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The Role of Student Evaluations in Improving the Engineering Teaching Laboratory

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ABSTRACT

Higher education in Australia is being transformed to focus more on student experience, but within the academic community debate continues as to the suitability and reliability of allowing student opinion to dictate quality systems. Research to date has been inconclusive in providing evidence to justify either side of the debate. Similarly, the focus on understanding if and how student opinion can define and improve quality in the engineering teaching laboratory is limited. This is important within engineering, because as a practicing profession the teaching laboratory is generally regarded as playing an important role in preparing graduates for their future careers. The purpose of this study is to create a more complete understanding of what contributes to a quality learning experience in the engineering laboratory.

The research examined laboratory and student evaluation data between 2007 and 2015 for twenty-five courses in the School of Electrical, Computer and Telecommunications Engineering at the University of Wollongong, Australia. Most laboratory studies typically focus on one or two courses at a time for one or two years, which means this is one of the first of these types of studies to be conducted over an extended period of time.

A variety of research methods are used, underpinned by an iterative refinement process to understand the quality relationship between the laboratory demonstrators, training, laboratory experiments, facilities, resources and perceived learning. For the first time, various lines of investigation are used to develop a process map which indicates the interconnections between the laboratory variables.

This mapping found that student evaluation scores associated with laboratory experiments are linked to students' perceived learning achieved in the cognitive and psychomotor domains, but they are also matched to assessment performance in the cognitive domain when measured by a laboratory exam. While laboratory demonstrators and questions to evaluate the facilities are not directly linked to learning, the mapping shows a complex series of interconnections that tend to influence student opinion on the experiment questions. The key to a quality laboratory experience are demonstrators that are well trained and mentored;

laboratory activities that are engaging, with clear instructions, and teach fundamental skills like troubleshooting; the inclusion of additional resources that support learning in the laboratory, especially for students who do not follow the standard learning pathway; ensuring there is quality hardware and software; and ensuring an effective management structure is in place to ensure quality practices and promote continuous improvement.

The findings from this study advance knowledge by providing evidence that student evaluation data can be used to guide improvements in the quality of laboratory experiences. The mapping also provides engineering departments with a tool to design holistic laboratory experiences that provide positive student experiences and improved perceived learning in multiple domains. It also proves to Deans and Heads of School the importance of effective management structures to ensure quality and implement continuous improvement practices in the laboratory.

DECLARATION

I confirm that the work presented in this thesis is my own. Any contributions made by other researchers have been acknowledged in-text. This work has not been submitted to any other institution for the award of a degree or other qualification.

Mr Sasha Nikolic

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TERMINOLOGY

Course	A series of lectures/tutorials/laboratories/workshops/seminars or other related activities in a particular subject which lead to an examination or qualification
Degree	A program of study consisting of a combination of courses and other requirements which lead to a specific higher education award
Degree Structure	Refers to a specific program of courses which a student undertakes to meet the requirements of a degree
Discipline	A branch of knowledge based on a degree major, such as in electrical or mechanical engineering
Laboratory Demonstrator	A sessional teaching assistant practicing teaching in the laboratory
Session	A period in which courses may be offered. Classed as Autumn (February – June) and Spring (July – November)
SET	Student Evaluation of Teaching
Team Based Teaching (TBT)	Multiple teaching staff in the classroom working cooperatively
Teaching Laboratory	A room or building equipped for scientific experiments (physical or simulated) that is used for teaching purposes

LIST OF PUBLICATIONS

Chapter 3:

Nikolic, S., Vial, P.J., Ros, M., Stirling, D., and Ritz, C. (2015). "Improving the Laboratory Learning Experience: A Process to Train & Manage Teaching Assistants," IEEE Transactions on Education, V58 (2).

Chapter 4:

Nikolic, S., Ritz, C., Vial, P.J., Ros, M., and Stirling, D. (2015). "Decoding Student Satisfaction: How to Manage and Improve the Laboratory Experience," IEEE Transactions on Education, V58 (3).

Chapter 5:

Nikolic, S., Suesse, T., Goldfinch, T., and McCarthy T., "Maximising Resource Allocation in the Teaching Laboratory: Understanding Student Evaluations of Teaching Assistants in a Team Based Teaching Format", European Journal of Engineering Education (accepted for publishing)

Chapter 6:

Nikolic, S (2015). "Understanding How Students Use and Appreciate Online Resources in the Teaching Laboratory". International Journal of Online Engineering, V11 (4). *This paper was awarded the 2015 International Journal of Online Engineering (iJOE) Outstanding Paper Award.*

Nikolic, S. (2014) "Training laboratory: Using online resources to enhance the laboratory learning experience," in Teaching, Assessment and Learning (TALE), IEEE International Conference on.

Chapter 7:

Vial, P.J., Nikolic, S., Ros, M., Stirling, D., and Doulai, P. (2015) "Using Online and Multimedia Resources to Enhance the Student Learning Experience in a Telecommunications Laboratory within an Australian University," Australasian Journal of Engineering Education, V20 (1).

Chapter 8:

Nikolic, S., Suesse, T., Goldfinch, T., and McCarthy T., (2015) "Relationship between Learning in the Engineering Laboratory and Student Evaluations" in AAEE2015 Conference, Geelong Australia

CHAPTER 1: INTRODUCTION

1.1. Background

The teaching laboratory plays an important role in engineering education because in an ideal curriculum, students develop laboratory skills in instrumentation, modelling, experimentation, data analysis, design, learning from failure, creativity, psychomotor, safety, communication, teamwork, ethics, and sensory awareness (Feisel and Rosa, 2005). This has resulted in a lot of research directed towards how best to conduct laboratory classes; it includes research on experimental design, learning objectives, learning tools, teaching staff, facilities, and quality measures. The common aims of these research studies are to improve laboratory use in order to facilitate learning and improve student experience.

Historically, practice based learning (now mostly conducted within the teaching laboratory) has always played an important role in engineering education (Feisel and Rosa, 2005). A recent Australia wide study confirmed how important a laboratory can be for developing future engineers (Kostulski and Murray, 2010). However, some Australian reports have highlighted a number of quality risks associated with learning in the laboratory. A report commissioned for the Australian Council of Deans of Science (O'Toole et al., 2012) found that most teaching in Australian laboratories is carried out by sessional teaching assistants, also known as laboratory demonstrators; mainly postgraduate research and undergraduate honours students who are untrained and lack experience. This finding was in addition to a number of earlier Australian government reviews highlighting that quality assurance standards for all sessional teaching assistants are generally inadequate (AUTC, 2003, ALTC, 2008), which means the quality of these demonstrators is an important issue that must be addressed.

While problems with quality have been identified in these Australian reports, other risks have also been acknowledged through academic research. Studies have identified that simply having a laboratory does not ensure that productive learning is taking place, or that it is enjoyable (Casas and del Hoyo, 2009); that the laboratory learning objectives and the type of learning can be unclear and misunderstood (Hofstein and Lunetta, 1982, Feisel et al., 2002, Salim et al., 2013); and that a balance between traditional and new laboratory approaches such as remote access to physical equipment and experiments is beneficial (Feisel et al., 2002). It is also important to acknowledge that a holistic laboratory experience which covers learning across the cognitive, psychomotor and affective domains is also needed (Salim et al., 2013). However, most of these investigations only occur across one or two courses and generally for a short period of time, such as one or two years. A better contribution to laboratory quality could be made if a study occurred over many courses and for a longer duration.

In order to improve the quality, it must be measurable, but measuring the quality of education is complex due to questions such as who can actually measure quality, and what attributes should be measured? Governments, such as in Australia and the UK, have been raising the cost to students of higher education and promoting the importance of data gathered by student experience questionnaires. These changes are having the effect of transforming the student into a customer whose experience is now front and centre (Bunce et al., 2016). Through the Australian QILT website (Australian Government, 2016) prospective students have access to data from surveys such as the Student Experience Survey (SES) and the Course Experience Questionnaire (CEQ), while similar surveys such as the National Student Survey Questionnaire (NSS) are used in the UK and the National Survey of Student Engagement is used in the USA (Calvo et al., 2010). These surveys are used to understand the quality of education as perceived by current and recently graduated students. They are also associated with attracting new students, building a university's reputation, and to attract funding (Ling et al., 2012). This therefore raises the question of whether students are capable of judging quality in education.

Many academics have questioned the suitability of students becoming de facto customers, believing they are incapable of judging the quality of education or learning outcomes. They argue that students have nothing to learn if they already know everything in order to demand it (Lesnik-Oberstein, 2015). A number of possible risks might include students seeking to 'have a degree' rather than 'be learners'; possible pressure to 'dumb down' the contents in order to receive higher ratings; and a greater sense of entitlement (Bunce et al., 2016). However, other academics argue that student opinions should be heard and that on average they are capable of judging the quality of their education (Marsh, 1987, Logothetis, 1995, Stehle et al., 2012). There is no conclusive research with which to determine which argument is correct. This provided an opportunity to undertake further research to help provide clarification and determine whether student opinions can be measured and used to improve the laboratory learning experience.

1.2. Purpose Statement and Research Question

The purpose of this study is to gain a better understanding of what contributes to a quality engineering laboratory learning experience. Student evaluations were examined to see whether they could be used as an accurate measure of quality. These evaluations, carried out via research, laboratory demonstrators, training, experiments, equipment, facilities, resources and biases led to the construction of a process map which clearly showed how acting upon student evaluation data would lead to a higher quality laboratory experience. This is one of the first studies of this type to be conducted across a large number of courses, and over an extended period of time.

Two methods were considered to determine what a quality laboratory experience is, or should be: first by considering student experience, and second, by studying the impact it has on perceived student learning. To achieve this, a mixture of quantitative and qualitative research methods, and statistical analysis were incorporated into an iterative research design. This research approach aimed to identify if, how, and why student evaluations changed teaching skills, laboratory experiments, facilities and resources, and whether or not these improvements impacted on perceived learning.

The overarching research question that this thesis sought to answer was:

Can student evaluations provide data that can be used to guide improvements in the quality of laboratory experiences?

1.3. Thesis Overview

A number of investigative paths were undertaken to try and answer the overarching research question. The research strategy for this thesis is described visually in Figure 1-1.

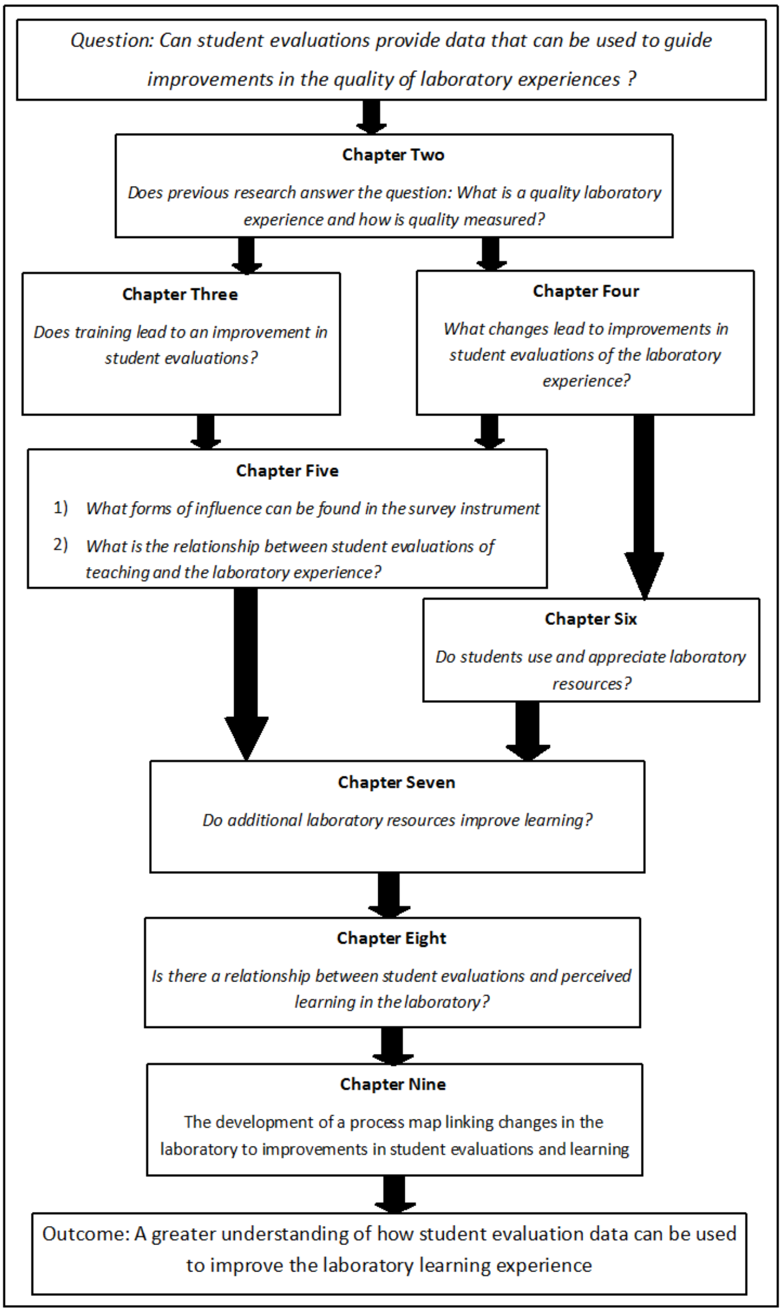


Figure 1-1: Diagrammatic representation of the research sub-questions used to formatively answer the research question

The lines of investigation in this study were guided by a number of research sub-questions which set the focus for each chapter and research approach. These sub-questions and chapters are:

Chapter Two: *Does previous research answer the question: What is a quality laboratory experience and how is quality measured?*
Chapter two presents an exploration of current literature to identify the reasons, including the learning objectives, used to explain why learning in the laboratory is important to engineering. An overview of why a quality education is important, and how it is assured and measured was also investigated. It also identifies the gaps in research that this study will try to address.

Chapter Three: *Does training lead to an improvement in student evaluations?*
It is generally assumed that training plays an important role in teaching. Chapter three uses an iterative refinement process to investigate the impact training and mentoring have on improving teaching effectiveness of laboratory demonstrators. The relationship between demonstrator training and student evaluation results is also explored.

Chapter Four: *What changes lead to improvements in student evaluations of the laboratory experience?*
Chapter four uses an iterative refinement process to explore changes to laboratory experiments, facilities, and resources, and their effect on student evaluations. An understanding of what students consider to be important to a quality laboratory experience is developed in this chapter.

Chapter Five: *Investigates two sub-questions:*
1) What forms of influence can be found in the survey instrument
2) What is the relationship between student evaluations of teaching and the laboratory experience?

A statistical analysis was undertaken to determine unwanted influences in the student evaluations, especially when using a team based teaching format. An investigation was then conducted to understand the relationship between student evaluations of laboratory demonstrators and to understand how much influence demonstrators have on their laboratory experience.

Chapter Six: *Do students use and appreciate laboratory resources?*
Chapter six extends the investigation into laboratory experience from chapter four to focus on the way students use laboratory resources. Using an iterative refinement process, learning resources were implemented with changes to student experimentation being observed and measured.

Chapter Seven: *Do additional laboratory resources improve learning?*
Chapter seven commences an investigation into understand whether positive changes in student evaluations are correlated with an improvement in learning. This is analysed through an iterative refinement process case study of a revised laboratory, improved through additional laboratory resources aimed at improving our understanding of the experiment and the facilities.

Chapter Eight: *Is there a relationship between student evaluations and perceived learning in the laboratory?*
An instrument based on laboratory learning objectives across the cognitive, psychomotor, and affective domains was used to measure perceived learning and laboratory examination performance and explore its relationship with student evaluations. In this respect, quality is considered as an improvement in student experience scores, perceived learning and performance in a laboratory exam.

Chapter Nine:
A discussion was carried out to determine how the findings from each sub-question can be linked via a process map. A comprehensive map of the relationships between teaching, experiments, facilities, resources and learning was devised. The outcome here is *a greater understanding of how student evaluations can be used to improve the laboratory learning experience*.

1.4. Scope and Limitations

This study conducted research on 25 courses with a laboratory component in an electrical, computer, and telecommunications engineering department at the University of Wollongong; this research only examined the laboratory component of the 25 courses. The list of courses is outlined in Table 1-I. Courses were surveyed over many instances, depending on the specific investigation. These details are provided in the research design section of each chapter. The first digit after 'ECTE' represents the course level; for example ECTE222 is a course in the second year of study. Since this study is concentrated at one institution the outcomes may differ at other institutions. Similarly, other disciplines (including other disciplines of engineering) may run laboratories using a different approach. However, this study provides a framework of knowledge that can be replicated and investigated at other institutions.

