perfect marks for their engagement. Students expressed pride in how successful they were at a task that they had initially feared. In a 2010 student's words, *"Really like the focus on scientific skills such as journal assessment"*.

Communication is the key to knowledge transfer. Research papers and conferences are the mainstay of professional scientific communication. Research papers are an essential currency of academic merit and their crafting is a vital skill for graduates to acquire. We transition students from the heavily guided partial practical reports that are common in 2nd year subjects to writing complete manuscripts suitable for journal submission. This represents a huge advancement in writing quality, data analysis and critically thinking skills. We carefully scaffold this transition with well-timed workshops on key skills such as statistics and literature searching and through an open door policy, encouraging students to drop in for support and advice. Conferences are also important forums for exchanging new ideas and encouraging critical debate. We model this experience with a mock conference in which students deliver both oral and poster presentations, forms of communication used in all major international scientific conferences. These authentic activities further develop communication and critical thinking skills. Modelling both the high pressure conference and manuscript writing experiences allows students to build confidence and skills in a low risk environment, where career advancement and professional reputations are not at stake.

SUSTAINED (2009 – 2013) RECOGNITION OF SUCCESS BY STUDENTS AND BOTH JCU AND INTERNATIONAL PEERS

Performance indicators Student feedback by standardised university instruments showed subject redevelopment improved feedback scores from below school and JCU 2008 averages to significantly above in 2009-13. Students were very satisfied with the quality and organisation of the revamped subject (Fig 1), feeling that it inspired them to engage deeply. Feedback scores verify that our authentic learning activities sharpened analytical skills and increased student motivation. The extensive feedback we provided on both written work and during practical activities was very favourably regarded (Fig 1), increasing student feedback scores by 67%. The high standards we set for ourselves and the students engaged them, encouraging them to stretch themselves within a safe environment. In formal institutional feedback students concluded the teaching was *"challenging enough to make us think"* (2012) and *"challenging, but plenty of support when needed"* (2011).

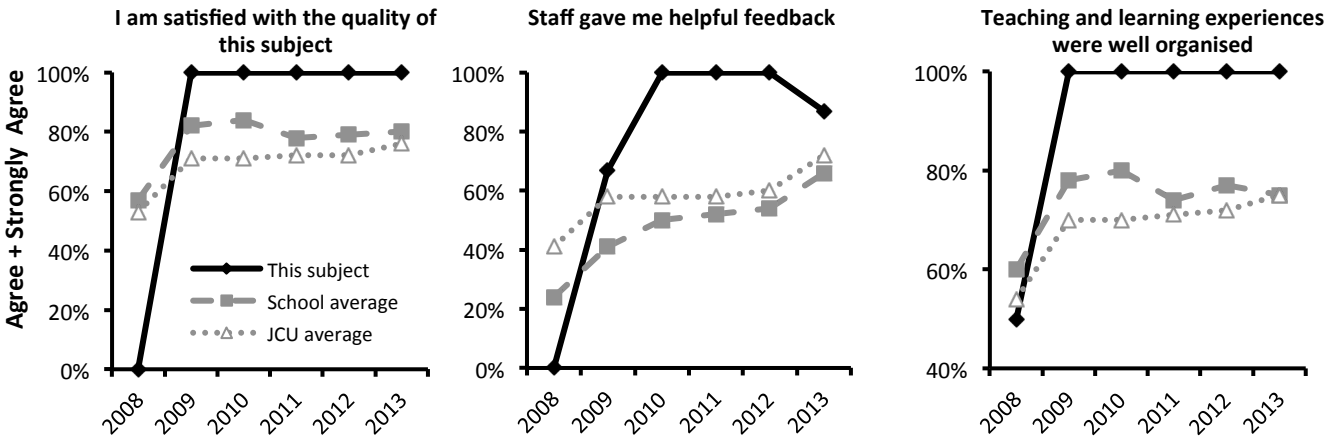

Figure 1: Subject redevelopment increased standardised JCU student feedback scores from below the school and JCU average (2008) to significantly higher (2009-2013). 2013 response rate 35%.

Student perceptions surveys (2009, 2012 & 2013) showed that 67% of students strongly agreed that *"the journal club sessions, poster session and written reports helped develop their ability to communicate and present research."* Student assessment performance has also increased since subject redevelopment; with an 11% increase in high distinction grades (from 6% in 2004-7 to 17% in 2008-13) and 3% increase in distinction grades (from 11% to 14%). Students reflected that the subject was *"challenging"* (2011) and *"fascinating"* (2012) and *"felt like turning a corner in terms of thinking scientifically"* (2010). Students *"really feel as though the publication standard expectations of journal article writes up made me*

feel more like a real scientist and I learnt a lot and also improved my skills DRAMATICALLY in literature searching skills!" (2010).

