Using undergraduate research to develop transferable skills for the modern workforce

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In the increasingly competitive global knowledge marketplace, Australian tertiary educators are looking to enrich their program offerings by providing authentic learning experiences for their students. In the biological sciences, this authenticity is best represented by hands-on inquiry and laboratory experimentation, often within the context of research internships. Authentic Large-Scale Undergraduate Research Experiences (ALUREs) aim to broaden the scope of these learning experiences by embedding research into coursework activities accessible by all students within the program. These experiences can promote learning gains in laboratory, analytical, and critical thinking skills, providing students with a transferable skillset applicable to many career paths across the science sector.

In 1998, the Boyer Commission on Educating Undergraduates in the Research University published a landmark report on the reinvention of undergraduate education. The report highlighted the emphasis on transmitting large volumes of theoretical knowledge within traditional science education, which often took precedence over practical training in inquiry-driven processes used by professional scientists. The proposed solution was to make research-based learning the standard, which has been shown to further stimulate student interest when compared to didactic instruction[1], and promote engagement and deep learning through active problem-solving[2]. Since the publication of the Boyer Commission report, undergraduate inquiry and research opportunities have increasingly been embedded in university curricula[3], spanning across a number of disciplines and higher education settings[4]. This movement has been further solidified by the Vision and Change in Undergraduate Biology Education program organised through the American Association for the Advancement of Science (AAAS) and the National Science Foundation (NSF).

Within the context of Australian higher education, the 2008 Bradley review placed significant value on student engagement in critical inquiry, citing access to these learning activities as strategic goals for all publicly funded tertiary institutions[5]. This view was further supported by the Learning and Teaching Academic Standards project conducted by the Australian Learning and Teaching Council (ALTC) in 2011[6] as well as the Office for Learning and Teaching's (OLT) Good Practice Guides for Science[7], all of which cite 'Inquiry and problem solving' as a key threshold learning outcome for Australian science graduates. The importance of these graduate attributes is further reinforced by the perceptions of STEM employers, who rank problem-solving and critical thinking as highly sought after graduate skills[8].

Undergraduate research provides training in scientific inquiry

The setting most amenable to research-based learning in large undergraduate science courses is the practical laboratory classroom – the physical site where scientific experimentation is conducted. Laboratory classes also operate in group-work settings, which enhance collaborative skills[9] and facilitate active learning[10]. There has been a shift away from the 'tedious', and 'repetitive' cookbook practical classes[11,12], and many programs have adopted student-driven inquiry within the undergraduate laboratory[1,13–20]. Inquiry-based learning classes can focus on an authentic research question and be implemented across a continuum of student responsibility, ranging from guided inquiry on specific research questions through to open-ended inquiry involving experimental design[14]. This inquiry-based learning continuum allows educators to scaffold the complexity of the research question according to prior student knowledge, and has been effective in driving student engagement across both secondary and tertiary education[13]. Furthermore, there has been a positive correlation between undergraduate research and student interest in scientific careers[13,14], as well as improved student retention into further research programs[21,22].

Developing authentic research projects for inexperienced undergraduate students can be both resource and time-intensive, and is therefore typically reserved for a small number of intrinsically

motivated high-achieving students via an apprenticeship-style model[23]. To improve student access to undergraduate research opportunities, the ALTC and OLT have funded a number of national leadership grants and fellowships to investigate and support undergraduate research[24–26]. Building on these previous findings, our UQ team launched an OLT leadership project in 2012 to support Australian academics in developing Authentic Large-Scale Undergraduate Research Experiences – the ALURE project.

ALURE: Authentic Large-Scale Undergraduate Research Experiences

An ALURE is characterised by student-driven investigations into research questions in hands-on undergraduate classes that can simultaneously accommodate large numbers of students (groups of 50–500 students). If developed and implemented effectively, an ALURE can provide the benefits of one-on-one research internships through normal coursework activities for hundreds of students, many of who would otherwise not engage in undergraduate research[27]. The real-world nature of research is a key motivator for student engagement in ALUREs, and in many cases their learning outcomes have directly contributed to research publications[13,28,29]. Effective scaffolding of the learning activity is also essential, as the research question needs to be investigated using laboratory techniques that are cost-effective, scalable for large classes, and subject to iteration and optimisation through student-driven inquiry[27].

