Introduction

Engineering laboratories at QUT have been transformed since 2010. The transformation is not limited to the physical space but also encompasses organisational structure, academic engagement model and technical service provision.

Rasmussen and Topoonyanont (2004) identified the need for change and that laboratories were “at a cross road” where decisions needed to be made about their future. They proposed that “If the true value of these resources is to be utilised development is required.” and made reference to the review “Universities in Crisis”, Australian Parliament Senate (2001) into the capacity of public universities to meet Australia’s higher education needs indicating a national trend in laboratory decline. Many references are made in the review to the decline of laboratories at the time. One such comment made by Professor Ian Chubb (AVCC), relating to research infrastructure, indicates dissatisfaction for himself and colleagues at resources “slowly but surely degrading”. Professor John Agnew (Australian Council of Engineering Deans) commented that hands-on learning in laboratories was suffering. Twelve years later the Office of the Chief Scientist for Australia lead by, Professor Chubb identifies the national concern about STEM education and presents reports from the Office of the Chief Scientist (2013) and (2014) outlining plans for Australia’s future in which the need for wide ranging reforms are called for “from classrooms through to laboratories and corporate boardrooms.”

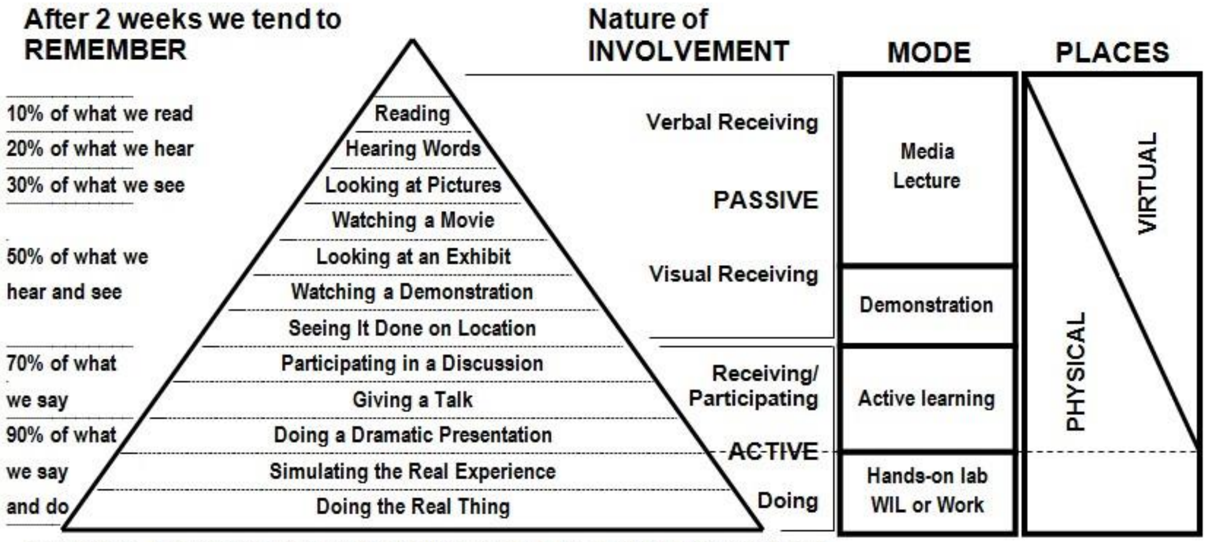
In response to these drivers and recognising the importance of continuing hands-on learning in laboratories the authors present a model for transforming physical laboratory learning and research spaces integrated with organisational, culture and pedagogy change. This paper describes the model of QUT engineering laboratories and presents results and outcomes of success.

The case for hands-on learning

Hands-on learning in laboratories is fundamental and part of the richness of the educational experience that can be delivered at the physical campus. Adams et al. (2011) argue that “Learners do not really understand until they can apply that understanding to a personal demonstration of the learning.” This is especially true in laboratory experiences where students can fully engage with experiments and not just watch a demonstration and take notes.

Laboratories provide the physical places for engineering students to connect with theory and have a personal hands-on learning experience. Learning space design and development is well established in many universities as described by Sen and Passey (2013), however laboratories are often not part of that movement. While active, collaborative and group learning pedagogies are all key words in relation to these new spaces the concepts have always been central to laboratory based learning. The opportunity to build on and strengthen good practice in laboratories is immense. With larger engineering classes becoming the norm, good educational motives need to support the laboratory experience. Mackechnie and Buchanan (2012) showed that laboratory education is more successful when integrated into a unit so that lectures/design studios anticipate the laboratory experiment and participation reinforces the theory taught. Many agree the laboratory experience is fundamentally important to engineering education, but it must show tangible benefits.