Table 1-I: Courses evaluated in this study

Course Code	Course Name
ECTE222	Power Engineering 1
ECTE233	Digital Hardware
ECTE301	Digital Signal Processing
ECTE333 A	Microcontroller Architecture and Applications Part A
ECTE344	Control Theory
ECTE363	Communication Systems
ECTE401/901	Multimedia Signal Processing
ECTE412/912	Power Electronics and Drives
ECTE423/923	Power System Analysis
ECTE433/933	Embedded Systems
ECTE170/172	Introduction to Circuits and Devices
ECTE182	Internet Technology 1
ECTE203	Signals and Systems
ECTE212	Electronics
ECTE290	Fundamentals of Electrical Engineering
ECTE323	Power Engineering 2
ECTE324	Foundations in Electrical Energy Utilisation
ECTE333 B	Microcontroller Architecture and Applications Part B
ECTE364	Data Communications
ECTE432/932	Computer Architecture
ECTE465/965	Wireless Communication Systems
ECTE469/962	Queuing Theory and Optimization
ECTE903	Image and Video Processing
ECTE906	Advanced Signals and Systems
ECTE955	Advanced Laboratory

The twenty five courses researched were undertaken by students from the computer, electrical, mechatronics, and telecommunications engineering disciplines, and one course was undertaken by students studying civil, environmental, materials, mechanical, and mining engineering. The laboratories consisted of physical, simulated or mixed experiments, and ranged from connecting or simulating electrical or digital circuits, controlling motors, programming microcontrollers, simulating network traffic, and programming in MATLAB. The types of experiment undertaken were based on meeting the course learning objectives dependant on available resources. Some examples of the laboratories and equipment used are as follows:

1) An electronics laboratory is shown in Figure 1-2; here the students design and construct electronic and digital circuits to reinforce theoretical concepts or to develop design skills. They use a variety of power sources and measuring instruments. Students also undertake simulation activities.
2) A power laboratory is shown in Figure 1-3; here students learn how a motor operates and how to use interchangeable LabVolt (LabVolt, 2015) modules to learn about power systems
3) A simulation from a computer laboratory is shown in Figure 1-4. MATLAB is used to teach students how to program and run simulations

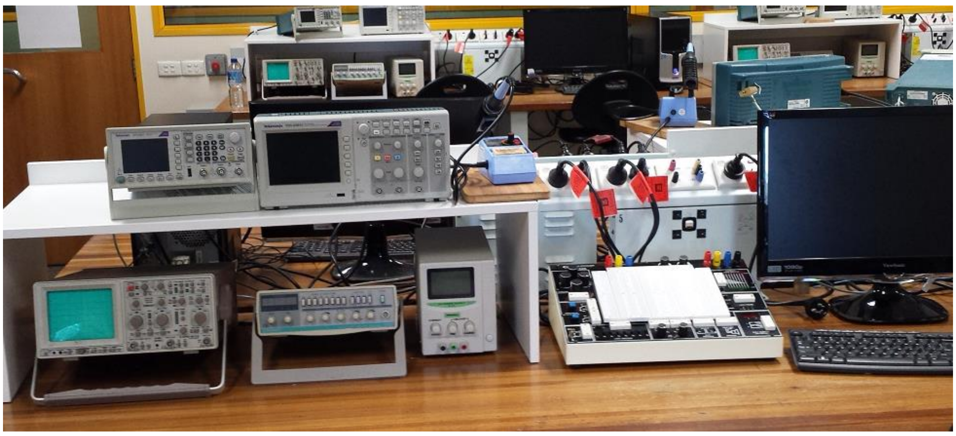


Figure 1-2: Equipment used in the electronics laboratory

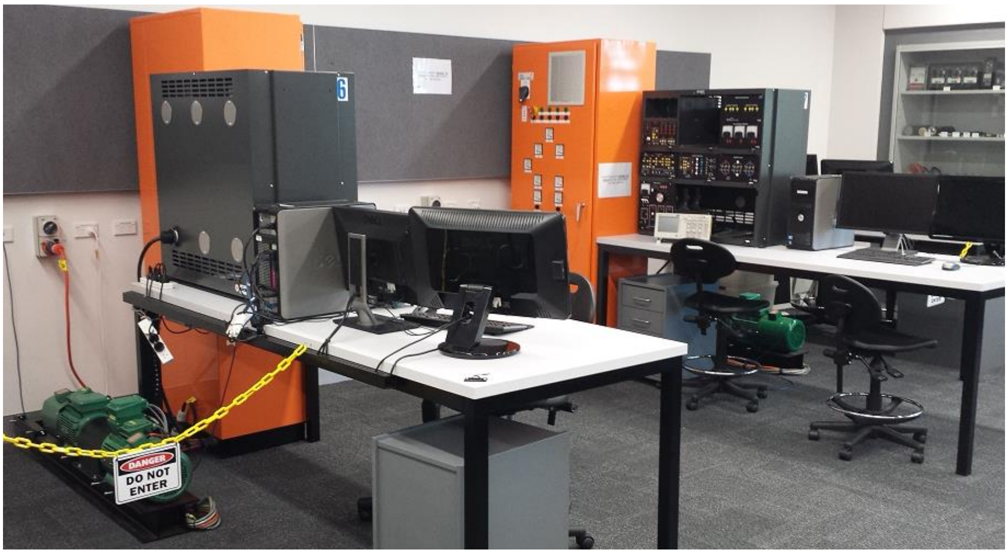


Figure 1-3: Equipment used in the power laboratory

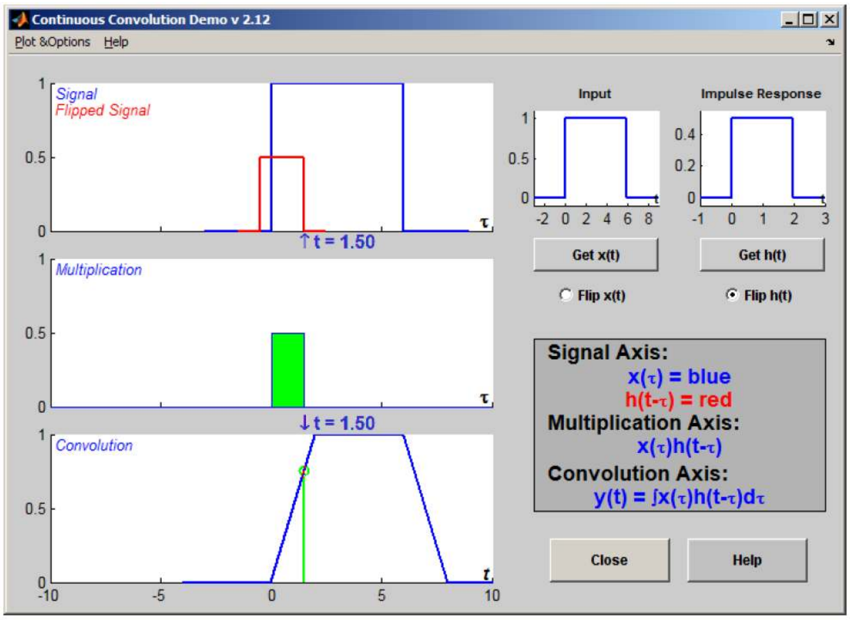


Figure 1-4: An example of a computer simulation using MATLAB

The laboratories examined and the student evaluations used only apply to laboratories where sessional laboratory demonstrators teach. This is associated with the overwhelming numbers of non-permanent staff teaching in the laboratory, as will be evidenced in the literature review. Therefore, the findings in this thesis would possibly differ if analysed on permanent academic staff.

Most laboratory demonstrators are higher degree research students, and most are international. These results could differ if other demonstrator's such as undergraduate students, people employed in industry, or a different make up of domestic and international students are used.

The university has a large cohort of international undergraduate and postgraduate students, in fact the city in which this university is located is known for its multicultural history. Different exposure to international persons may produce different results. While differences in the application of teaching staff or the profile of student cohorts can change between universities, the teaching and laboratory structures can be applied elsewhere leading to studies that confirm or disprove the thesis findings.

Data collection commenced in 2007 and concluded in 2015. During this time some courses were discontinued, some commenced, changed structure, or were upgraded as a result of this research. The author of this thesis was employed as a Laboratory Manager responsible for the quality of laboratory experience. As Laboratory Manager the author was responsible for working with the academic staff that coordinated the courses, to ensure that the experiments, facilities, and teaching staff were organised to a high standard. Therefore, as benefits were identified, changes were made and their impact was observed. This method of repetitively enacting change and learning about the impact is known as *action research* but applied as an iterative refinement process and underpins the importance of the methodology used in this thesis.

1.5. Action Research

The term "Action Research" was first used in the 1940's by Kurt Lewin from MIT. It is a research design that combines action (implementing a plan) with research (evaluating the changes that occurred from the implementation), that is under-utilised in engineering education (Case and Light, 2011). Action research is cyclic (as shown in Figure 1-5), and consists of five processes (NSW Department of Education and Training, 2010):

1. Planning – identifying the issue to be changed, developing the questions and research methods, and developing a plan of implementation
2. Acting – implementing the change according to plan, collecting and compiling evidence, and questioning the process
3. Observing – analysing and documenting the evidence and findings
4. Reflecting – evaluating the process and implementing findings
5. Identify action – the reflection process should identify new actions that can be implemented

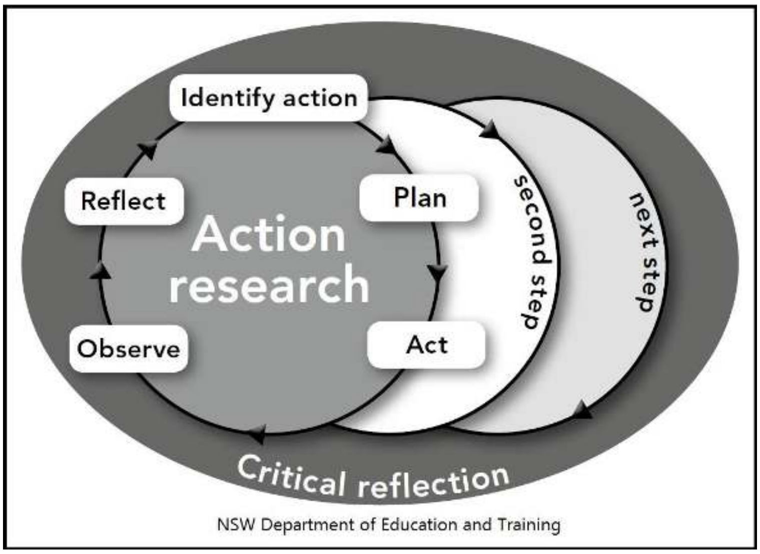


Figure 1-5: The Action Research Design Cycle

The benefits of action research were demonstrated for engineering education by Case and Light (2011) who found that the design is flexible and open to change. This design is best suited to educators (pg. 197) "*who are not only interested in systematically researching their own educational practices but also in implementing substantial personal and social change in their practice*". In support of this, Dick and Swepson (2013) outlined that action research should be used when , "*you wish to involve the people in the system being researched… [and] you wish to bring about* *change at the same time*". A valid action research study involves dialogic, process, outcome, catalytic, democratic, and process validity. A validation criteria of using action research has been developed and is summarised in Table 1-II (Rahman et al., 2012). This table outlines how the goals of action research can be linked to dialogic, process, outcome, catalytic and democratic validity.

Table 1-II: Validity Criteria in Action Research

	Goals of action research	Validity criteria	Comments
1	The generation of new knowledge	Dialogic and process validity	The determination of the 'goodness' of research through peer review.
2	The achievement of action-oriented outcomes	Outcome validity	The extent objectives of study were met and the problems resolved.
3	The education of both researchers and participants	Catalytic validity	The understanding of all who were involved in the research was increased and they were moved to some action of change.
4	Results that are relevant to the local setting	Democratic validity	The accounting of multiple perspectives and interests.
5	A sound an appropriate research methodology	Process validity	The inclusion of multiple perspectives and the determination of what constituted as suitable evidence of the study's assertions.

Source: Roselainy Abdul Rahman, Yudariah Mohammad Yusof, Sabariah Baharun

An example of action research being used in engineering is a study by Mejía et al. (2007) who used multiple action research cycles to develop a methodology for collaborative engineering environments. This led the researchers and users to improve technologies for the support and collaboration of engineering activities. Action research was also used to determine how mathematics educators could improve their teaching and student learning in engineering mathematics (Rahman et al., 2012). This study was carried out over nine years, in three different phases. The actions associated with phase two are based on the findings of phase one, while the actions of phase three are based on outcomes of phase two.

Virkki-Hatakka et al. (2013) used action research to improve the quality of teaching in two chemical engineering courses. Two action plans were carried out each year based on student feedback and teacher reflection from the previous year. The action research cycle lasted for six years and resulted in better learning outcomes (student achievement) and a more positive student experience. These studies highlight that action research designs are usually long term studies that involve many iterations in order to gain a better understanding, and there is always room for further improvements.

The cyclic nature of action research has its roots deeply embedded in the process of continuous improvement. This is highlighted in work carried out by Jørgensen and Busk Kofoed (2007) where action research was used to teach students who were actively involved in the research in order to understand the basic principles of continuous improvement and innovation. In this learning by doing approach the students were required to design and implement solutions for the subject they deemed relevant and important. At the end of the subject the students had developed some first-hand experience in continuous improvement processes.

As continuous improvement is the basic philosophy behind active research, many research studies based on continuous improvement could be classified as an action research study. The basic premise of continuous improvement is based on three basic steps: 1) study the current situation, 2) identify problems and solutions, and 3) implement these solutions. This process is repeated continuously, as shown in Figure 1-6, and follows the same premise as the action research shown in Figure 1-5. The main difference is that action research is used to improve quality and gain an understanding of teaching and learning. However, within this study theoretical models did not drive the research; instead the evaluation data was used to guide the research. The evaluation data provided clues to possible improvement that were researched and enacted upon in an iterative process. As this approach did not directly align with the traditional action research methodology, the research method used is described as *iterative refinement process*.

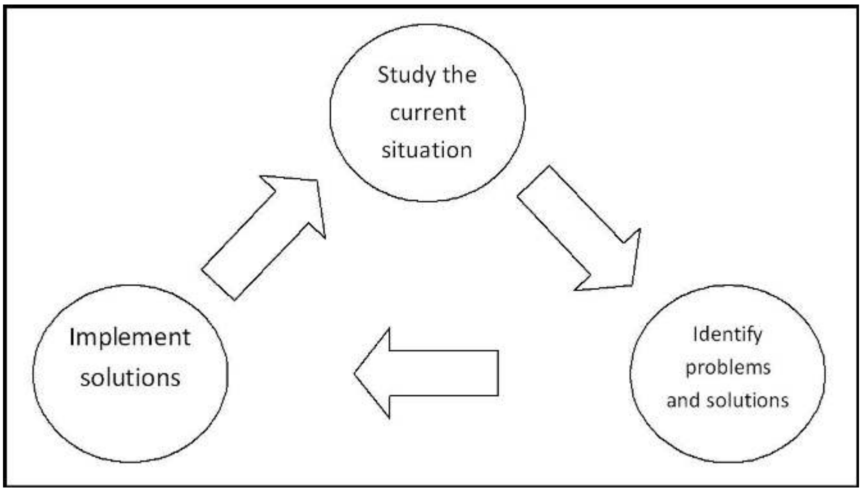


Figure 1-6: The Continuous Improvement Cycle

Since this thesis will examine improvements to the sessional teachers used in the laboratory and the experiments and facilities, two separate but linked research cycles were undertaken. The iterative refinement process was best suited to this thesis because of the need to examine changes across multiple instances of each course with immediate impact desired. Improvements to teaching and changes to laboratory experiments and facilities were phased across multiple years allowing impact to be measured. In order to determine if student evaluation data can be used to improve the laboratory experience the data needed to be analysed, changes within the laboratory implemented, observed and revaluated with further changes enacted as required. The changes to the student evaluation data guided the findings of the research questions.

A visual representation of the iterative refinement process for chapters four and five can be seen in Figure 1-7 where the cyclic process is the same but the changes and improvements being researched are different. This means that investigation one focuses on improvements to teaching covered in chapter three and investigation two focuses on improvements to the laboratory experience covered in chapter four. Before the research cycles can commence, a detailed study of the literature is needed to understand what is important about the laboratory? What is quality in the laboratory and who can define and judge, and how are student evaluations conducted and used? This forms the basis of the literature review in chapter two.

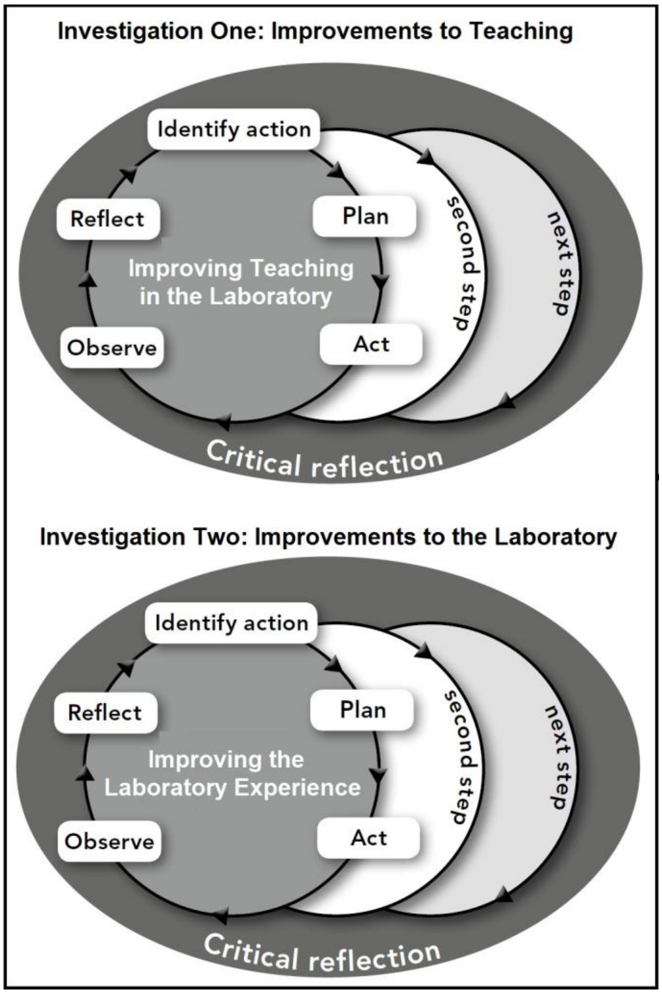


Figure 1-7: Iterative Refinement Process for Improving Teaching & the Laboratory Experience as Outlined in Chapters 3 and 4

1.6. Chapter Summary

This chapter outlines how important the laboratory is to engineering education, and the major gaps associated with understanding the validity and reliability of student evaluations, especially in terms of the teaching laboratory. It also shows that the desire to simultaneously increase quality and knowledge resulted in an action research styled approach labelled as an iterative refinement process. By implementing quality processes, changes to student evaluations can be linked to a process map leading to new knowledge that will improve teaching and learning in an engineering laboratory. To start the process and develop our understanding, a literature review was undertaken.

CHAPTER 2: LITERATURE REVIEW

The need for engineering education to incorporate learning in the laboratory is traditional and still highly valued in the engineering academic community (Feisel and Rosa, 2005, Kostulski and Murray, 2010). However, the teaching laboratory of today may be very different to what was taught ten, twenty, or fifty years ago. This chapter presents the outcomes of a review of literature on three main topics: learning in the laboratory, quality in education, and student evaluations.

The first topic is about understanding what is currently taught, how it is taught and measured, and what are the learning objectives in the laboratory from the literature. The second topic is used to define quality and appreciate why and to whom a quality education is important, and to consider the quality processes that are used in higher education. The final topic explores the ability of students to evaluate their experiences, their teachers, and their learning.

The goal of exploring literature related to these three topics is to establish what has been investigated and reported previously, in order to understand why learning in the laboratory is important and if student evaluations can improve quality in the laboratory? The sub-question for this chapter is therefore:

Does previous research answer the question: What is a quality laboratory experience and how is quality measured?