At The University of Queensland, ALURE modules have been systematically embedded throughout the microbiology major as part of the three year undergraduate Bachelor of Science degree. In second year, microbiome samples from 400–500 students are crowd-sourced each semester, and used in an ALURE project investigating microbial composition across different human body sites using culture dependent and independent identification methods[30]. Following on to third year coursework, students apply techniques in DNA analysis and protein expression in an immersive 5-week ALURE to isolate and clone bacterial vaccine antigens against Uropathogenic *E. coli*[31]. Participating in these research experiences as a normal part of their undergraduate coursework has impacted hundreds of students each semester at UQ, consistently resulting in learning-gains in key skills following ALURE modules.

Figure 1 illustrates statistically significant increases in student confidence across a range of scientific skills following completion of the third year microbiology research experience at UQ. Students reported increased confidence levels in vocational laboratory skills (e.g. using a plasmid map, designing PCR primers, DNA gel electrophoresis), as well as generic skills in numeracy (graphing, calculations, measurements) and problem solving (planning experiments, choosing between experimental strategies, and data formatting). These perceptions were further corroborated by our previous findings that revealed the high quality of student performance in

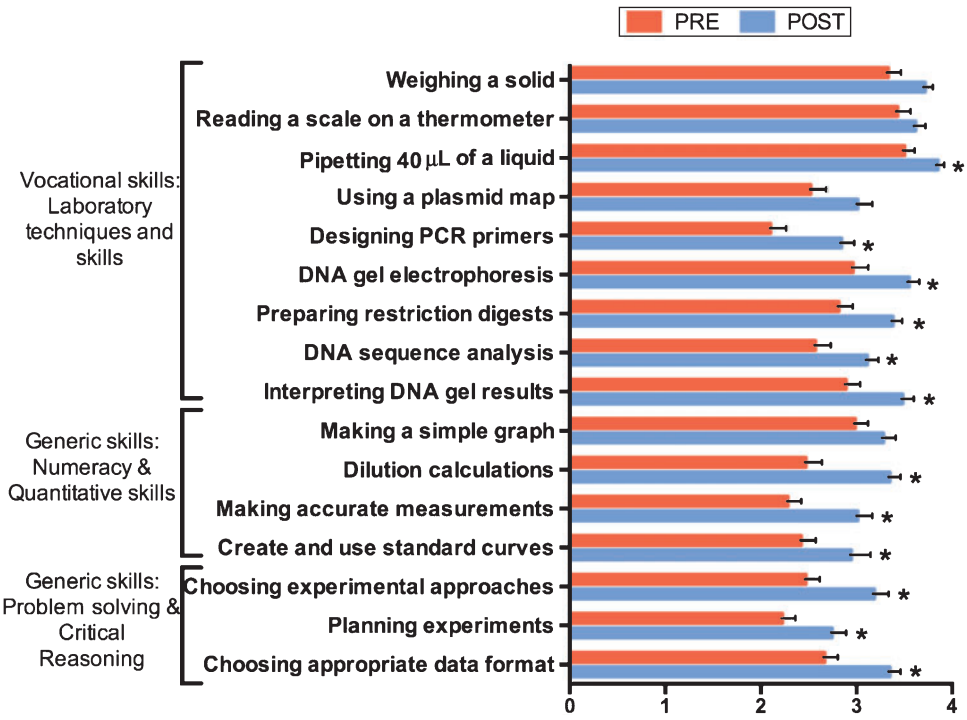

Figure 1. Research experiences promote student learning gains in vocational and generic transferable skills. Pre and post course survey results following completion of an undergraduate research experience in a third year Microbiology course at The University of Queensland in 2012 ($n = 41$, 30% survey completion rate). Bars represents mean ± SEM of student confidence on a 0-4 scale (0 = Do not know how to do; 1 = Not confident; 2 = Need Practice; 3 = Confident; 5 = Highly Confident). * denotes $P < 0.05$ using a two-tailed Mann–Whitney *U*-test.