Feisel and Rosa (2005) provide much insight into laboratory learning and while acknowledging the benefit, also note that relatively little has been written about laboratory instruction. Dawes, Murray, and Rasmussen (2005) refer to the work by Edgar Dale creator of the Cone of Learning shown in Figure 1 that presents a visual classification of learning experiences from most active and concrete to abstract. They note the benefits of learning in hands-on laboratories and the strong indications that more is remembered when we learn by doing and make the statement, “the question is not; is experiential learning important?; it is; how can experiential learning be achieved, sustained and improved?”. A mapping has been added to the Dale (1969) cone in Figure 1 by the authors indicating typical modes and places used in university education. With the growing sophistication, accessibility and desirability of virtual (on-line) places for learning the traditional modes of delivery in physical places are being abandoned by students. Virtual simulations and remote labs as described by Lowe, Dang, Daniel, Murray, and Lindsay (2015) add to the rich mix of possibilities for laboratory connected learning and will add greatly to the full learning experience. Hands-on learning has its place and that is in physical laboratories at university and Work Integrated Learning (WIL).



Edgar Dale, Audio-Visual Methods in Technology, Holt, Rinehart and Winston (1969).

Figure 1: Dale’s cone of learning (adapted)

The case for transformation

Existing spaces, pedagogy and organisational structure in many universities are no longer suitable for the needs of current learning modes. Fixed and specialist use teaching laboratories in particular often suffer from chronic underutilisation and mostly do not present a connecting environment for students with their peers or the engineering technologies of their discipline. Increasing numbers of students, budget constraint and reducing or unchanging floor area for laboratories brings more focus on the need for transformation to address the issues and still provide good learning experiences and outcomes. The National Engineering Laboratory Survey, Kotulski and Murray (2010) provides A Review of the Delivery of Practical Laboratory Education in Australian Undergraduate Engineering Programs and reports “the current inflexible operation of, and constrained access to physical laboratories is misaligned with the increasingly complex lifestyles of students and the demands on their time.” The UNESCO report, Engineering Education: Transformation and Innovation, Beanland and Hadgraft (2013) acknowledge these challenges and states “Laboratory programs need to be reassessed and redesigned as part of the implementation of an effective transformation of engineering education.”

Many universities in Australia and New Zealand aspire to make fundamental change as can be seen in the comments below.

> *(We seek) …to transition the focus of our engineering teaching and learning away from information delivery and closed problem analysis towards the tackling of open ended problems requiring multi-disciplinary approaches and increasing group work, peer learning and laboratory*

time. To achieve this goal, in the context of a new building project, the physical laboratories, equipment and scheduling approach would be transformed and most importantly, empowering our technicians through the structure and professional culture to deliver against this teaching and learning vision. *The University of Auckland*

(We seek) …to transform the engineering precinct to enable the projected growth, develop research capabilities and enhance the student experience. To think outside the typical engineering educational space design and identify ways to use space effectively depending upon the permanency of the activities undertaken and to situate research, teaching, and commons spaces so that students and staff will feel more connected to the Faculty. Master Planning will inform the infrastructure requirements, strategic consideration of the future modes of teaching and consideration of the urban design of the precinct such that it promotes more intellectual "collisions" between the academic staff and students. *The University of Sydney*

This paper seeks to demonstrate that effective transformation is only possible through an integrated approach that is inclusive of physical laboratories, pedagogy, operation, organisational structure and culture.

QUT model

The QUT Model provides a holistic approach to laboratory operation through the integration of highly flexible, physical environments, with specialised support and tailored processes that ensure all aspects of laboratory activity are targeted towards the provision of outstanding learning experiences for our students. This model is focused on exceptional operational outcomes through the deliberate unification of all laboratory functionality around three pillars of People, Place and Process. This unification of resources, support and services has significantly improved the effectiveness of laboratory operation and delivered increased student satisfaction through a dedicated focus on all elements affecting laboratory learning experiences.

Throughout this transformation, QUT has reimagined physical spaces and created laboratory environments that draw students to a centralised hub of activity and provide a home for engineering cohorts. Spaces have been designed to maximise exposure and connectivity through the establishment of large open facilities with full height glazing and the integration of dedicated social spaces within the precinct. Laboratories are provisioned with extensive services to enable a diverse range of activities to be undertaken simultaneously or in multiple areas. This practice has disassembled discipline silos and created a cohesive environment, based on activity needs and seamless student experience. The 'Engineering Precinct' encompasses a broad array of environments including, flexible teaching and research laboratories, a dedicated motorsport facility, specialised medical and civil engineering laboratories, an engine development centre, a world class Design and Manufacturing Centre, and a relaxed student Garden Lounge. All areas are provided with wireless connectivity and cater for an extensive array of client and activity needs.