2.1. Learning in the Laboratory

This section looks at the history of the laboratory to determine why laboratory learning is important to engineering education. It investigates what type of learning is conducted in the laboratory, and how this learning benefits students.

2.1.1. The Laboratory – Past and Present

In engineering, practice based learning has always played a role in developing skills and knowledge. Up until the 18th century engineering could be classified into two types: Military, for building fortifications, catapults, canons, and other weapons; and Civil for building bridges, buildings, harbours, roads, and other structures (Futures in

Engineering, 2016). Before the first engineering schools were established, engineering was taught in apprentice style programs (Feisel and Rosa, 2005). The first schools of engineering were founded in France to support state consolidation and expansion, they were associated with the military and included mathematical rigor (Mrázek, 2002, Feisel and Rosa, 2005). Similarly, the first engineering school in the United States was associated with the Military Academy at West Point in 1802, and served primarily to educate engineers for military and civil service (Pérez, 2014). Maths was integrated into the curriculum following the French model, where the practical component of 'learning by doing' was acknowledged as being an important part of the learning process (Feisel and Rosa, 2005). The apprenticeship model of learning in which novice students learn a technique in which they could not only see but do from expert students within the laboratory was also used in other scientific disciplines such as Chemistry (Elliott, 2006); a process that continues to be taught.

The Industrial revolution in the mid-19th century led to a number of engineering universities commencing around the world, including the first engineering course at an Australian university in Melbourne in 1861 (Feisel and Rosa, 2005, University of Melbourne, 2016). Universities with engineering courses and societies continued to grow in Australia and in 1919 Engineers Australia (now responsible for accreditation) was formed as a result of the amalgamation of 12 existing engineering societies in Australia (National Library of Australia, 2016). The use of textbooks and laboratory manuals increased across disciplines and different approaches to laboratory learning, such as demonstrating laboratory concepts in a lecture for confirming and illustrating information were introduced, leading to the emergence of laboratory education research (Hofstein and Lunetta, 1982, Oliver, 1975).

In a historical overview of the laboratory, Feisel and Rosa (2005) outlined that in the 1970's institutions increased the importance of maths and science in the curriculum. To cope with this extra material, the amount of time learning in the laboratory was reduced, which reduced the practical skills. In the 1980's students were graduating without being adequately prepared in laboratory techniques, with the result that accrediting bodies such as Engineers Australia and ABET (previously the

Accreditation Board for Engineering and Technology) in the USA, put standards in place that forced institutions to improve their practical learning. This was done to highlight the importance of learning in the laboratory for engineering education.

Accrediting engineering degrees is important because it ensures that institutions meet quality standards established by the profession and will produce graduates capable of starting their careers. Indeed the stamp of approval provided by accreditation provides students, parents, employers, other institutions, and the public confidence in the degree. In Australia, engineering degrees are accredited by Engineers Australia, and like ABET and other accreditation bodies around the world, Engineers Australia has sound criteria in regards to practical learning. Each institution must ensure they have modern experimental facilities that will provide students with a holistic range of practical skills and learning ensuring that their curriculum meets the accreditation criteria. Relevant extracts of the current accreditation criteria applicable in 2016 (Engineers Australia, 2008) include:

> *"Appropriate experimental facilities must be available for students to gain substantial experience in understanding and operating engineering equipment, of designing and conducting experiments and undertaking engineering project work. The equipment must be reasonably representative of modern engineering practice and facilitate sound learning design. Facilities need to support structured laboratory activities, experiments of an investigatory nature and more open ended project based learning. Access to modern analysis, synthesis, visualisation, simulation, planning, organisational and measuring tools in the engineering, sciences, business, communication, and management domains is expected."*

In 2010 a report titled "The National Engineering Laboratory Survey" (Kostulski and Murray, 2010), data was reported on engineering laboratories across all 34 universities in Australia that provide an engineering degree at that time. The report investigated how important the teaching laboratory was currently viewed within Australia. It found that the executive staff from all thirty four universities agreed or mostly agreed that practical, experimental laboratory experiments are an integral and very important part of engineering education. It also found that sixty two per cent of academics ranked the laboratory component as the most important part of their subjects. The study also investigated how laboratories are run, and found that:

- 79.5% of laboratory sessions are between 2 to 3 hours in duration
- 74.4% of academics stated that all experiments are performed in groups
- Around 66% of subjects had at least one postgraduate or senior undergraduate student involved in running scheduled laboratory sessions

A laboratory does not simply need to be a room full of equipment and measuring devices. As computers and software have become more powerful, there has been a gradual shift towards conducting experiments in a simulated environment. While simulations are cheaper, safer, faster, and take less floor space (Hardy, 2008), they enable students to easily adjust and replay models to observe how the simulations affect the system. The biggest problem educators find with simulations is that the data are not real, simply a model of a physical process, whereas the data in hands-on laboratories are real (Corter et al., 2007).

A trend has recently emerged towards having a 'remote laboratory' which supplements traditional laboratories by allowing users to perform experiments on real systems via remote access (Fabregas et al., 2011). The experiment actually takes place and real data is obtained, but as with simulations, a student does not need to be close to the physical equipment and can conduct experiments any time of the day (Corter et al., 2007). The other advantage of remote laboratories is that they can be shared between institutions and require less maintenance due to less wear and tear, resulting in substantial cost saving to universities (Lowe et al., 2009). While providing real data, remote laboratories do not provide hands-on experience (Corter et al., 2007), and if all experiments are simulated or remote, students are deprived of the many important learning experiences found in a traditional laboratory; therefore, a balance is needed. Simulations and remote laboratories will probably predominate in the future with the arrival of MOOCs (Massive Open Online Courses) and other forms of online education because these learning formats encourage new ways of teaching engineering in higher education using an online/remote environment (Buchanan, 2013).

To validate the notion that remote laboratories can assist learning, Wolf (2010) undertook a small scale study on a computer networks course. Twenty nine students participated in a study that involved numerous assessments of learning in lectures and remote laboratories. The remote laboratory took place after the lecture. Students participated in a quiz before the lecture, between the lecture and lab, and after the lab, to provide a timeline on how learning was taking place. The study found that 54.1% of learning could be attributed to the lectures and 45.9% to the laboratory. While this was a small study, it did provide some evidence for the usefulness of a laboratory for learning, but it failed to address what type of learning took place, or whether the learning objectives of traditional hands-on laboratories are the same as simulated or remote experiments.

The complexities associated with learning was investigated by Lindsay and Good (2005) exploring the impact of different access modes. Conducted in a third year Mechanical Engineering course at an Australian university, the study explored the differences between cohorts of students undertaking the same experiment in three different modes (proximal, remote and simulation) based on constructivist theory that different types of laboratories should lead to different learning outcomes. The courses eight learning outcomes was used as a measure: appreciation of the hardware involved; reasons for calibration; the complexity of signals; identification of assumptions; exception handling; processing of data; limitations of accuracy; and comparison of data. Additionally, students were required to undertake a post-test survey that gauged student perceptions. Findings from the study indicated that alternative access modes may improve some learning outcomes at the expense of degradation in others. Moreover, differences in the perceived objectives by the students were discovered between the three modes. The study reinforces the need for a balanced approach to different laboratory delivery modes. Also of importance was that the course learning outcomes were all associated with cognitive learning. The findings could have been different if the learning outcomes were different; for example, if the learning outcomes were associated with greater manipulation of the technology used. If all course learning objectives are cognitive based it could be possible that learning objectives based on the laboratory experience could be overlooked. In order to balance the historical apprenticed trained engineer with the modern theory based engineer, it may be appropriate to consider learning objectives beyond the course and discover the learning objectives that could be associated with the laboratory.

2.1.2. Laboratory Learning Objectives

To comprehend the learning effectiveness of a laboratory, a general understanding of the different learning domains is needed. A holistic instrument to help measure student development, which has been revised over the years, is Blooms Taxonomy (Krathwohl, 2002). This taxonomy is named after psychologist Benjamin Bloom, who originated this concept with measurement specialists in the USA; Max Englehart, Edward Furst, Walter Hill, and David Krathwohl formed the committee of educators and published their first work in 1956 (Armstrong, 2015). The purpose of the framework was "*for classifying statements of what we expect or intend students to learn as a result of instruction*" (Krathwohl, 2002, pg. 212). The committee identified three domains of educational activities or learning. Blooms Taxonomy can be generally applied to all learning and is used as a measure of student development over the cognitive (knowledge), psychomotor (skills), and affective (attitude/self) learning domains. The idea of having three domains is to encourage educators to provide a more holistic approach to learning where each domain consists of a number of levels, with higher levels of learning depending on lower levels of learning (Anderson et al., 2001). While the levels within each domain are generally important (and the level descriptors and dependence are revised over time), it is the fact that the three domains exist that is important to learning in the laboratory.

Uncertainty of the laboratory learning objectives became increasingly apparent in the 1980's creating the need to consider three domains of learning. A paper by Graham (1983) raised the need to undertake more research on laboratory learning because the focus had been mainly on what and how experiments are carried out, rather than why; this means that engineering educators needed to develop a better understanding of how the learning process occurs in a laboratory environment. In part, this was a response to research which questioned the benefits of the laboratory (Bates, 1978, Saunders and Dickinson, 1979). These studies began to question whether student learning was improved by the laboratory, and hence justified the cost of running and maintaining laboratories in an environment of budget cuts. At this time the alternative to running laboratory classes was a lecture with a laboratory demonstration. During this period many studies investigated how effective laboratories were compared to the laboratory and laboratory demonstration methods.

Once such study by Oliver (1975) investigated the difference between a lecture-discussion with demonstrations, and a lecture-discussion and demonstrations with laboratories in biology. The study concentrated on the cognitive domain and found no significant difference in learning. A similar study by Coulter (1966), also found no significant difference in cognitive learning, but Coulter looked beyond the cognitive domain and found those students who had completed the experiments, appreciated the laboratory experience and had gained psychomotor skills. The problem with implementing these studies was first alluded to in an analysis of thirty seven studies by Cunningham (1946). The issue here was that any comparison between the learning styles would be affected by the learning objectives being measured. That is, learning in a laboratory is more than just developing cognitive skills. A more recent review of such studies by Hofstein and Lunetta (1982) reached a similar conclusion; they found that the research design in terms of the learning being measured is a major issue, and therefore more attention is needed to understand the learning goals of undertaking an experiment in order to better compare teaching methods. The underlying tone in this literature is that more research is needed to determine the effectiveness and the role the laboratory plays in learning outside of the courses defined learning outcomes (Cunningham, 1946, Hofstein and Lunetta, 1982, Majerich, 2004). As a consequence, researchers began to explore learning in the laboratory outside the cognitive domain.

To explore learning in the laboratory means that a consensus of the goals of laboratory learning is needed. In the late 1990's the possibilities of simulated learning and distant education, along with advances in computer and networking technology, continued to raise questions about the learning objectives associated with the laboratory (Feisel and Rosa, 2005). Without a consensus of the learning objectives it was difficult to assess the impact that new technology would have on laboratory learning. In response, ABET and the Sloan Foundation (an American not-for-profit grant making institution that supports original research and broad-based education related to science, technology, and economic institutions (Sloan Foundation, 2016)), organised a three day American colloquy in January 2002. This colloquy featured prominent engineering educators from the Unites States and some guest academics from Hong Kong and China. The goal was to develop a set of learning objectives for the learning laboratory that could be further discussed by the engineering education community (Feisel et al., 2002, Peterson and Feisel, 2002).

A detailed summary of this colloquy was provided by Peterson and Feisel (2002). At the colloquy a broad statement was defined to answer the question, "What are the fundamental objectives of engineering education laboratories?" After significant discussion the following statement was decided upon (pg. 167):

> *"The instructional laboratory experience is personal interaction with equipment and tools leading to the accumulation of knowledge and skills required in a practice-oriented profession"*

In addition, a set of thirteen learning objectives were developed to apply across the undergraduate engineering degree. These objectives are listed in Table 2-I.

Table 2-I: The thirteen laboratory learning objectives, each starting with the statement "By completing the laboratories in the engineering undergraduate curriculum, you will be able to…" (Peterson and Feisel, 2002, pg. 167-168)

Objective	Laboratory Experiences
Objective 1: Instrumentation	Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities
Objective 2: Models	Identify the strengths and limitations of theoretical models as predictors of real world behaviors. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles
Objective 3: Experiment	Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system
Objective 4: Data Analysis	Demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions. Make order of magnitude judgments, and know measurement unit systems and conversions
Objective 5: Design	Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements
Objective 6: Learn from Failure	Recognize unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions
Objective 7: Creativity	Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving
Objective 8: Psychomotor	Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources
Objective 9: Safety	Recognize health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly
Objective 10: Communication	Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports
Objective 11: Teamwork	Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable
Objective 12: Ethics in the Lab	Behave with highest ethical standards, including reporting information objectively and interacting with integrity
Objective 13: Sensory Awareness	Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems

These thirteen learning objectives are important and can be mapped across the courses undertaken in this study, but not all learning objectives are assessed within a laboratory environment. For example, at the author's institution the learning of ethics in the lab is not assessed or measured, which for example, they can demonstrate when reporting measured data which may not appear as the answer expected. This is because some learning is tacit, knowledge that typically is not openly expressed or stated (Polanyi, 1966). In an attempt to discover some of the unmeasured benefits of learning in a laboratory, an Australian study (Razali and Trevelyan, 2008) explored a pilot instrument to measure practical intelligence (psychomotor skills) and tacit knowledge. This instrument was tested in a small scale experimental study (Bahri and Trevelyan, 2013) that found a significant difference in practical intelligence and tacit knowledge between students who had and who had not experienced learning in a laboratory. Furthermore, these studies highlight that learning in the laboratory goes beyond explicitly specified learning outcomes, and these other forms of learning are difficult to measure. However, they are essential for preparing students for a practicing profession and provide further evidence for this thesis to explore what constitutes a quality laboratory experience and its relationship to learning. More importantly, learning in the laboratory that is outside the cognitive domain has not been adequately considered in the research.

The learning objectives of laboratory work (Peterson and Feisel, 2002), practical intelligence, and tacit knowledge (Razali and Trevelyan, 2008) can be mapped to the cognitive, psychomotor, and affective domains of learning outlined in Blooms Taxonomy. An instrument to measure the thirteen laboratory learning objectives across the three domains was developed by Salim et al. (2013) who grouped the engineering learning objectives in Table 2-I to identified learning outcomes across the cognitive, psychomotor, and affective domains. Their research highlighted the wide range of skills developed in the laboratory and the fact that multiple domains of learning are involved in almost all learning activities. The mapping of laboratory learning objectives into three domains, as determined by the authors, is shown in Table 2-II, Table 2-III, and Table 2-IV. While this was only a pilot study with 26 students, it is still the best attempt identified to measure laboratory learning objectives across multiple domains. As a result, this thesis will test and build upon their "Measuring the Learning Outcomes of Laboratory Work (MeLOLW)" instrument. This framework will be used to consider more than the cognitive learning in the iterative refinement process, it will also be used to measure perceived learning in chapter eight. Expanding this knowledge is an important contribution to laboratory learning, especially when comparing the advantages and disadvantages of learning in a physical laboratory rather than a virtual or remote laboratory.

Table 2-II: Laboratory work learning outcomes (cognitive domain)

No.	Items
1.	Improve knowledge about theory learned in class
2.	Help to verify theory learned in class
3.	Improve ability to use formulas in solving problems / questions related to theory
4.	Improve ability to use the correct unit for the measured values
5.	Help to develop basic statistical technique (i.e. draw graph and chart)
6.	Improve understanding about safety in the lab
7.	Improve ability to analyze / discuss experimental result
8.	Improve ability to write the conclusion of the experiment
9.	Improve ability to write laboratory report

Source: Salim et al. (2013) pg. 5

Table 2-III: Laboratory work learning outcomes (psychomotor domain)

No.	Items
1.	Improve ability to conduct experiments
2.	Improve ability to select appropriate instruments
3.	Improve ability to plan experimental work
4.	Improve ability to construct circuits
5.	Improve ability to connect instruments
6.	Improve ability to operate the instrument (i.e. select proper range)
7.	Improve ability to take the reading of the instruments

Source: Salim et al. (2013) pg. 6

Table 2-IV: Laboratory work learning outcomes (affective domain)

No.	Items
1.	Improve team working skill
2.	Improve communication skill
3.	Improve ability to learn independently
4.	Improve ethics (i.e. plagiarism, copy other students' results)
5.	Improve creativity
6.	Learn from failure
7.	Improve motivation

Source: Salim et al. (2013) pg. 6

The ability to better understand learning in the psychomotor and affective domains could lead to a possible rethink in the way learning outcomes are assessed. An Australian study by Nightingale et al. (2007) which analysed the civil engineering programs in three universities across three Australian states, found a significant mismatch between the stated learning objectives of these courses and how the students were assessed. All three institutions relied heavily on examinations to assess cognitive learning outcomes, with assessments from the laboratory being close to negligible. The authors argued that concentrating the assessment to examinations sends the wrong message to students about what learning is important. Therefore, by better understanding learning in the laboratory it might be possible for students to engage in a wider range of learning modes and broaden their learning across the three domains.

2.1.3. Learning by Doing

An example of understanding the importance of learning in the laboratory was highlighted by a study conducted by Casas and del Hoyo (2009). They investigated the effect of applying the learning objectives to two Electrical Machine courses at a Spanish University. The original delivery in the laboratory was via a laboratory instructor who demonstrated the operation of laboratory equipment as described in the laboratory manual. An analysis of the courses found that students had low satisfaction, which affected their attention, motivation, and learning. Student achievement (via assessment) was lower in the practical component of the course than with the theoretical component. After redeveloping the practical component to incorporate a ‘learning by doing’ approach, guided by the learning objectives defined at the ABET colloquy (Table 2-I), there was a significant improvement, and student satisfaction, participation, and achievement increased. This study illustrates that having a laboratory component is no guarantee that learning takes place, or that it is a gratifying experience. Careful consideration must be given to the design and learning objectives. One of the weaknesses of this study was that it did not specify the number of participating students, and student achievement could have been measured better if they had an instrument to measure learning across multiple domains.