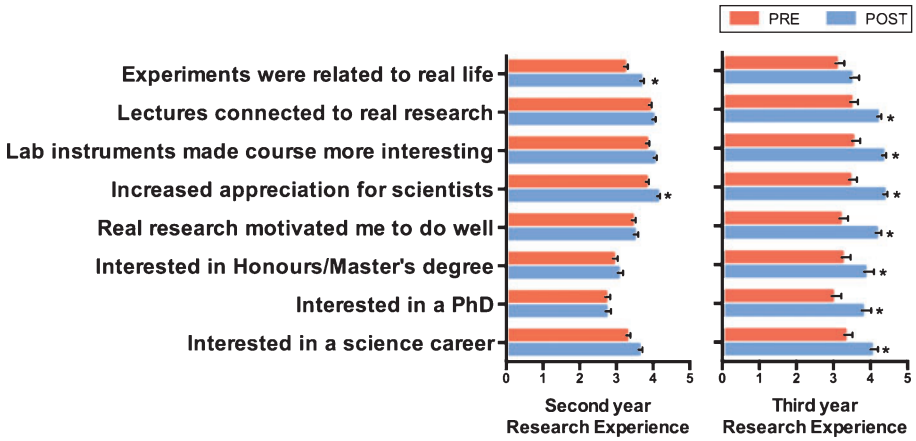

Figure 2. Undergraduate research influences students' educational and career goals. Pre and post course survey results following completion of undergraduate research experiences in second (n = 119, 28% survey completion rate) and third year (n = 38, 30% survey completion rate) Microbiology courses at The University of Queensland in 2012. Bars represents mean ± SEM of student agreement with statements on a 0-5 scale (0 = Strongly Disagree; 1 = Disagree; 2 = Barely Disagree; 3 = Barely Agree; 4 = Agree; 5 = Strongly Agree). * denotes $P < 0.05$ using a two-tailed Mann–Whitney U-test.

laboratory and reporting assessment tasks as part of second and third year ALURE modules[30,31]. The range of learning gains observed following ALURE participation align with graduate attributes desired by STEM employers[8] – improvement in practical competencies for pathology and research laboratories, and generic transferable skills applicable to workplaces both in and out of science[30–32].

Consistent with previous findings, we have also observed a positive shift in student attitudes towards scientific career pathways following their participation in undergraduate research experiences[13,14]. Pre and post survey analyses of second and third year UQ microbiology students revealed increased motivation and appreciation of science, and interest in pursuing postgraduate study and careers in science following the completion of an ALURE (Figure 2). Notably, these shifts in perception were much more evident in third year than second year ALURE students, perhaps indicative of smaller class sizes and increased focus on post-graduation prospects in the final year of undergraduate study. These trends could also signify the success of progressive scaffolding in ALURE activities across second and third year courses at UQ, which gradually increase the cognitive load required for student-driven inquiry while minimising extraneous cognitive burden[33]. Given the impact of engaging with undergraduate research on student retention within science programs[21,22], the long-term value of exposure to research-based learning early in undergraduate education should not be underestimated[34].

Future directions and conclusions

Throughout 2012–2015, the ALURE project has documented 21 different ALUREs developed by 39 academics at Australian tertiary institutions, spanning across Biochemistry, Physiology, Chemistry, Ecology, Genetics, Biology and Microbiology. Using a mixed-methods evaluation strategy of student surveys and focus-group interviews, the ALURE team consistently reported student-learning gains in scientific skills following the completion of ALURE modules[30,31], with higher gains observed in critical thinking and problem-solving skills when compared to traditional practical modules[32]. Undergraduate research is a high-impact activity that can be of great benefit to students, and the ALURE project has demonstrated that it can be a valuable addition to the instructor's toolkit to bolster student-learning outcomes in transferable skills.

To facilitate the development and implementation of new ALUREs to grow our community of practice, the project team has developed assessment frameworks, implementer's checklists, ALURE exemplars, and laboratory manuals, which can be accessed via the project website (http://alure-project.net).

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Biography

Dr Jack Wang is a lecturer and convenor of the microbiology major at The University of Queensland. His work revolves around undergraduate research and technology-enabled assessment in science education, for which he received a Citation for Outstanding Contribution to Student Learning from the Australian Awards for University Teaching in 2015.

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