In order to maximise flexibility, a significant proportion of equipment has been designed to incorporate mobility as a key element. This practice enables equipment to be rapidly deployed in a safe and effective manner to ensure that maximum utilisation is available across the entire range of learning environments. Where experiments are restricted to specific facilities, the technical team undertakes a design and development program to improve portability or reduce impact on space allocation. Further, the technical team have embarked on a design program to create hybrid experiments using a virtual demonstrator with a physical piece of infrastructure to allow students to complete experiments at a time suitable to their own lifestyle. These delivery techniques have proved very successful and continue to expand across a growing number of experimental activities with over 50 percent of students preferring to use the hybrid approach where available.

This transformation has been underpinned by an equally important transformation in the means by which practical experiments are promoted to and supported by academic staff. The QUT model has enabled the creation of a central repository of experiments which provide staff a shopping cart experience to access a wide variety of maturely developed activities and the ability to add new activities. This process capitalises upon the significant knowledge base within the organisation to promote a transparent and accessible means for academic staff to include hands-on activities within their units. Once selected, each experiment is timetabled through the conventional timetabling process which provides students with a detailed and granular view, of their semesters learning requirements. Through the promotion of activities from across the faculty, students are exposed to far wider span of experiments than previously available within their unit and additionally allows for significant gains in utilisation of both facilities and resources.

These changes have inspired a new approach to laboratory management, which provisions a centralised Technical Team as operational custodians of the environments. This custodianship enables a holistic approach to service delivery which allows for the lifecycle management of all activities within the Precinct. The technical team oversees the day-to-day operation of the area as well as responsibility for health and safety implementation. Technical staff liaise with academic users to ensure selected experiments are targeted to their needs, then organise the induction and training of demonstrators. The technical team oversees the preparation of laboratories and equipment for the timetabled events, and captures dedicated student feedback from each session. This feedback provides live update enabling continuous improvement to ensure a consistently high level of student satisfaction.

This integrated approach to laboratory operation has delivered a 25% reduction in required floor area and increased utilisation to 6 percentage points higher than the TEFMA (2009) target utilisation rate for specialised laboratories. Importantly, the Engineering Precinct is a facility that attracts students and provides a sense of community for students, staff and the community.

Results and discussion

The laboratory transformation described has involved numerous stakeholders and identified the importance of people, place and process. This new model has allowed more positive interaction and communication between academics, technical, demonstrators and timetabling staff and inspired new pedagogical practices. The large flexible laboratories enable engagement at scale with classes of 90+ now common, and competitive assessment drawing 800+ students into the areas through the day. As a result of these practices, laboratory utilisation is far higher than pre-existing environments, with the added benefit that new spaces are heavily utilised outside of timetabled periods for engagement and student project activities.

To support the success of transforming laboratory environments, evaluation of how students perceived these new laboratory environments and how practical experiments linked to learning objectives have been captured since 2010 through voluntary student surveys in each laboratory session. The surveys were designed to understand student experiences and engagement in relation to delivery, learning outcomes, links to content knowledge and appropriate class size in these spaces. Data collection involved distributing hard copy survey questionnaires to all undergraduate engineering students in every unit within timetabled laboratory sessions. Demonstrators emphasised the importance of feedback to students in introducing the activity. This has resulted in thousands of student responses across more than 50 practical experiments over 3 years and allowed staff to gain a very good understanding of any environmental, equipment and/or delivery issue and allow ongoing quality assurance.

Survey questions used a 5 point Likert scale with one open ended question for student comments at the end of the 4 question survey. The Likert scale allows you to uncover degrees of opinion and also help you to more easily identify areas of improvement. As an example, response rates for a 3rd year Water Engineering laboratory (averaged 53%) along with student numbers are given in Table 1.

Table 1: Response rate example

Year	Unit	Laboratory	Class Size (n)	Response Rate
2013	Water Engineering	Flume	231	48%
2014	Water Engineering	Flume	292	51%
2015	Water Engineering	Flume	249	59%

Note: If students did not individually select numbers on the Likert scale or response was incomplete, data was excluded. (9 responses were excluded*)*

Feedback

An example of student feedback from a third year Civil Engineering unit Water Engineering using the Flume experiment in the redesigned laboratory spaces was selected to gain an understanding of student experiences and engagement. The experiment aimed at students understanding the hydraulic characteristics of open channels with data collected, interpreted and results applied to a project based learning scenario. In 2013 student feedback identified some issues with noise from the pumps inhibiting student hearing and impacting the learning environment. The new process allowed responsive change with staff able to reduce noise before the next day.