The benefits of learning by doing resonates with the ‘Learning Pyramid’ created by The National Training Laboratories (Dale, 2005). The Learning Pyramid is designed to indicate the average retention rates of various learning methods, and is shown in Figure 2-1. While the Learning Pyramid has taken on many forms over the years, and the accuracy of the original research has been criticised for not producing the original data, it is highly referenced in training circles to show the importance of learning by doing (Lalley and Miller, 2007, Strauss, 2013). The structure of the pyramid suggests that active forms of learning are strongest for retention, which provides some evidence that practical learning in the laboratory can be very effective as a learning tool.

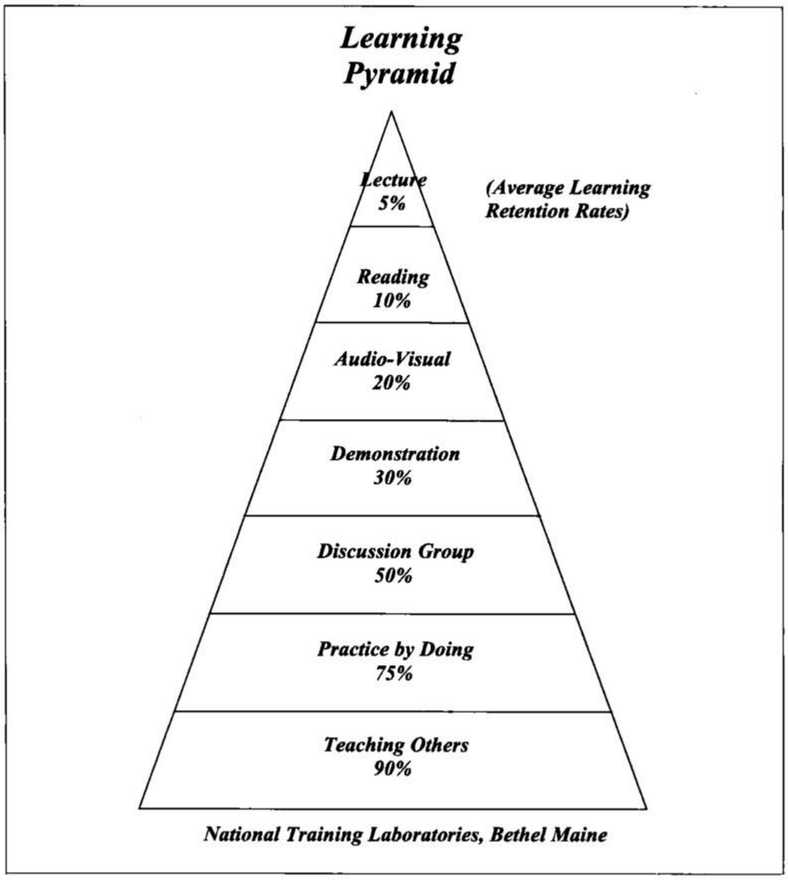


Figure 2-1: The Learning Pyramid by NTL

The laboratory study by Casas and del Hoyo (2009), and the Learning Pyramid indicate that learning by doing (using multiple learning domains) has a positive influence on learning. Whereas learning by watching, whether in a laboratory or lecture, has a lower retention; this means that active approaches to learning in the laboratory are important. For example, an inquiry based learning approach (posing questions, problems or scenarios—rather than just providing facts) was investigated by Boxall and Tait (2008) in a civil engineering degree course at the University of Sheffield. Students were required to work in small groups with little direct supervision, with information being provided on the equipment, background theory, and advice on experimental design. The students were then left to undertake their own investigations into hydraulic phenomena. Unlike the previous less active format, the students enjoyed and appreciated this new approach, which resulted in a better understanding of hydraulics observed with an improvement in class averages. Active learning approaches, like inquiry based learning, do not automatically result in greater student experiences. For example, an Australian study on civil engineering students by Dawes et al. (2005) investigated the impact on learning in a new student experimental learning centre. The centre was developed to provide students with focused, hands on experience using multiple forms of media. In 2003 (the centre's first year) a study was conducted on an engineering materials course with 100 students. The students had to conduct one experiment using the active approach and four experiments using the traditional passive approach. More than 70% of students preferred the passive approach due to start-up problems with the equipment and the extra workload. In 2005 the study was repeated with 99 students undertaking four active experiments and one passive (the reverse of the previous study). The outcome was reversed with 72% of students enjoying the active approach. The authors believe that the change in attitude could be attributed to the change in the first experiment in which the students became accustomed in the following experiments. Moreover, most of the equipment issues had been resolved. It is therefore important to consider the experimental approach and the relationship between student experience and the equipment used. This will be examined in chapter four using an iterative refinement process.

2.1.4. Section Summary

The literature has shown that the laboratory still plays an important role in engineering education because it is an environment where learning takes place 'by doing', a learning process considered highly effective and well received by students. However, simply including a laboratory component is no guarantee of learning or for a satisfying student experience. Therefore, more research is needed into what learning occurs in the laboratory, how students learn, and how this can be related to the student experience.

The laboratory has been evolving over time with simulations and remote laboratories gaining more influence. These new technologies are advantageous to laboratory learning and concentrate on cognitive development and specific course learning outcomes leading to the possible underdevelopment of skills across the thirteen laboratory learning objectives. Since most literature concentrates on cognitive learning, an identified gap is the need to consider the laboratory learning across the psychomotor and affective domains. This thesis will therefore consider the three domains across the iterative refinement process and will use the Measuring the Learning Outcomes of Laboratory Work (MeLOLW) instrument developed by (Salim et al., 2013) to evaluate learning. The outcomes will help to design more effective experiments and an improved understanding of learning that can be used to find the appropriate balance between traditional and new forms of laboratory learning. This would result in changes to the quality of learning, an important factor that must be understood.

2.2. Quality in Education: Benefits for Stakeholders

Quality is important because simply exposing students to a laboratory is no guarantee that learning is taking place or that they appreciate the experience. To ensure positive learning experiences means that quality processes are needed. This section will examine literature to determine how quality is defined in relation to education. Of interest is to investigate who are the stakeholders in education, and to define who can determine a quality experience.

2.2.1. The Customer

Mustafa et al. (2012) defined customer satisfaction as being when (pg. 64) "*a customer is satisfied with a product or service that meets their requirements, needs or expectations*". A product or service that meets customer satisfaction can be described in terms of quality (Kelso, 2008), and therefore products or services of high quality are generally sought after. One of the problems about service quality is "*that it is subjective, unlike quality of products, which can be measured objectively*" (pg. 501) (Owlia and Aspinwall, 1998).

In terms of business, quality is a fairly easy concept to grasp because companies try to make products that meet customer requirements so that their product/service is purchased/used and they can make a profit. Excluding the monopoly environment, if a customer is not satisfied they can seek the service or product from a competitor, which then reduces the value of the business to its stakeholders; stakeholders being management, employees, owners, or shareholders (Grygoryev, 2005).

In terms of education, quality is a very complex issue (Grygoryev, 2005, Kelso, 2008, Doherty, 2008) because the customer is not easy to define. In business, the customer is usually the purchaser of the product or service, but with education, the financier of the service and the number of stakeholders interested in the outcome is more complicated. An American study on quality in education by Grygoryev (2005) claimed that parents wanted the best possible education for their or child's money, students wanted the best possible education to get the best job, industry wanted the best students to increase competitiveness, and governments wanted to see the taxpayer's dollar spent efficiently. Moreover, unlike in business, students are less likely to change providers in higher education, opting instead to discontinue their studies, thus resulting in a lost opportunity for the institution and the individual (Bain et al., 2012).

In a UK discussion paper on quality in education, Doherty (2008) listed a number of paymasters, including the student, parent, employer, and the government. The makeup of these stakeholders is very diverse and can have conflicting expectations on what constitutes a quality education. To add to this complexity (pg. 258) "*there may be many different purposes*" to what is being measured as a quality outcome; is it the percentage of students graduating or the percentage of graduating students deemed worthy of obtaining a job?

One of the important stakeholders in education is the government. They are interested in the quality of education for a number of reasons; one being an efficient use of taxpayer's money, and to keep tax rates low in order to remain competitive and stay in power (Grygoryev, 2005). Another reason is that education is a driving force for national prosperity; for industry to thrive and grow, they need well trained and educated workers that can increase their competitive advantage (improve GDP). This is important for governments because the performance of the economy plays in the mind of voters (Kelly, 1992). For some governments, especially Nordic countries such as Denmark, Finland, Iceland, Norway and Sweden, a quality education is primarily seen as a way to offer equal educational opportunities for all their citizens (Välimaa, 2015).

While Nordic countries offer free education, England and Australia have been increasing the university fees payable by students over the last two decades, leaning towards US styled funding models (Woodall et al., 2014). A consequence of this has been the transformation in the way government's identify the student as the customer (National Committee of Inquiry into Higher Education, 1997). The notion of education being regarded as a product or service has caused concern within the academic community. This was well summed up by Lesnik-Oberstein (2015), "*for* *what is there left to learn, when you already know it in order to demand it?*". A review of literature by Bunce et al. (2016) found the following concerns: students seeking to 'have a degree' rather than 'be learners' (students become less engaged with learning); rating popular lectures over rigorous ones (possible pressure to 'dumb down' content); and greater sense of entitlement resulting in increased complaints. If such concerns are valid, quality cannot be guaranteed by focusing on the student as a customer.

While some governments are increasingly seeing students as customers, it is important to understand how students see themselves. While research in this area is limited and needs extending, some initial findings are quite interesting. A study of first year students in a north east United States university has been carried out by Saunders (2015). A survey was completed by 2674 students (offered to 4469 students) at orientation, before actually experiencing university, seeking to understand their perceptions as a customer. Students were asked questions such as, "*If I'm paying for my college education, I'm entitled to a degree*"; "*I would take a course in which I would learn a little or nothing but would receive an A*"; "*As a student, I believe that my role is that of a customer of the university*"; and "*If I cannot get a good job after I graduate, I should be able to have some of my tuition and fees refunded,*" which were then rated against a five point Likert scale. Considering that paying high tuition fees is well established in the United States, the survey data suggests that most students do not express a customer orientation towards their education; in fact the study found that only 3 of every 10 students expressed a customer orientation. One serious limitation with this study is that it was carried out at orientation and the students could have been 'idealistic' before experiencing the realities of university life.

A small scale English study by Tomlinson (2015) who interviewed 68 undergraduate students, found findings that were similar to Saunders (2015) in that students did not see themselves as customer orientated. This was followed by another English study by Bunce et al. (2016) who surveyed 608 undergraduate students across 35 universities in their first, second and final year (a very low sample). This design eliminated the possibility of any idealistic responses as might have occurred in

Saunders (2015). The survey posed statements including: "*I think of my university degree as a product I am purchasing*"; "*I would choose to study even if I didn't achieve a degree from i*t"; and "*I always try my best in assignments*". The study found that students with low academic performances were customer orientated who could possibly be linked to the 3 in 10 students in Saunders (2015) study, but this was not investigated.

These three studies do suggest that to average students, some academic concerns may not actually play out in the classroom, so it is possible that students can evaluate education fairly without a customer orientated bias. However, this possibility is questionable; hence the need for the overarching question asked in this thesis, "c*an student evaluations provide data that can be used to guide improvements in the quality of laboratory experiences*". Section 2.3 examines the literature on student evaluations and the link to quality.

2.2.2. Learning

Section 2.2.1 outlined some concerns raised about treating students as customers and judging the quality of their experience, and as discussed, the quality of a product or service is well understood. What is the impact of a quality education? Does a happy student equate to a student that is learning?

The implications of the quality of education and national prosperity was highlighted in a World Bank policy research paper by Hanushek and Wößmann (2007), who investigated the role that education plays in economic growth. The paper defined quality as student performance on a standardised test, and claimed that parents and policy makers accept this as a measurement of cognitive skill. The performance data from the standardised test (such as the Program for International Student Assessment (OECD, 2015)) were then compared to economic factors such as its impact on individual incomes. A number of important findings from the paper include that, (pg. 2) "*educational quality, measured by cognitive skills, has a strong impact on individual earnings… and has a strong and robust influence on economic growth*"; that (pg. 60) "*there is no relationship whatsoever between expenditure and* *performance*". This is highlighted in the graph shown in Figure 2-2 which compares expenditure on education and student achievement via maths performance across many countries. The graph shows that high spending on education does not correlate to better maths performance. This leads to the notion (pg. 77) "*that knowledge rather than just time in school is what counts*". This research highlights the importance of governments as stakeholders, and the need to develop policies that pay more attention to quality. While it can be extremely difficult to compare spending across different currencies, the research suggests that it is the quality of the education or cultural attitudes towards education, not the amount of time spent in school, or the amount of money spent that is important, and since running and maintaining teaching laboratories is very expensive, the need to ensure quality is paramount.

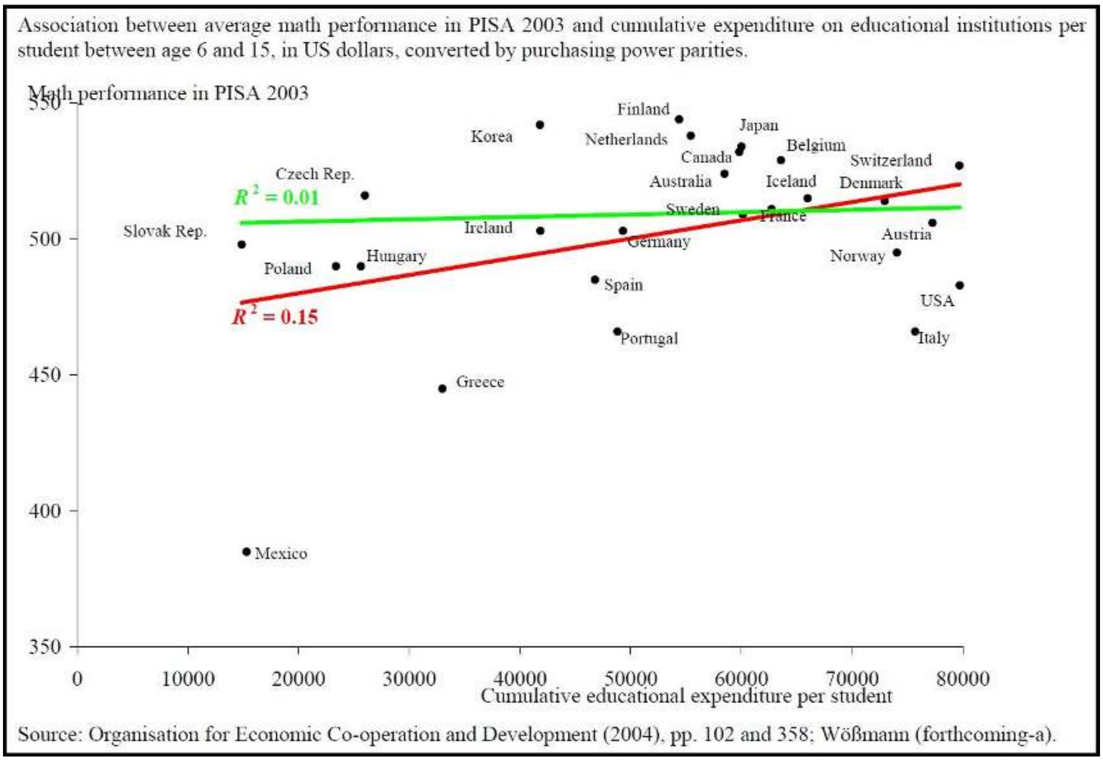


Figure 2-2: Student Achievement Compared to Education Expenditure

While the scope of this thesis is on laboratory learning in tertiary education, the focus of PISA by (Hanushek and Wößmann, 2007) is an important one. PISA involves measuring the assessment of the reading, mathematics, and science of 15 year old students (OECD, 2015), i.e., the skills needed for engineering and science degrees. A recent Australian study on the participation of HSC mathematics courses (for entrance into university) by Wilson and Mack (2014) shows that maths participation is in decline. The trends in Figure 2-3 show that the uptake of advanced mathematics is in decline while the number of students undertaking basic or no maths is increasing. As mathematical rigor is vital for an engineering education (Feisel and Rosa, 2005), any decline in mathematical skills for students entering university can result in negative quality consequences for engineering and science departments. This result raises the importance of implementing and ensuring quality processes. As the study by Bunce et al. (2016) indicated, students with lower academic performances tended to relate towards a customer orientated approach, so if the performance of students entering university increases at the lower end, their ability to judge educational quality becomes even more questionable.

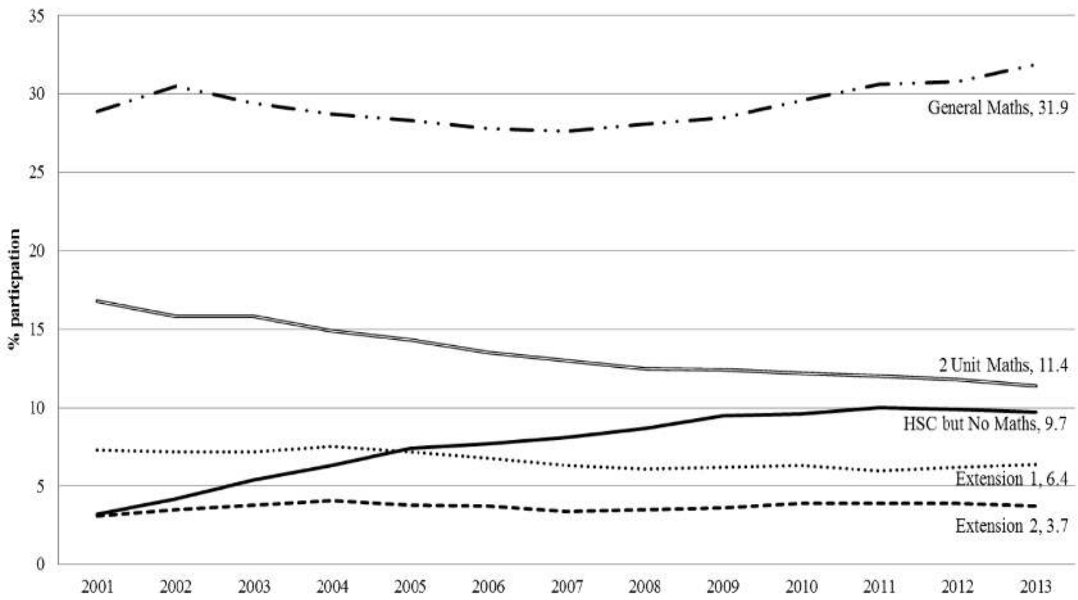


Figure 2-3: Participation in HSC mathematics courses 2001-2013 Source: (Wilson and Mack, 2014)

Assuming that students are actually able to measure quality in education, the most important outcome would then be the measurement of learning; that is, do they really know the value of learning obtained from their experiences? The problem with research into education is that learning is extremely difficult to measure; most assessments measure the level of competency and not the amount of learning gained from the start of the course to the point of assessment. Indeed, if the literature in

Section 2.1 is considered, it can be debated that even academics are not clear on the best ways to measure the learning objectives of the laboratory, so how then would students recognise learning and could this be associated with student satisfaction? This is important because many research studies focus on implementing a new teaching approach, comparing the difference in assessment performance, and then compare this to the satisfaction of the student (quality of experience). That is, is there any link between learning and student satisfaction?