In the 5 years since subject redevelopment, 62% of our graduates immediately continued to postgraduate studies or found employment in a scientific field (compared to approximately 23% in the 6 years prior). These pursuits include honours, masters and PhD programs, research assistants, diagnostic pathology and scientific communication degrees. Indeed, this year we have the largest enrolment in Honours in Biomedical Sciences in a decade, in part reflecting the increased interest in research and increased academic achievement in our subject in 2013. Our subject is only one aspect of these students' undergraduate journey, however, this high success rate suggests that not only do aspiring scientists elect to enroll in *Advanced and Integrated Physiology*, but that successful completion provides students with the confidence and advanced skills required to pursue their scientific career goals. A recent graduate with first class research honours in biomedical science commented, "*I feel as though the subject, and the way it was run by the lecturers was an exceptional preparation for the real world of science*" (student email, 2013).

Success confirmed by internal and external peer review. International peer review by Dr Robert Carroll, Editor of *Advances in Physiology Education* (the world's leading physiology teaching publication), praised our willingness to offer ourselves as exemplars of science culture and behaviour, and our authentic learning activities, which address a significant weakness in science education: "*Science is what scientists do, rather than what they know. Too often, science education emphasizes facts over process. The consequence of this approach is a general public that is incapable of communicating data, following scientific discourse, and unable to employ critical appraisal skills. This course is an excellent model for promoting scientific literacy, an essential step to inform and strengthen the public scientific discourse*". Mr John Smithson, JCU Associate Dean Teaching and Learning (2010-2013), judged that our initiatives were perceived by students as authentic, providing a "*fantastic exemplar of the idea that process, product and student performance were equal in terms of importance.*" The subject "*modelled scientific and professional behaviours that will increase the likelihood of students progressing onto research training*". Our innovations were judged by Professor Wayne Hein, our Head of School, as "*imaginative and pedagogically advanced… [they] promote a culture of inquiry and scholarly dialogue and provides deep insight into the philosophy underpinning scientific research.*" Our success with this subject has led us to implement similar innovations in other undergraduate subjects in Biomedical Sciences.

CONCLUSION

A 2006 *Advances in Physiological Education* article urged that "what is urgently needed is an educational program in which students become interested in actively knowing, rather than passively believing"[9]. We have shown that our unique approach of blending the RSD framework with an apprenticeship model of learning, combined with adapting first year experience transitional pedagogies for use with graduating students, achieves this aim. Our innovative approach earned a Citation for Outstanding Teaching and Learning at JCU in 2013 and received commendation from peers both within JCU and from an international expert in science education. We dramatically improved student satisfaction, final assessment success and the number of students progressing to higher degrees in science or advanced scientific posts. The extraordinary success and sustained impact of our teaching approach is best captured in the words of a current postgraduate student: "*it confirmed to me that I wanted to be a research scientist as it was one of the first subjects to really address the critical thinking and writing skills actually required of someone working in the field*" and "*the lecturers gave me a glimpse of the challenges and realities that I now face on a day to day basis, as well as a glimpse of the things that make my career in science so incredibly rewarding*" (2009 student, received via email in 2013). Providing students with authentic scientific experiences, taught by active scientists who use their experiences to enrich the learning environment, arms our graduates with the knowledge, skills and critical thinking needed to facilitate future scientific and medical breakthroughs in Australia.

REFERENCES

1. Chubb, I (2013) The Future of Science in Australia. www.chiefscientist.gov.au; **2.** Willison, J, O'Regan K (2007) *HERD*, 26: 393-409; **3.** Kift, S, Nelson, K (2005) *Proc 28th HERDSA Ann Conf, 2005*: pp 225; **4.** Willison, JW (2012) *HERD* 31: 905-919; **5.** Lombardi MM (2007) In: D. G. Oblinger (Ed.), *Authentic learning for the 21st century: an overview.* EDUCAUSE; **6.** Callison D, Lamb A. (2004) *School Lib Med Act* 21:34-39; **7.** Herrington J, Oliver R, Reeves TC (2003) *Aust J Edu Tech* 19:59-71; **8.** Platow MJ. (2012) *Stud Higher Ed* 37:103-18; **9.** Michael J. (2006) *Adv Physiol Ed* 30:159-167.