Student feedback was collated to determine level of student engagement and learning experiences within the designed activities and learning spaces. Response frequency across the years 2013 to 2105 identified high satisfaction with their learning experience in laboratories (2013; 90%, 2014; 95%, 2015; 91%). Analysis revealed students were very clear about the learning objectives of the laboratory experiment and satisfied that the experiment helped them meet these learning objectives (Figure 2). They also believed the information presented was delivered in a clear and professional manner (Average 91% over 3 years) and the class size was appropriate for the experiment and the space provided (Average 97% over 3 years).

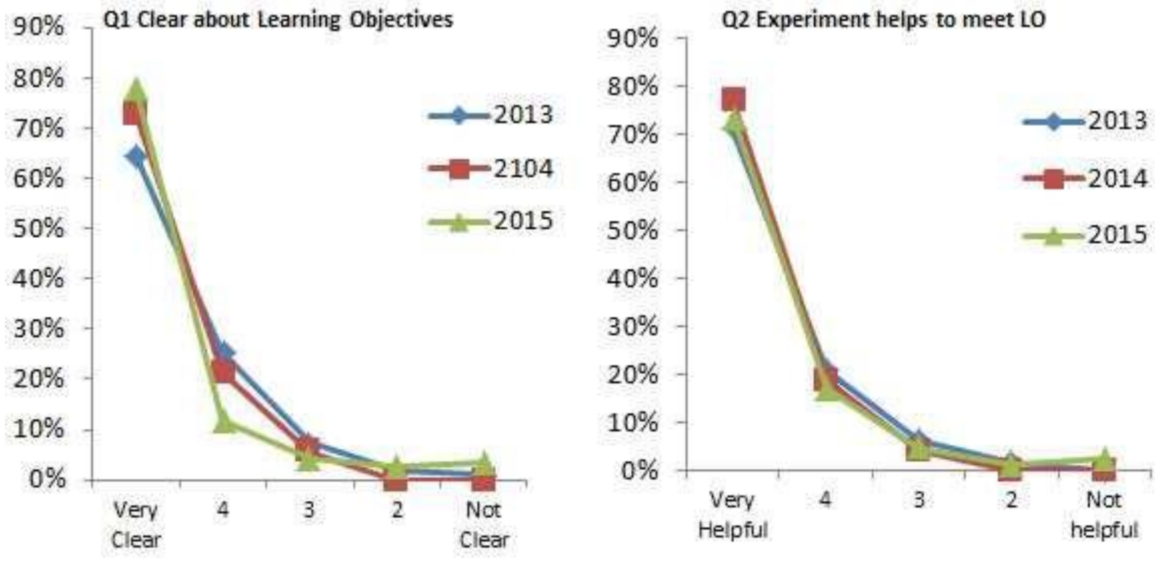


Figure 2: Student feedback 2013 to 2015 flume experiment

The open ended question yielded very positives responses from students with the following comments received from students supporting this numerous times. Positive comments far outweigh the need of improvement comments which mainly focused on background noise and language issues with some tutors. These comments have been used by teaching teams to respond to issues with faulty equipment, background noise inhibiting student hearing and overall engagement of students. Feedback is very useful in assessing best modes of delivery and quality assuring the practical activities. Examples of feedback;

- Good to see real examples rather than just textbook problems
- Experiment was explained clearly and helped me connect theory with practice
- Tutor asked us questions to challenge our understanding
- Good to consolidate theory from lectures
- This experiment made all the theory make sense.
- Practicals are great to further understand the concepts
- Very informative and supplying context was useful

Combining student feedback, utilisation rates and improved academic and technical staff interactions indicates a very positive outcome for the transformed laboratory places and processes. Academic staff feel supported, technical operations are efficient and laboratories are effectively utilised. Students are more motivated to learn and engage if they see a strong connection between theoretical and practical components of the unit. Boxall and Tait (2008) found limited educational benefit for laboratory demonstrations with little student engagement and interaction. Thus, it is important to provide laboratory experiences where students are actively involved and take responsibility for their own learning. Often forgotten are other benefits of laboratory learning including working collaboratively in groups and providing opportunities for reflection to reinforce critical thinking.

Conclusion

Recognising the importance of continuing hands-on learning in laboratories, a model of transforming the physical learning environments integrated with organisational, culture and pedagogy change has been presented. Continuous improvement and quality control are evident in using the student feedback to rectify faults and improve equipment, environment and process. The model is easily articulated and visible to other universities contributing to sector wide development of learning environments and operation. In order to be successful, spatial redevelopment must be supported by an integrated organisational approach.

This transformation has delivered increased student and staff satisfaction and connected social and formal laboratory environments that address the challenges of active, collaborative and group learning pedagogies. Student feedback evaluations, utilisation rates and academic and technical staff engagement indicate very positive outcomes encouraging the continued application and advancement of the model.

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