For example, a study between three modes of learning (online instruction, traditional instruction, and a combination of online and traditional) was carried out by Lim et al. (2008) to compare student achievement and satisfaction. One hundred and fifty three undergraduate students in an undergraduate wellness psychology course completed a survey to convey their perceptions and levels of satisfaction, and then a written pre and post-test was used to measure student achievement. The study found that the online learning group and the combined learning group had statistically higher levels of achievement than the traditional group. In terms of student satisfaction, the combined learning group was most satisfied; but this was the only group with any significant difference to the others. After the mean scores were compared, the order for student achievement and student satisfaction was the combined group, the online group, and the traditional group, and since the approach with the most learning was associated with the highest student satisfaction, this study suggests that a link is possible.

A similar study conducted by Mason et al. (2013) compared the effectiveness of a control systems course in a flipped classroom and a traditional classroom, in a mechanical engineering department. The course was evaluated over a two year period, with one year in each format. All the major variables needed to run the course such as a professor, textbooks, timeslots, contents, and order remained the same, except for the delivery and student cohort. This study found that the flipped classroom increased student achievement, but in terms of student satisfaction it only slightly rated better than the traditional classroom. However, student satisfaction was tracked regularly, with students only beginning to appreciate the new approach towards the end of the course. This new approach was initially associated with the frustration students felt adapting to the new format, and although, a link between student satisfaction and learning could be established, the importance of timing the evaluation was raised.

While other researchers support a positive relationship between satisfaction and achievement (Elliott and Shin, 2002, Zhang, 2005), some other research has raised questions. Lewis (1994) carried out an experiment at an Australian university to determine what effect incorporating videos into an undergraduate physics laboratory would have on student satisfaction and achievement. This study was conducted in two first year level courses. To assist in this comparison, the videos were only used in half the laboratory sessions; that is, they were either not used in the first half, but used in the second half, or vice-versa. Student achievement was assessed via reports of the laboratory experiment and class mark based on understanding and performance exhibited in class. The study found that the videos helped increase student satisfaction, but this was not reflected in student achievement so there was no link between student satisfaction and learning. However, perhaps the assessment did not reflect the benefit of learning outcomes associated with watching the videos.

A study by Lucke et al. (2013) investigated the impact of flipping the classroom in an Australian third year fluid mechanics course. This required students to work through study material at home before participating in workshops used to replace the traditional lecture approach. This small scale study found that student engagement increased with the flipped approach, and the students found the approach better than the typical learning approach used at the university. Student comments reinforced this result: "*I enjoyed a fresh new way of learning. The ability of learning at your own pace is something I liked. Coming into workshops was much easier then going into a regular lecture due to having the hand-e-lecture*". However, when the authors compared the assessment marks against previous cohorts they found no significant difference in achievement and the increase in student engagement could have been associated with a novelty effect. That is, there was no link between student satisfaction and learning, but again, the measurement of learning may be questioned. For example, considering that student engagement had increased significantly, could this have resulted in an increase in development in the affective domain; particularly considering that Bloom's Taxonomy educators should be developing students across all three domains.

A flipped learning approach was also investigated in a New Zealand university engineering management course by Wilson (2013). Findings from the study of 44 students mirrored those of Lucke et al. (2013) with students finding the flipped approach more enjoyable and beneficial than the traditional approach used in other courses at the university. Assessment performance remained the same as student cohorts in the previous two years, but there was a significant increase in student engagement, so if student engagement increased during class activities, could this be associated with unmeasured learning in the affective domain?

The literature has shown that some studies show a link between student satisfaction with learning while others dispute this fact; further reinforcement of the need for this thesis to investigate whether "student evaluation data can be used as a tool to help improve quality in the laboratory". The literature also suggests that performance in assessment tasks is not a guaranteed measure for all types of learning; learning could also be improved in ways academic staff did not intend beyond the specific course learning outcomes. This also reinforces the approach whereby learning should be considered across the cognitive, psychomotor, and affective domains by building on the Measuring the Learning Outcomes of Laboratory Work (MeLOLW) instrument developed by (Salim et al., 2013).

2.2.3. Quality by Student Experience

A report into the quality processes in teaching and learning in Australia and OECD countries by Chalmers (2007) found that the Australian higher education sector had a well-established range of quality measures in place, most of which is leading practice that triggered the implementation of similar practices elsewhere. A variety of different measures are used to monitor and promote learning quality that meets international standards. Australian attempts to measure, promote and reward quality include:

- National student experience survey (SES)
- National graduate outcomes survey (GOS)
- National course experience questionnaire (CEQ)
- National employer satisfaction survey (ESS)
- National regulator of tertiary education quality and standards (TEQSA)
- Australian Awards for University Teaching (AAUT)
- National research evaluation framework (ERA)

The SES, GOS, CEQ and ESS surveys for comparing higher education institutions are accessible from the Quality Indicators for Learning and Teaching (QILT) website (Australian Government, 2016). This website is designed to provide prospective students with relevant and transparent information from the perspective of recent students and graduates. The SES is used to show the percentage of current students satisfied with their education experience in relation to the overall quality of educational experience; teaching quality; learner engagement; learning resources; student support; and skills development. The GOS is completed after students graduate and is used to provide prospective students with data on labour market outcomes. The indicators relate to graduates in full-time employment; graduates undertaking further full-time study; and the median salary of graduates. The CEQ is administered as part of the GOS (completed after graduation) and the indicators relate to overall satisfaction; good teaching; and generic skills. The ESS is currently in pilot and will be used for ongoing assurance from employers about the quality of higher education experience. The promotion of this information by the Australian Government indicates their confidence in student's ability to evaluate at least some aspects of quality in an educational setting during and after their undergraduate study. As was raised in the literature, this outcome is still debatable, especially if a student has a customer orientated approach to education.

The Australian Government is not alone in using student surveys to measure quality in higher education. Since 2005, students (mainly final year undergraduates) from all publically funded higher education institutions in England, Wales, Northern Ireland

and Scotland are requested to complete the National Student Survey Questionnaire (NSS). The outcomes of the NSS will assist prospective students to make choices; provide a source of data for public accountability; and assist institutions to implement quality enhancing activities (Chalmers, 2007). Data from the NSS is published on a UNISTATS website which is similar to the QILT website. The UNISTATS website provides student satisfaction from the National Student Survey; student destinations on finishing their course from the Destinations of Leavers from Higher Education survey; how the course is taught and study patterns; how the course is assessed; course accreditation; and course costs (such as tuition fees and accommodation) with information provided by Higher Education Funding Council for England (HEFCE) (UK Government, 2016). As with Australia, this suggests that students will continue to play an important role in evaluating the quality of their education well into the future.

The approach used to consider the student as a customer and provide data on their experience has resulted in universities developing sophisticated brands and advertising programmes and improving services such as accommodation, campus environment, careers, information technology and social activities (Bunce et al., 2016). This response stems from their desire to grow and attract the best students and research funding opportunities (Wilkins and Balakrishnan, 2013). However, a risk identified by Ling et al. (2012) is that universities might tend to focus too much on enhancing student satisfaction rather than improving learning; which means that students might have a great experience, but are they actually learning any better? The push by government to use student opinion to evaluate quality and the uncertainty in this relationship to learning provides further evidence as to why this thesis is attempting to evaluate whether student evaluation data can be used to improve quality in the laboratory. However, further understanding of student evaluations is needed and this is covered in Section 2.3.

2.2.4. Teaching in the laboratory

The literature has shown that a quality education is desired, but it also suggests that the quality of teaching is a contributing factor in obtaining a quality education.

Therefore, it is important to understand the challenges inherent in teaching in order to provide a quality laboratory experience.

One of the most comprehensive reports on teaching in the laboratory was carried out by O'Toole et al. (2012) on behalf of the Australian Council of Deans of Science. A synthesis of literature found that: laboratory demonstrators (sessional teaching assistants used in a laboratory setting) have a critical impact on teaching and the learning experience; most demonstrators are PhD, Masters and Honour students and are inexperienced teachers in need of training, and general training programs do not develop the skills required in the laboratory. Identified was that most training programs concentrated on administrative matters or did not address laboratory instruction directly. The report made a number of recommendations that institutions need to implement in order to improve the quality of teaching in the laboratory. These recommendations are (pg. 20):

1. An explicit vision for the teaching laboratories should be articulated that provides focus for demonstrator development as well as teaching and learning of students

2. Demonstrator development should be planned within a framework focused by the vision, which could include

- *Formal professional learning sessions that are linked to lab practice*
- *Pre-lab briefing sessions*
- *Formal and/or informal mentoring during the session*
- *Promotion of a learning culture where demonstrators share ideas and knowledge, and where new knowledge is embedded in the documents and practice of the lab*
- *Debriefing or "lessons learned" sessions at the end of the semester*

3. Laboratory program coordinators should provide feedback (both positive and developmental) to demonstrators at regular intervals and encourage feedback from demonstrators

4. Student feedback mechanisms on demonstrator performance should be established

One of the key findings from the report was that most teaching in the laboratory is undertaken by inexperienced research and honours students, not by qualified academic staff. In 1983 it was observed that it was becoming increasingly rare to find professors in the laboratory (Ernst, 1983). Thirty years later this trend has continued with over 71% of laboratory demonstrators in the USA being sessional teaching assistants (Baumgartner, 2007), and even this thesis is being carried out in a climate where approximately ninety per cent of teaching in the laboratory is conducted by sessional teachers. This ratio is similar to the findings by O'Toole et al. (2012). For this reason, when considering the impact of teaching in the laboratory it is imperative to understand how sessional laboratory demonstrators influence student satisfaction.

The trend in the increasing numbers of teaching assistants is not just limited to the laboratory; they are being used throughout higher education. Australian universities are a prime example of this trend with a report finding that "*the full-time equivalent (FTE) hours performed by estimated sessional staff, by contract, increased 92% between 1996 and 2012*" (2014). This increased use of sessional teaching assistants has resulted in the Australian government commissioning reports (AUTC, 2003, ALTC, 2008). These reports concluded that the quality assurance of sessional teaching in many institutions is inadequate and there are virtually no instances of formalised standards of practice or professional development. The reports stated that the general lack of performance management of sessional teaching assistants is a high risk factor for universities that can result in low quality teaching because untrained teachers tend to focus more on what they are expected to do, rather than on student learning (Santhanam and Codner, 2012).

A review of the role teaching assistants (of all types) play in the UK was carried out by Lueddeke (1997) who found that the increased rate of using teaching assistants was worldwide, that most teaching assistants were postgraduate students, and that the highest percentage were used in the laboratory. Cited reasons for the increased use of teaching assistants included rising student numbers, resource constraints, cost efficiencies, and an increasing amount of time spent undertaking research. Many UK universities had failed to consider appropriate training for their teaching assistants, but thanks to the UK's Higher Education Funding Council (HEFCE) Review of

Postgraduate Education (1996), the conversation had begun to change. Lueddeke reported that formal training programs are needed and the ideal program would be flexible and combine both theory and practice. When implemented, training programs are of benefit to students, teaching assistants, and the institution. This UK based research further supports the findings outlined by O'Toole et al. (2012), that the use of inexperienced, and untrained laboratory demonstrators poses a potential quality risk to learning in the laboratory.

To emphasise this quality risk further, teaching in a laboratory is very different from teaching in a lecture or tutorial, because a wider range of skills are needed (O'Toole et al., 2012). Teaching staff must know how to teach, to motivate, to manage a classroom, use instruments, monitor lab safety, and most importantly know how to troubleshoot. Troubleshooting in particular is important because students seek help from the demonstrators when things go wrong. This is especially the case in electrical and related engineering disciplines where it is common for students to design, build, troubleshoot, measure, and then analyse data. As a result demonstrators require different training programs than general teaching assistants (O'Toole et al., 2012). Without proper training most demonstrators will not be experts in the discipline and in teaching (Luft et al., 2004).

A comprehensive study on teacher training in 22 universities across 8 countries carried out by Gibbs and Coffey (2004) highlighted the quality risks of untrained teachers. An experimental study was carried out to compare the effect of teaching with trained and untrained staff. It also investigated the use of teacher focus (presenting lots of facts), student focus (using difficult or undefined examples to provoke debate), a deep approach (attempting to make sense of the content), and a surface approach (attempting to remember the content) to teaching. The training programs ranged from 60 hours to 300 hours and were spread over a period of 4 to 18 months. While the study had a number of control issues due to the diverse institutions involved, the results showed that the group which received training experienced a significant improvement in teaching as judged by students. According to student feedback, this trained group became more student focussed, gained an increase in teaching skills, and encouraged more deep learning. On the other hand, the control group became less focused on the students and their improvements in teaching skills were lower, and the deep approach to teaching remained almost constant. While this study did not actually measure learning via assessment, it was by student feedback, it did show the importance of having well trained teaching staff, and therefore training in the laboratory needs further investigation. In chapter eight this thesis will try to extend these findings by trying to link teaching to learning.

An important teaching style in the laboratory is the notion outlined in Section 2.1.3 and others (Bateman, 1990, Volkert, 2012), that inquiry based learning is important in engineering, especially in the laboratory. This means laboratory demonstrators should not help students by giving them the answer or doing the experiment themselves, they should question the students strategically so they come up with the answer or process (Randall et al., 2012, Kurdziel et al., 2003). Therefore the need to train laboratory demonstrators to teach with this style is important.

2.2.5. Training Programs

Methods for training teaching assistants vary across disciplines and universities. Some of the variations include who provides the training, what the program and requirements should be, differences between domestic and international teachers, and how to evaluate the effectiveness of the program (Weimer et al., 1989). Some common training components include seminars, videos, faculty demonstrations and classroom observations (Abbott et al., 1989).

Young and Bippus (2008) designed a three day training program that focused on preparation, presentation, and practice. The first day focused on policy and procedure, the second day focused on the role and strategies of teaching, and the third day was spent simulating a classroom environment. This last day allowed participants to gain confidence, practice the theory before standing in front of students, and most importantly, obtain feedback on their teaching style. Research into the success of the program found the training to be effective based on surveying the participants before and after the training program. While this research was designed to prevent the survey data from being influenced by time spent in the classroom, the data is based on self-evaluation, so the teachers could have felt obligated to report that the training was helpful. That is, there was no indication that the students perceived the training to be beneficial. The authors also commented that (pg. 124) "*nothing can replace actual experience in the classroom*" without it actually containing that component. Indeed, no training simulation can prepare for all the random questions, technical problems, nerves, or other issues that teachers face in the classroom, but this form of training still makes the transition to teaching beneficial for both the teacher and the student.

Santhanam and Codner (2012) outlined a teaching development program (TDP) to enhance engineering education. A certification process was put in place to ensure all teaching assistants in the faculty received training via a two day training program to explore: facilitating learning, diversity and inclusive teaching, communication skills, and planning for managing the teaching classroom. At the university the faculty gathers annual feedback from the students via questionnaires. Two questions are indirectly related to the sessional teaching staff:

- *Q1: The practice classes/tutorials were a useful resource for my learning*
- *Q2: The laboratory sessions (if any) were a useful resource for my learning*

The results from the surveys improved between Semester 2, 2006 (prior to the commencement of the TDP program) to Semester 1, 2010 (3 years after the program had been implemented). Student satisfaction increased by 2% for question 1, and increased by 7% for question 2. The results show that any effect of the TDP program was most noticeable on laboratory demonstrators. The major problem with the analysis is that the two questions do not provide a clear link to the training because as presently worded, factors such as changes to the experiments or equipment could help to increase satisfaction. In support of this, chapter five explores the relationship between the demonstrators and the laboratory sessions.

Mark et al. (2011) defined a training program that involved a multi-directional engagement team-teaching approach, supported by e-learning technologies. The team-teaching approach consisted of an on-the-job learning component where a team of new and experienced teachers would work together in the classroom and the main speaker would change every 10-15 minutes. Video technology was also used for self-reflection together with feedback from peers and instructor. Feedback on the program was obtained from a learning experience questionnaire and a reflective portfolio submitted by participants, describing what they had learned from the course. The program was found to be successful and showed that many people can be trained together. It also highlighted that training in a real classroom was beneficial, that e-learning was a valuable supplementary tool, and that feedback played an important role in the training process. However, more understanding is needed on the impact that team based teacher training had on student experience. This relationship is investigated in chapter five.

An earlier study on training programs also raised the importance of feedback. A study of 13 different training programs by Abbott et al. (1989) found that each program in their own way resulted in a positive contribution. A common element in the most successful training programs was the inclusion of feedback. This was usually conducted via student ratings using a mentor (such as a trainer, manager or experienced academic), direct feedback from a mentor, or from recording the teaching assistant in action. The study highlighted that more needs to be done to investigate training programs to find those that produce the greatest benefit.

The use of a mentor and student ratings to improve teaching was also confirmed by McKeachie (1980). This study randomly assigned teaching assistants into three groups. The first group consisted of personal feedback of student ratings, with consultation from an experienced teacher; the second group received a computer printout of the ratings but with no other consultation; while the third group did not receive any ratings or consultation. The study found that the first group, receiving ratings and mentoring were rated the most effective by the students.

The literature showed how important training laboratory demonstrators are to ensure a quality learning experience. A good training program covers theory, practice, and feedback. Chapter three explores if and how a training program modelled on the recommendations made by O'Toole et al. (2012) can improve the demonstrator and student experience in the laboratory. In particular, it will be of interest to understand if student evaluations increase in line with the training, providing some form of evidence that students can evaluate quality in education.

2.2.6. Laboratory Quality

The importance of laboratories has resulted in much research on how best to conduct them, though most studies are isolated, small scale investigations, typically on one or two courses over one or two years. Many use a quasi-experimental approach that is limited by a pre-determined cohort of students, and the location and biasing factors associated with the background of the students and teachers. However, evidence from each study with regards to the factors that contribute towards a quality laboratory experience can still be gathered; for example, Stanisavljevic et al. (2013) developed a simulation tool to help teach digital logic. This software tool was developed to facilitate self-learning anytime and also improve learning in the laboratory. A key focus for the software was to be user-friendly, visual and provide an interactive environment. The outcomes from the software were correlated to an increase in numbers who enrolled in the course, to the substantial increase in assessment performance, and to the greater enjoyment students experienced undertaking the course.

Howard and Boone (1997) investigated what influenced students to enjoy science laboratories by comparing student satisfaction with an old and a newly designed experiment in a chemistry laboratory by surveying 222 students. The study found that pair or team based activities were more satisfying, that the pace at which the students had to complete the experiments mattered, procedures needed to be error free, and that students preferred to undertake experiments that were connected to real world applications. Moreover, the level of interaction with the laboratory staff and their ability to solve problems was also found to be important.

Boxall and Tait (2008) tried to improve learning in a civil engineering laboratory by implementing an inquiry based learning approach. The study compared the traditional watch and learns approach to one where students could develop and explore their own lines of inquiry. The laboratory was self-paced and was also supported with a range of materials including video, images, spreadsheets, background briefing notes and written instructions. The research found that the new approach had a very positive impact on student satisfaction measured by survey responses from 31 students and on grades by comparing different cohorts.

Gallardo et al. (2007) re-developed an electronics laboratory based on student satisfaction, by applying a learner-centred approach. The study found that the factors which influenced student satisfaction included content, user interface, ease of use, and motivation. It also found that by applying the learner-centred approach and the laboratory improvements, student satisfaction and achievement both increased.

An attempt to improve the student experience by increasing laboratory engagement was conducted by Shahnia et al. (2016). The Australian study investigated the impact of modifying the course away from students observing a laboratory supervisor undertaking experiments to a learner-centred approach with the students being actively involved through simulation and practical based activities. The study compared 120 students across two years and found that by having the experiments redesigned so that the students engaged with the equipment that feedback, student motivation and the distribution of grades improved.

Two Indian studies by Deshwal et al. (2012) and Gonsai et al. (2013) investigated the laboratory facilities at their respective universities. Their studies found factors such as the age of the equipment, internet connections, practical literature, and teaching staff had an impact on student satisfaction, but being short term studies, the implication for student satisfaction by improving these concerns was not investigated.

As was outlined in section 2.1 Lindsay and Good (2005) exploring the impact of different access modes in a third year Mechanical Engineering course at an Australian university, the study explored the differences between cohorts of students undertaking the same experiment in three different modes (proximal, remote and simulation). Findings from the study indicated that alternative access modes may improve some learning outcomes at the expense of degradation in others. This highlighted that the type of experiment needed to be considered within the learning outcomes desired.

These studies have concentrated on one or two courses, so they are limited and tend to be a one-off event to determine what drives the satisfaction of students at a particular point in time. Findings from such studies can also be supported by investigating the effects of change on multiple laboratories at a time over a longer time period.

Regardless of the time based limitation, the examples have provided some evidence for how to improve achievement and/or student satisfaction. The studies by Howard and Boone (1997), Deshwal et al. (2012) and Gonsai et al. (2013) supported the connection between demonstrators and student satisfaction as outlined in section 2.2.4. The ability to solve problems when things went wrong was identified as important and this can be mediated through appropriate training. Therefore, chapter three explores the relationship between demonstrator training and student satisfaction.

Some of the improvements outlined above can be categorised under the term *experiment* including developing self-learning tools, the manner in which the experiments are conducted, considering the experiment workload, and developing engaging experiments. Other improvements can be categorised under *facilities* including providing reliable and modern equipment and user-friendly and interactive computer interfaces. Therefore, chapter four examines quality of equipment and facilities in terms of student satisfaction.

Most of the examples associated improvements in student satisfaction with performance in assessment. As outlined in section 2.1 learning has multiple layers including course learning outcomes, laboratory learning objectives and learning over multiple domains. As learning is a key outcome of education, chapter eight explores student perception of learning.

2.2.7. Section Summary

The literature has shown that although quality is subjective, it is important for education. University education has many stakeholders, including students, parents, industry, government, and society, and therefore a quality education is needed for student learning, efficiency, economic prosperity, and competitive advantage. The trend to determine what a quality education actually is, is increasingly being measured by student opinion of their experience. This has been driven by government policies that have added weight to the student voice, by entrenching them as a customer. While many are concerned with considering education as a product or service, the research that students can actually judge a quality education is still inconclusive. Quality factors in the laboratory have been found to include the demonstrators, the laboratory experience (experiments and facilities) and learning. The literature supports the need to evaluate if student evaluation data can be used as a tool to help improve quality in the laboratory.

2.3. Student Evaluations

The literature suggests that a quality education is vital for all stakeholders, but increasingly, students are used to determine through their experience, whether or not they have received a quality education. As examined in Section 2.2.3, the Australian Government promotes the data collected by the Student Experience Survey (while studying), the Graduate Outcomes Survey and Course Experience Questionnaire (after graduation) and the UK government promotes the National Student Survey. Data from the surveys are used to encourage the transformation of the universities to provide a quality learning experience. This section will consider the literature relating to quality measurements via student evaluations to determine whether or not students can actually judge the quality of their education.

At the institution level, one of the most used forms of quality management used by universities are student evaluations of teaching (SETs). The SET is a widely used tool to evaluate the quality of instruction of individual teachers. The first use of students to evaluate teaching was carried out in 1920 at the University of Washington (Bernold, 2007). The original intention for SET was to provide student feedback in order to improve teaching. In 1973 the number of institutions using SETs had increased to 29%, and by 2000 had increased to over 90% (Larry Crumbley and Fliedner, 2002). The use of SETs has now gone beyond simply being a tool to improve teaching, they are now being used for purposes such as to help make decisions on retention, tenure, and promotion (Walker and Palmer, 2009). However, how they are used differs between institutions and countries.

Like every other tool, a SET must be carefully understood to be used effectively, especially when used for retention, tenure, and promotion. The controversial issues in regards to the validity, benefits, and biases of SETs has resulted in several thousand research studies (Spooren et al., 2013). An analysis of 154 research articles between 1924 and 1998 by Aleamoni (1999) (one of the developers of the Course Experience Questionnaire) found that SETs can be extremely beneficial for students, staff and institutions when they are well-designed and analysed correctly, but they can also be easily misinterpreted and misused, thus undermining their credibility.

While the SET is used to evaluate teaching performance, universities also use the student experience for other forms of quality measurement. This includes, measuring the student experience of the entire program. Some of these university surveys used around the world include the National Survey of Student Engagement (NSSE) in North America, the National Student Survey (NSS) in England, and the Course Experience Questionnaire (CEQ) in Australia (Calvo et al., 2010). The results of the CEQ are used by the Australian Commonwealth Government, tertiary institutions, researchers, and the annual Good Universities Guide for prospective students (Ginns et al., 2007).

The CEQ is conducted the year after students graduate so there is a long time lag so universities such as the University of Sydney are now using modified versions of the CEQ such as the Student Course Experience Questionnaire (SCEQ), to gather reliable information without the time lag associated with the CEQ (Ginns et al., 2007). The University of Wollongong uses a similar survey called the Student Experience Questionnaire (SEQ). The SEQ (UOW, 2014a) has only one question that relates to the laboratory, "*Learning resources and facilities (laboratories, studios, equipment, lecture theatres) are appropriate for my needs*". This question does not provide much feedback on how engineering students would perceive the laboratory learning environment because it is too generalised.

On a more granular level, subject evaluation surveys (SES) (UOW, 2014b) are run for courses selected by the organisational unit so that student experience can be understood at the level of individual courses. The questions in this survey do not provide any direct information regarding the laboratory component, but the survey does allow for an optional question that can be used to ask about laboratory experience.

The SES is similar to the Unit of Study Survey (USS), previously Unit of Study Evaluation, used at the University of Sydney. Calvo et al. (2010) used data obtained from USE to investigate the student satisfaction of engineering students at the University of Sydney. The study measured 1226 engineering courses taught at the university over 11 semesters (2001-2007) with 42,853 responses. This comprehensive study provided an insight into what students believe to be important, and found that engineering students are satisfied when (pg. 144):

- *The learning outcomes and expected standards are clear*
- *The teaching helps them to learn*
- *They developed valuable graduate attributes*
- *The assessment enabled them to demonstrate what they understood*
- *They could see the relevance of a particular course to their degree*
- *Staff are responsive to feedback*
- *Their prior learning prepared them well*
- *They could understand their teacher*
- *The faculty infrastructure is supportive*

The research also found that the year of study, class size, and professional development influenced student responses. The findings highlighted the importance of relating the staff and infrastructure to the teaching laboratory and the need to understand factors that may influence the ratings.

2.3.1. SET Research

One of the most cited SET researchers in recent times is educational psychologist Herbert W. Marsh. Marsh developed the Student Evaluation of Education Quality (SEEQ) evaluation instrument, which is based on psychometric analysis and is claimed to be one of the most reliable and widely used instruments in the USA to evaluate teaching (Coffey and Gibbs, 2001). In a monograph (Marsh, 1987) of research about student evaluations of teaching, he established from his own and other published research that class-average student ratings are (pg.255): "*(1) multidimensional; (2) reliable and stable; (3) primarily a function of the instructor who teaches a course rather than the course that is taught; (4) relatively valid against a variety of indicators of effective teaching; (5) relatively unaffected by a variety of variables hypothesized as potential biases; and (6) seen to be useful by faculty as feedback about their teaching*". These findings depend on the measuring instrument because student ratings (pg.401) "*can be no more valid than the instrument used to collect the information*" (Penny, 2003).

Validating student evaluations is difficult because there are no specific criteria or definition for effective teaching. As a result there has been much debate on how best to validate an instrument that measures students evaluation of teaching (Marsh and Roche, 1997, Onwuegbuzie et al., 2009, Spooren et al., 2013). Onwuegbuzie et al. (2009) stated that (pg. 201) "*validation refers to the process of systematically collecting evidence to provide justification for the set of inferences that are intended to be drawn from scores yielded by an instrument*". The authors conducted a meta-validity analysis on SETs and found that the current methods are questionable. Similar findings were deduced by Spooren et al. (2013). Research investigating the validity of student evaluations and the outcomes for this study are examined in chapters three, five and eight.

This literature review has showcased a number of studies with a positive correlation between student evaluation and learning (Gibbs and Coffey, 2004, Gallardo et al., 2007, Lim et al., 2008, Boxall and Tait, 2008, Mason et al., 2013), but some recent studies have questioned the suitability of having students evaluate teaching effectiveness. One such recent study by Braga et al. (2014), investigated student responses of a SET in a private Italian university. Management, economics and law degree students were investigated by splitting lectures into more than one class. Student academic history, demographics, class identifiers, weather reports and student assessment were used to help evaluate the SET responses; their research suggested that not all students were able to rate a teacher's ability. They also found the following correlations: higher evaluations with classes providing higher grades; evaluations from the best students are more aligned to teaching effectiveness because weaker students provide lower evaluations when teachers tried to exert more effort; and the weather has a marginal effect on evaluations, such that the ratings were lower on rainy days.

A similar study by Carrell and West (2010), investigated the SET by comparing the data to future achievement. This study was conducted at a U.S. Air Force Academy, an undergraduate institution with high achievers (due to the highly competitive entry process) where teaching is undertaken in small classes (approx.20). The study investigated data from 10,534 students and 421 teaching staff between 2000 and

2007. The investigation compared the deep and surface learning (defined in section 2.2.4) approaches of teachers in first year mathematics and how this was correlated with SET and future achievements. The study found that the student evaluations were linked to staff that delivered the best short term results, that is, students performed better in the introductory course but then lapsed in the follow on courses. The author suggested that this could be because less experienced staff concentrated more on the curriculum. Teaching staff that concentrated on deep learning received lower student evaluations and lower student achievement initially, but were linked to students that achieved better long term results. The author also suggested this could be because more experienced teaching staff expand the curriculum and provide a deeper understanding.

Another study designed to measure the validity and usefulness of SET on learning was conducted by Galbraith et al. (2012). Data from 116 business related courses in an American university were analysed using a multi-sectional and pool sample analysis. The study found that class size was a major influence on SETs ability to predict student performance and the SET scores were non-linear. SET scores in the "high" and "low" range were associated with lower student ratings. These studies also questioned the appropriateness of having students evaluate teaching.

Research by Stehle et al. (2012) found that the type of assessment played an important role in the correlation between student achievement and student evaluation. A multi-section validity approach was used in a medical school consisting of 883 students. This study compared two different instruments of student learning, a multiple choice exam and a practical exam, and was carried out over seven terms, which resulted in 32 classes being taught by 21 different instructors. During this study every aspect of the curriculum remained the same; the results showed that in practical examinations, student achievement correlated with student evaluations, but there was no correlation for the multiple choice test. The authors believe that the instructor has an important role in a practical exam because practical skills are taught, which means students require more understanding than can be obtained just from a text book. However, multiple choice exams focus on students recognising the correct answer, meaning that they do not necessarily need to fully understand the answer. Moreover, the authors claim that the knowledge required to pass multiple choice exams is easier to obtain from other forms of study, such as a textbook at home, and this can to some extent change the relationship between teaching effectiveness and student achievement. Therefore, a possible reason for student evaluation and student achievement not correlating could be due to the assessment medium.

This result implies that a laboratory could be a more suitable environment to test the correlation between teaching effectiveness and student achievement. However, as outlined in Section 2.1.2, the learning objectives of the laboratory across the three learning domains must also be known, otherwise a practical exam could be just as unreliable as a multiple choice exam. This relationship is explored in chapter 8.

2.3.2. Influencing Student Evaluations

To gain a better understanding of student evaluations, the biases and influencing factors must be understood. Research has investigated how student evaluations can be influenced by teaching staff; an exploratory study by Simpson and Siguaw (2000) investigated the ways in which teachers try to influence the SET. A research questionnaire was completed by 52 respondents from the USA, Australia, England, Peru, and Ireland. The types of SET influences include: *inducements* (16.7%), where teachers gave snacks or food on the day of the evaluation; *pre-evaluation activities* (6.9%), where teachers would source evaluation comments from students and justify approaches to negative comments or telling the class how wonderful they are before the evaluation; *Manipulation* (19.4%) such as using easy assessments before the SET and hard assessments after, or conducting an unusually fun class before the evaluation; and *Grading leniency* (23.6%) using no or easy exams, or unchallenging course material. Fortunately for the laboratory evaluations the structure of the class is set by the course coordinator, meaning that many of these influences should not take place.

While grading leniency is a controlled variable in this study, as mentioned by Simpson and Siguaw (2000) above, it is one of the most influential and debated sources of bias. A synthesis of literature by d'Apollonia and Abrami (1997) found that grading bias depended on the context. That is, if students were graded leniently and learning did not improve this would be considered a bias, but if students were graded leniently and this encouraged them to work harder, be more motivated, and also improve learning, then it would not be a biasing factor. In this study a substantial proportion of marks are obtained easily, but they are used to encourage participation and learning in the laboratory. The laboratory demonstrators in this study cannot choose the degree of leniency because they follow a marking rubric that is common for all demonstrators teaching in the course, so any expectation of high grades would be applied across all demonstrators in any one course.

Substantial research has been undertaken to investigate a range of other possible biases in student evaluations, and almost every bias is associated with research that either proves or dismisses potential biases. One example of this is research conducted by Cranton and Smith (1986) who investigated 1,777 classes in five departments over three years. The authors examined five variables; permanent vs sessional staff, time of day, campus, course level, and class size. The interesting finding in this research is that the biases in the variables changed depending on the department. More recent studies have also shown different biases depending on the department involved (Badri et al., 2006, Narayanan et al., 2014).

A range of other studies also investigated bias in student evaluations. For example: Calvo et al. (2010) investigated the years of study, class size, and coordinators professional development; Johnson et al. (2013) looked at class size, course level, course type, gender, experience, academic rank, and grades; Stolte (1996) considered the effect that teacher age had on evaluations; and Badri et al. (2006) measured the influence on expected grade, actual grade, course level, course size, course timing, and gender. These studies indicated that class size was one of the most prominent influences on student evaluations. The importance of understanding bias, and factors that could influence student evaluations in the laboratory, are examined in detail in chapter five.

2.3.3. Section Summary

Undertaking student evaluations is a very complex process because it involves validating the measuring instrument, understanding the complexity of using the correct instrument to measure outcomes, the potential for teachers to influence ratings, and possible bias in ratings. All these factors need more research to gain a better understanding. Finally, only a small number of studies investigate these factors regarding learning in the laboratory so this forms the basis of chapter five.

2.4. Chapter Summary

The question this chapter tried to answer was:

Does previous research answer the question: What is a quality laboratory experience and how is quality measured?

The literature has shown that a quality laboratory experience is important because engineers 'learn by doing' and that the laboratory is an environment that supports learning in the cognitive, psychomotor, and affective domains. However, the literature also revealed that simply including a laboratory component in a course is no guarantee of learning or for satisfying student experience, and therefore sustainable quality processes are needed. Moreover, most laboratory studies are either small or they only concentrate on only a small number of laboratory courses at a time. A comprehensive study which covers a large number of courses would help clarify the findings of these smaller studies.

The complex nature of a quality education is identified in the literature, and the definition of a quality education is extremely subjective. Education has stakeholders such as students, parents, industry, government, and society where the outcome is student learning. In terms of the teaching laboratory the literature suggests that quality is considered to be an improvement in both student learning and their experience with demonstrators, experiments and facilities.

In higher education the notion that quality can be measured via student evaluations is almost universal, but the literature has shown that the suitability and capacity of students to judge quality is disputed. Even after publishing over a thousand SET based studies, many important questions remain unanswered, and in comparison, little research has focused on the quality of student evaluations in the laboratory. However, most studies measure the quality of their implementations, at least partly, based on student opinion. Therefore, there is a need to develop more evidence to support or reject the notion that student evaluation data can help improve quality in the teaching laboratory.

CHAPTER 3: STUDENT EVALUATIONS OF TEACHING

3.1. Introduction

The literature review identified a link between the qualities of laboratory demonstrators to the laboratory learning experience, particularly the high use of sessional teaching assistants who are untrained and unaware of how to teach effectively. This problem is compounded by the fact that generic training is usually not suitable for laboratory demonstrators because it is not specific enough for the skills required and generally does not deal with inquiry-based approaches.

A number of training programs that contributed to the structure of laboratory training were identified in this study (Park, 2004, Young and Bippus, 2008, Mark et al., 2011, Santhanam and Codner, 2012), with a particular focus on the recommendations made in a report for the Australian Council of Deans of Science (O'Toole et al., 2012). The outcome was a training program that included certification and was based around on-the-job training with mentoring and feedback.

The success of most training programs was via trainee reflection, as indicated by how well teachers felt prepared after the training program compared to before the training. The work by Santhanam and Codner (2012) was intended for laboratory demonstrators, and while the research showed a positive contribution to the student experience, more research is needed to prove it was linked to the training program. The literature showed that the most common tool used to measure teaching effectiveness was student evaluations, but debate as to whether student evaluations can be correlated with teaching effectiveness still remains.

An iterative refinement process was used to improve the training program and observe whether or not the training led to an improvement in student evaluations. This was based on an assumption that training, mentoring and self-reflection does lead to more effective teaching, as expressed in the literature. If such a relationship exists, it could provide some evidence that student evaluations of teaching in the laboratory is valid.

This chapter presents the method and the results used to answer the sub-question: *Does training lead to an improvement in student evaluations?*

3.2. Method

3.2.1. Background and Implementation

The teaching laboratory is regarded by the School of Electrical, Computer and Telecommunications Engineering as an essential component of learning, but in 2006 the school became aware from student and staff feedback that quality within the laboratory was a growing concern. One outcome of the feedback was the author being appointed as Laboratory Manager in December 2006. At that time the long term goal set by the Head of School was to improve the quality of the teaching laboratories, with the term quality being open to interpretation. Using the definition derived from the literature review quality is considered to be an improvement in both student learning and their experience with demonstrators, experiments and facilities.

To gain an understanding of the issues within the teaching laboratory, student surveys were proposed. The University of Wollongong uses two official instruments for evaluation of courses: the first is a Teacher Evaluation (UOW, 2016) that generally targets teaching staff involved in lecturing, usually the course coordinator. This survey is generally not suited to laboratory demonstrators because they have no real say on how the laboratory is run or courses delivered. The second instrument is a Subject Evaluation Survey (UOW, 2014b) that takes a holistic view of the entire course. Because the school rates laboratory learning as very important, laboratory tailored evaluations were deemed necessary. As a result, the two official university survey instruments are only used to measure course quality in its entirety, they are not used to specifically measure quality in the teaching laboratories. This led to the formation of laboratory specific evaluations, which are the focus of this study.

In 2007 the engineering department approved a trial student evaluation instrument to measure student experience in the teaching laboratories. The trial instrument was based on a meeting with academics staff members outlining what they believed reflected a quality laboratory experience. The data from the trial evaluation was used to fine tune the survey instrument and develop policies and procedures that approved its ongoing use. In 2008, the school approved a certification program for training laboratory demonstrators, and approved a revised student evaluation instrument. These evaluations commenced in 2009, and training was carried out by the author as Laboratory Manager.

The evaluation questions were not guided by research; they were developed through metrics that the committee valued as important to the students and the school, so their wording could have been refined through research into student evaluations. The data collected from the student evaluations was not used for research until March 2013. This is when the author and other members of the academic staff found value in the work undertaken and obtained approval from the universities human research ethics committee (ethics approval number HE13/129). Having gathered a significant amount of data, and with an ethics clearance to use the data for publication purposes, it was decided to keep the questions originally approved by the school committee.

Using a new survey instrument raised issues with validity and reliability, as outlined in the literature review in section 2.3. The first test was to check the face validity (Onwuegbuzie et al., 2009) by confirming whether the demonstrator questions aligned with characteristics that students value the most from teachers. The study by Pozo-Munoz et al. (2000) which investigated what students believed was needed to be an effective teacher, found that knowledge, communication, and competence were valued the most. This was consistent with the themes that came from the trial survey in 2007 which was used to craft the approved survey. The questions approved to evaluate the teaching effectiveness of laboratory demonstrators are:

- Question 1: At the start of each laboratory does the casual demonstrator give you a satisfactory introduction to the laboratory?
- Question 2: Is the casual demonstrator well prepared for the subject?
- Question 3: Does the casual demonstrator communicate the subject matter clearly?
- Question 4: Did the casual demonstrator appear interested in helping me to learn?

- Question 5: Is the casual demonstrator helpful in responding to questions or problems?

The questions provide data that are used to evaluate if an improvement in the student experience with the demonstrators occurred. The 2007 trial survey found that students wanted an introductory overview of the experiments (communication and knowledge) and in many cases this had not occurred, which led to the inclusion of question one. Question two was included due to a common complaint that some demonstrators were not aware of the procedures or logistics such as location of equipment (knowledge and competence). The third question was included due to comments about being unable to understand or follow instructions from the demonstrator (communication). The final two questions were included to measure a demonstrator's enthusiasm and ability to provide support to students (knowledge, communication and competence). Therefore, the survey instrument has alignment to the work of Pozo-Munoz et al. (2000) providing some evidence of having face validity. Discriminant and structural validity will be examined in chapter five and convergent validity in chapter eight.

A paper based survey instrument was administered to students towards the end of each semester where laboratory subjects that run at least one and a half hours per week (or three hours per fortnight) were surveyed. Twenty-five laboratory courses were evaluated each year, as was shown in Table 1-I. Of all the laboratories evaluated, the laboratory is only one component of a complete course, which typically consists of a lecture, tutorials, and the laboratory. In the laboratory, the ratio of laboratory demonstrators to students was aimed to be one to 15, so on average if a laboratory consists of 15 students, one laboratory demonstrator was used, if 35 students' two laboratory demonstrators were used, and if 45 students' three demonstrators were used.

Each laboratory has one main demonstrator (DEM1), so question one only relates to that demonstrator. In a team teaching scenario, all other laboratory demonstrators (DEM2 and DEM3) receive a "Not applicable" for that question. There may be instances when statement one is not applicable to the main laboratory demonstrator, so they are treated as DEM2.

A five point Likert scale from "Strongly Agree" to "Strongly Disagree" was used to collect responses from the students. A comments field was also available to capture qualitative feedback which was used as a cross-check against the survey responses. A score was developed to easily compare performance over time. The score is a weighted average of the survey data with Strongly Agree (5) and Strongly Disagree (1).

Approximately 30 to 40 sessional demonstrators are hired and evaluated each semester (including demonstrators continuing from previous semesters), and approximately ten of them receive training each year. The average length of demonstrating is three years. Approximately 400 student evaluations are received each semester. These student evaluations were carried out between 2009 and 2013.

3.2.2. Development of Training Program

An iterative refinement process was used to develop a training program for the laboratory demonstrators, and each year a plan was developed to improve and implement the program. The implementation was then observed on demonstrator training and interactions between demonstrators and students, after which a reflection was undertaken on the observations and new actions were considered for the next cycle. This means the training program was always evolving.

The first training program was implemented in 2007, and was heavily focussed on administrative matters; this type of training is common and has been found to be ineffective (Shannon et al., 1998). It was noted that many laboratory demonstrators struggled to interact effectively with the students, so in 2008, advice was sought from the university's Learning and Development Centre to explore what resources and solutions were available for training purposes. The training program was then modified to include instructions on their role in the class, how to engage with students, and to use inquiry based questioning (not providing an answer, but using many questions to guide the student to the answer). In the training program it appeared that the demonstrators understood, but in practice many failed to implement the practice, and since students would ask questions in a variety of ways, an inexperienced teacher would not know how to interpret or handle them correctly.

The literature review indicated that Abbott et al. (1989) found that feedback was an extremely important part of any training program. This supported the research of McKeachie (1980) who found that a combination of student evaluations with mentoring was most effective. Therefore in 2009, the year the student evaluation instrument was officially implemented, the ratings were used to provide feedback to the demonstrators via mentoring by the laboratory manager. In addition, and based on reflections of the 2008 training program, on-the-job training became part of the training program to help the demonstrators transition to inquiry based questioning in the laboratory, and to learn how to respond to a multitude of questions.

The feedback component of the training was carried out by having each demonstrator meet with the Laboratory Manager to discuss the student evaluations and their teaching experiences, and to develop a plan to improve their method of teaching. For example, demonstrators receiving: 1) a low communication score might be asked to attend an English conversation group or to undertake regular discussions with the Laboratory Manager; 2) a low introduction score might be asked to give their introduction to the Laboratory Manager for feedback before each scheduled class; and 3) a low helpfulness score could be given practice at answering questions before each scheduled class.

The training program implemented in 2009 was far more successful than earlier attempts. Since the author was involved in both interviews and training, by the end of the on-the-job training component it was evident through observation that most demonstrators had vastly improved their teaching ability compared to what they demonstrated at the interview. Reflection on the training program over the following years resulted in a range of additional measures such as videos, on-line reinforcement of theory, and demonstrator teaching forums have also been introduced.

The training program consists of 7 stages: interview, school induction, university induction, online training, on-the-job training, feedback via student evaluations and mentoring from the laboratory manager. At the end of each year the laboratory demonstrators are asked to provide a response to the following question on a Likert scale, “The school provided me with enough resources/training to perform my job successfully”. A weighted average of the Likert responses is used to create a score, and to track demonstrator experience with the training program over time. As Table 3-I shows, the continuous rise in score to a small degree indicates that the demonstrators considered the changes implemented via the iterative refinement process to be appropriate.

Table 3-I: Changes to Training Program over Time, and response scores to the statement: “The school provided me with enough resources/training to perform my job successfully”

Year	Changes to Training Program	Training Score
2007	Training program initiated. Consisted of a one hour school induction and two hour university induction. School induction primarily consisted of rules and policies. A sessional teaching guide was created to provide a reference guide for sessional teachers	N/A
2008	The sessional teaching guide and school induction was expanded to include instruction on their role in the class, how to engage with students, and inquiry based questioning	75.3
2009	Certification process commenced that included on the job training. Teaching guide and school induction further enhanced	81.1
2010	New interview process commenced. Videos introduced showing a range of laboratory demonstrator scenarios	83.3
2011	Online training site created to provide a comprehensive review and revision questions	84.2
2012	Online resource, 'The Training Lab' created to provide extensive resources on how to use equipment and how to fault find. Sessional teaching forum	87.2
2013	Some small content recommendations from the 2012 sessional teaching forum added to the training program	87.5
Training Score determined by the question: "The school provided me with enough resources/training to perform my job successfully"		

3.2.3. Student Evaluations

The major change to training occurred in 2009 with the introduction of on-the-job training and the use of student evaluations as feedback. Observations by the author and course coordinators indicated that demonstrators were displaying a higher standard of teaching. The participation of demonstrators in this program was gradual because only those demonstrators new in 2009 commenced this program; those with previous experience were not required to participate in the new training program. This meant that in 2009 the student evaluations covered only a small number of demonstrators who had completed the program. However, each following year the student evaluations covered a greater percentage of trained demonstrators than untrained ones.

The literature review indicated that training with feedback results in more effective teachers. Every year from 2009 a greater percentage of demonstrators evaluated had completed the training program, and from 2009 all the demonstrators were receiving feedback from a mentor (the laboratory manager). The laboratory manager and course coordinator's observations indicated that teaching in the laboratory was definitely improving. Therefore, considering these conditions, it would be expected that student evaluations should on average trend higher over each year. If this occurred, it would provide some evidence that the students were capable of judging quality. Therefore the results of this study would answer the sub-question:
Does training lead to an improvement in student evaluations?

A limitation of this study is that the first student evaluation was conducted at the end of the on-the-job training so there is no student evaluation to compare before and after this training. Considering the improvement in teaching performance as observed by the laboratory manager at the interview, compared to the end of the training program, it is expected that any improvement in student evaluation would be less than had the original evaluation occurred before the training program.

3.3. Results

The student evaluations of laboratory demonstrators contained up to five questions that must be answered using a Likert scale. As outlined in the method, the evaluation data was summarised into scores for easy interpretation, and therefore the proceeding sections will analyse the results from each of the evaluation statements.

3.3.1. Overall Change in Evaluations

The student evaluation data showed that demonstrator ratings increased over the five-year period; in 2009 the overall satisfaction with demonstrators was 79.69%, and by 2013 it had increased to 89.74%, a 13% increase. An overview of all the scores is shown in Table 3-II, and further evidence is shown in Table 3-III. This table shows the percentage of demonstrators obtaining a score within a defined range by year, and as expected, the percentages were gradually trending higher each year. This data is important because it shows that the improvements in evaluations were not just occurring to a few individuals, but to the entire group. This data together with the course coordinator and laboratory manager observations suggests that training and mentoring does lead to an improvement in student evaluations, aligning with the definition of quality in terms of an improvement in the student experience with the demonstrators. Within this definition it provides evidence that students can on average be judges of quality.

Table 3-II: Student evaluation scores with sessional laboratory demonstrators, by year, showing the total change over the 5-year period.

Year	Q1	Q2	Q3	Q4	Q5	Average
2009	71%	82%	79%	83%	83%	80%
2010	77%	84%	81%	84%	84%	82%
2011	81%	88%	85%	87%	88%	86%
2012	85%	89%	88%	89%	90%	88%
2013	87%	91%	89%	91%	91%	90%
Change	**22%**	**10%**	**13%**	**10%**	**9%**	**13%**

Table 3-III: Percentage of demonstrators obtaining a score within a defined range by year (Bolded figures are the peak of the annual score distribution):

Score	2009	2010	2011	2012	2013
95-100	0%	2%	7%	9%	10%
90-94.99	6%	17%	19%	29%	**43%**
85-89.99	24%	**31%**	**48%**	**42%**	35%
80-84.99	26%	25%	24%	12%	8%
75-79.99	**28%**	12%	2%	6%	5%
<75	16%	13%	0%	3%	0%
Demonstrators	18	28	36	42	33

3.3.2. Providing an Introduction

The survey statement upon which the largest improvement (22%) occurred is the ability to provide a suitable introduction. In the trial survey conducted in 2007 one of the most common complaints was the lack of an introduction at the start of a laboratory class. The Laboratory Manager observed that most of the sessional demonstrators were not comfortable delivering an introduction so the training program enabled the demonstrators to deliver an introduction, while the survey question reinforces the process that an introduction should take place.

3.3.3. Preparation

The evaluation suggests that students perceive that the demonstrators' level of preparation had increased by 10% over the five year period. The training program teaches demonstrators that preparation includes: understanding the theory, knowing how to build/code/troubleshoot the experiments, knowing where to find the equipment/software and notes, understanding the assessment, and talking to the subject coordinator.

3.3.4. Communication

Communication skills have seen the second largest (13%) improvement over the period, partly because the weakest communicators are eliminated at the interview stage, and also because the training program focuses on using inquiry-based questioning to guide students to the information they seek. As a result the demonstrator does less explaining and more guiding. Communication is also a skill that can be enhanced by practice. The communication score can also be heavily influenced by the ratio of international to domestic demonstrators, but this ratio has remained fairly constant over the five years, with most demonstrators being international with English as a second or third language. A limitation is that the more selective interview process may automatically increase the communication score, regardless of the training.

3.3.5. Interest and Helpfulness

The final two evaluation statements relate to the demonstrators' interest and helpfulness in the laboratory, scores that have been closely linked over the five year period. The training program emphasises that the demonstrator must be constantly engaged with the students and always provide support, even when students have not asked a question. This builds a relationship between teacher and student and shows that the demonstrator is interested in their education. A demonstrator is deemed helpful if they can enhance student education by facilitating learning (O'Toole et al., 2012).

3.4. Summary

This chapter investigated the implementation of a training program in an engineering department to improve the quality of teaching. Quality was defined as being an improvement in both student learning and their experience with demonstrators, experiments and facilities, with this chapter focused on the student experience with the demonstrators. The expectation being that the training program would increase teaching effectiveness and this would be represented by increased student evaluations. The sub-question for this chapter is:
Does training lead to an improvement in student evaluations?

Based on the improvement in student evaluations over the five year period together with the observations from the course coordinators and laboratory manager, the research does suggest that training does lead to an improvement in student evaluations. A limitation of the study is the impact on the results from simply improving the selection process.

Feedback from the student evaluations are used to refine the training; which suggests that students can judge teaching quality to some degree, and their ratings will help to improve quality. However, this data does not provide any evidence that learning actually improved. Research in chapter eight will examine whether or not a relationship exists between student evaluations and learning and determine the convergent validity of the survey instrument. Chapter five will investigate the relationships between teaching and laboratory satisfaction (chapter four) and also determine the structural and discriminant validity.

CHAPTER 4: THE LABORATORY EXPERIENCE

4.1. Introduction

The literature review in chapter two discussed a number of research studies that showed how laboratories could be improved by modifying their experiments and teaching styles (Howard and Boone, 1997, Gallardo et al., 2007, Boxall and Tait, 2008, Stanisavljevic et al., 2013). However, since most studies only concentrated on one particular laboratory at a time, those that looked at all laboratories collectively mainly looked at issues in their department at a particular point in time (Deshwal et al., 2012, Gonsai et al., 2013). The long term nature of this study provides a larger timeframe of data allowing the analysis of the short and long term impact of changes, particularly for any novelty effect. Other studies investigated a broad range of university facilities such as general computing, the library, accommodation, furniture, parking, lecture theatres, and recreation facilities (Douglas et al., 2006).

This chapter therefore aims to address the limitations outlined above by analysing laboratory improvements over a number of courses; these improvements will then be compared to any changes to student evaluations. An iterative refinement process will be used to better understand what students believe to be important for a quality laboratory experience. Quality was defined as being an improvement in both student learning and their experience with demonstrators, experiments and facilities, with this chapter focused on the student experience with the experiment and facilities. Therefore, this chapter will present the method and the results needed to answer the sub-question:
What changes lead to improvements in student evaluations of the laboratory experience?

4.2. Method

Section 3.1 explained how and why the School of Electrical, Computer and Telecommunications Engineering at the University of Wollongong commenced evaluating the teaching laboratories. Chapter three identified that training the laboratory demonstrators led to improved student evaluation scores. Using the same iterative refinement methodology (and same ethics approval number HE13/129, this chapter explores the relationship between laboratory improvements (experiment and facilities) and changes to laboratory experience scores.

The school committee approved six statements in 2008 (implemented in 2009) to evaluate the laboratory experience, three of which were targeted at the experiments, and three were targeted at the facilities. These statements are:

- Statement 1: I have a great overall impression of the laboratory component for this course.
- Statement 2: The contents of the laboratory notes provided me with enough information to successfully complete the required exercises.
- Statement 3: The experiments undertaken in this laboratory are worthwhile learning experiences.
- Statement 4: The computers in the laboratory are suitable for the work required.
- Statement 5: The electronic equipment in the lab, other than the computers, is suitable for the work required.
- Statement 6: The laboratory is in a good condition.

A five point Likert scale from “Strongly Agree” to “Strongly Disagree” was used to collect responses from the students. A comments field was also available to capture qualitative feedback which was used as a cross-check against the survey responses. A score was developed to easily compare performance over time. The score is a weighted average of the survey data with Strongly Agree (5) and Strongly Disagree (1).

The first statement was used to understand if students valued the experiments in their entirety. The second statement was used to measure student perception of the instructions provided. This does not specifically relate to following recipe styled instructions, it seeks to understand whether students can gather enough information to move forward and complete an experiment. The third statement was used to determine whether students appreciated the learning experience. The fourth and fifth statements were targeted at how students had perceived the equipment used. The final statement was used to determine how students had perceived working conditions in the laboratory.

Data was collected from the 108 laboratory surveys carried out between 2009 and 2013. The author as laboratory manager collected the data and worked with the course coordinators to improve the laboratories, as guided by the student evaluations. An iterative refinement process was used to apply changes and learn how the changes corresponded with the student evaluations. The student evaluations were only one form of data used in this process. If issues were identified, contact was made with student representatives for clarification, as well as feedback from the laboratory demonstrators.

4.3. Results

The student evaluations consisted of six statements that were answered using a Likert scale, and as stated in the method, the evaluation data was summarised into scores for easy interpretation. The proceeding sections will analyse the results from each evaluation statement.

4.3.1. Overall Change in Evaluations

Student evaluation data showed that the laboratory experience ratings increased over the five year period. In 2009 the overall satisfaction was at 78.44%, and by 2013 it had increased to 87.74%, a 12% increase. An overview of how the scores changed is shown in Table 4-I. A summary of this data grouped into experiment and facilities, is shown diagrammatically in Figure 4-1. The data in Figure 4-1 seems to indicate that a relationship exists between the experiment and facility categories; that is, does improving one variable automatically improve another? In order to gain a greater understanding, a number of case studies under the iterative refinement process will be detailed.

Table 4-I: Student evaluation scores measuring laboratory experience, by year, showing the total change over the 5-year period

Year	S1	S2	S3	S4	S5	S6	Average
2009	75%	75%	79%	83%	77%	81%	78%
2010	79%	75%	80%	84%	80%	82%	80%
2011	83%	82%	86%	87%	85%	88%	85%
2012	83%	82%	85%	87%	86%	87%	85%
2013	86%	85%	87%	90%	88%	90%	88%
Change	14%	13%	10%	9%	14%	11%	12%

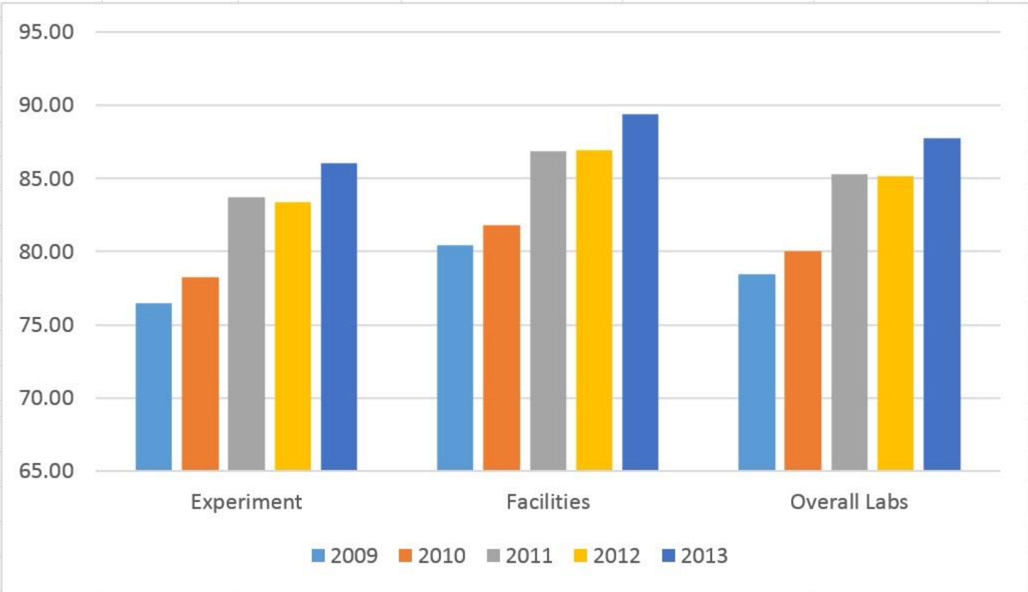


Figure 4-1: Student evaluation scores categorised, by year, showing the total change over the 5-year period

4.3.2. Laboratory Notes and Equipment

The laboratory notes dictate the type and level of instruction students follow to undertake an experiment; it can range from a detailed recipe styled step by step instructions to limited instruction with inquiry based questioning. Different styles and approaches to laboratory notes can lead to different learning outcomes being achieved with the same base experiment. The equipment refers to the tools students use such as computers and software, measuring devices, electronic components and circuits. A number of case studies will investigate the impact that notes and equipment play on the laboratory scores.

4.3.2.1. ECTE344

The first course to undergo review was ECTE344, a laboratory used to teach control, where a combination of modules are connected to control a DC motor. In the trial survey in 2007, the students showed the most dislike for the laboratory component of this course. The trial survey did not use all the same statements implemented from 2009, but three of the questions aligned and can be seen in Table 4-II. The low laboratory scores in 2007 were accompanied by negative feedback regarding 'equipment *that does not work*' or '*faulty equipment*' together with the need to '*clarify instructions and circuit diagrams*'.

Table 4-II: Change in ECTE344 Laboratory Evaluation Scores

Survey Statement	**2007 N=35**	Added information on equipment and troubleshooting	**2009 N=56**	**2010 N=84**	**2011 N=62**	**2012 N=33**
S1	24%		80%	79%	82%	82%
S2	24%		83%	82%	87%	82%
S3	n/a		85%	81%	85%	85%
S4	n/a		88%	90%	89%	93%
S5	38%		76%	79%	82%	82%
S6	n/a		80%	81%	85%	82%
Score	*31%*		*82%*	*82%*	*85%*	*84%*

In 2008, the author acted as an observer to gather evidence on the shortfalls of this laboratory. One of the first major observations was the lack of prerequisite laboratory knowledge displayed by some students. In part, this was because mechatronics engineers did not follow the degree structure followed by the electrical, computer, and telecommunications engineers (ECTE) students. As a result the mechatronics engineers were undertaking the course in the first semester of the second year of the program instead of in the third year, and were therefore using complex laboratory equipment such as oscilloscopes that the ECTE students had gained substantial practice with in the second semester of the second year. Moreover, large cohorts of international students commence onshore enrolment in the third year and they had very little previous practical experience. This meant they faced a steep learning curve before they could even begin to think about the learning objectives of the experiment. Moreover, most students (except for those repeating due to failure) had no previous exposure to the control hardware and the laboratory notes contained scant information on the function of the various control modules.

After investigating why so little information was available on the control modules, the author discovered that when this laboratory had been developed a decade earlier, some information had been provided in videos and other web interactive elements. However, as the codec's that the original information had been encoded with became unsupported by the IT department, no attempt had been made by the subject coordinators to transfer this information to new forms and had therefore been removed. The awareness of the importance of providing this information had become lost because there were no appropriate forms of quality control.

Student dissatisfaction with the laboratory equipment and claims of faulty equipment were directly related to a lack of information on the control system and an inability to troubleshoot induced the students to complain about the equipment as a means of expressing their concerns. This problem was compounded because the teaching assistants also suffered from this lack of information in their ability to help the students. The consequence of the issues highlighted here was observed as low student morale, because as soon as a problem occurred the students would just stop and wait for help instead of challenging themselves to move forward.

At the end of the teaching semester the author worked with the course coordinator to redevelop the laboratory notes; the experiments would remain the same, with only slight modifications. Most of the work was tailored at developing a fundamental understanding. A web based laboratory instruction approach was used to provide detailed instructions on the operation of each module as well as providing learning support on using the signal and measuring instruments used in conjunction with the control hardware. An example shown in Figure 4-2 uses the Pre-Amplifier module to illustrate how the module operates together with a description of the input and output ports. This information was hyperlinked throughout the laboratory instructions so students could refer to it as necessary. On the left window of Figure 4-2 other resources can be accessed, such as the terminology and background information used for the experiments to further support fundamental knowledge. The benefits of using resources such as the one explained are investigated in further detail in chapters six and seven. A three to five minute video introducing the laboratory concepts was also added to the start of each experiment. The laboratory preparation activities the students performed before class were amended to focus on the new resources to encourage students to take advantage of them.

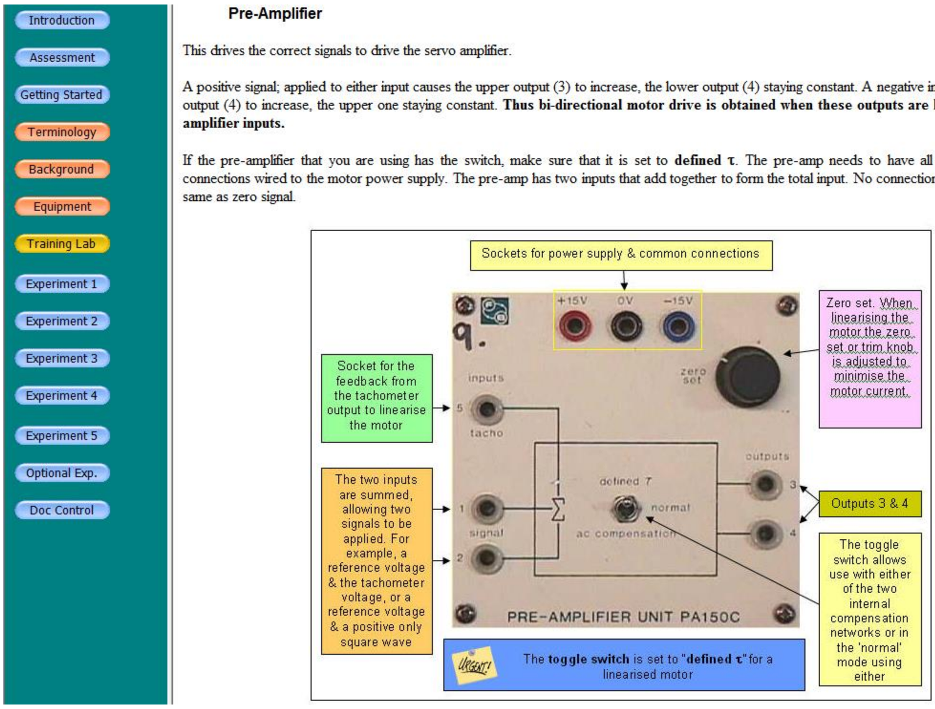


Figure 4-2: An example of the information provided on the various control system modules

The course contained six experiments, with students completing one experiment per fortnight. The first section of Experiment One was altered to introduce troubleshooting techniques where students are given activities to trace system signals with a number of working and purpose built faulty wires. These activities also provide students with the opportunity to become familiar with control modules and measuring equipment. They are also taught to colour code wiring with different voltages, for example red for +15V, so if they measure the signal at a point with a red wire and find a voltage that is not +15V, they should suspect immediately there is a fault in the connection. The students really appreciate troubleshooting activities because they are developing skills they can use beyond the classroom. The added activity was not associated with the course learning outcomes, but is reflected in the laboratory learning objectives outlined by Feisel and Rosa (2005). This suggested the benefit of considering the use of the holistic set of objectives for the laboratory. All other experiments received cosmetic changes such as updated pictures and some improvements to clarify instructions.

In 2009 the updated laboratory notes were implemented. The addition of supporting information and the lessons on troubleshooting had an immediate impact on the student experience. Most students observed made substantial progress in completing the experiments and had success in troubleshooting problems when mistakes were made configuring the circuit. The remaining major issue was based on clarity. Many students were happy to express frustration when they could not understand the activity they were expected to perform, but since the notes are web based, corrections are made in real time and are not seen by students in the preceding classes. The impact of changing the laboratory notes can be seen in Table 4-II, where a comparison of scores between 2007 and 2009 show a substantial improvement that remained consistent over time. Comments from students across 2009, 2010, and 2011 changed to a mixture of praise, but with some concerns about the equipment being used. Some standard comments included:

- "*Good overall. Interesting labs with good support*" Autumn, 2009
- "*Frequency generator and brakes are a bit dodgy*" Autumn, 2009
- "*Update electrical equipment*" Autumn, 2010
- "*I learnt some great troubleshooting skills*" Autumn, 2010
- "*Equipment looks aged*" Autumn, 2011

The comments show that while most students are happy with the new laboratory notes there are still some concerns about the equipment. The age of the equipment shows through physical wear and tear. For example the function generators are more than twenty years old. While the changes to the laboratory notes increased the laboratory score, it was suspected that the student evaluation of the equipment limited any further increase. As a consequence, money was reallocated for a total redevelopment of the laboratories in 2014.

4.3.2.2. ECTE233

The second course to receive negative feedback in the trial survey in 2007 was ECTE233, a course that introduces digital hardware. This course had a low score for laboratory equipment. The focus of written comments from students was heavily targeted at the Wishmaker, an electronic tool used to build and prototype electronic circuits. Comments included:

- "*sick of rebuilding my circuit due to faulty Wishmakers*" Autumn, 2007
- "*Replace the Wishmakers*" Autumn, 2007
- "*How am I expected to learn with this equipment*" Autumn, 2007

The negative feedback with the Wishmakers was confirmed by the laboratory demonstrators, so this feedback was used to justify replacing them. The cost to replace them was approximately $60,000 and was approved by the Dean of the Faculty. Student feedback provided evidence to fund the purchase within the 2008 budget.

The change in laboratory scores between 2007 and 2009 is shown in Table 4-III, which shows that by only changing the Wishmakers, the scores for the overall impression, laboratory notes, and laboratory equipment increased. Without any further changes to the laboratory made between 2009 and 2011 the consistency in scores indicated that the improvement was more than simply a novelty effect. Building upon the negative feedback on the old equipment used in the ECTE344 laboratory, this shows how the equipment can alter student perceptions of their laboratory experience.

Table 4-III: Change in ECTE233 Laboratory Evaluation Scores

Survey Statement	2007 N=35	Replaced Wishmakers	2009 N=51	2010 N=28	2011 N=40	Added information on equipment and troubleshooting	2012 N=52	2013 N=44
S1	60%		78%	70%	75%		89%	86%
S2	68%		76%	63%	76%		86%	88%
S3	n/a		79%	79%	82%		90%	90%
S4	n/a		78%	79%	75%		92%	90%
S5	53%		73%	82%	82%		92%	90%
S6	n/a		82%	84%	81%		92%	89%
Score	**58%**		**78%**	**76%**	**79%**		**90%**	**89%**

Table 4-III shows that the laboratory scores remained relatively constant between 2009 and 2011, but there was room for a substantial improvement. Student comments between 2009 and 2011 were centred on the following themes:

- "*Hot environment, need aircon*" Autumn, 2009
- "*Lab notebook vague at times. Improve clarity. Misses important steps*" Autumn, 2009
- "*Difficulties with Datasheets*" Autumn, 2010
- "*Computers run very slow. Might be issues with VMs slowing down computers*" Autumn, 2011

In 2011 the author observed student behaviour in the ECTE233 laboratory, and was able to validate the common concerns expressed by students. The room contained fifty computers with no air-conditioning, which made it an uncomfortable working environment in the warmer months. The laboratory notes contained some minor activities that were slightly confusing as to which activity to perform. The main problems with the laboratory notes, as in the ECTE344 laboratory, were gaps in understanding how to troubleshoot, how to use the simulation software and Wishmakers, and how to read datasheets. The experiments lacked building a solid foundation, and the simulation software had performance issues running in the virtual machines due to a memory hungry application.

When the semester finished the author worked with the course coordinator to modify the laboratory notes by using a similar framework to the ECTE344 laboratory. The notes were converted into a web format, a short introductory video was added to each experiment, and resources were provided to help understand how to use the software and hardware; but the biggest change came from making adjustments to the first experiment.

The modified first experiment guides students through the simulation software (Multisim by National Instruments) to select logic gates and build a simple circuit; they were then required to investigate the ‘model information’ (parameters that defined operations such as rise and fall times) built for the logic gate, and then follow activities to extract information from the datasheet so they could become familiar with reading them. The final activity involved students comparing the model information from the simulator with the information provided in the datasheet, followed by troubleshooting activities based on the common mistakes students faced in 2011. These activities included outlining the procedure to troubleshoot a scenario, or identify mistakes in a built circuit. An example of such an activity is shown in Figure 4-3, with a circuit with four mistakes; two of which are related to an incorrect use of the Wishmaker and two with errors connecting the IC. The activity encouraged students to read the datasheet, the Wishmaker resources, and the troubleshooting processes. As with the changes in ECTE344 the added activity was not associated with the course learning outcomes, but reflected in the laboratory learning objectives outlined in Feisel and Rosa (2005).

Task 2

A 74HC08N IC is placed onto the breadboard of the Wishmaker as shown in the picture below. The input of the circuit comes from the Logic Switches S1 and S2. The output of the circuit goes to Monitor Channel 1.

A student tries various switch combinations but the IC is not operating as expected. Looking at the picture what are the FOUR corrections that need to be made to get this IC working as expected? (The mistakes should be obvious). Do not build this circuit yourself. Just undertake a visual inspection.

Note: As it is a bit hard to see -> the yellow wire is connected to pin1, the green wire into pin 2 and the white wire is connected to pin 3 of the IC.

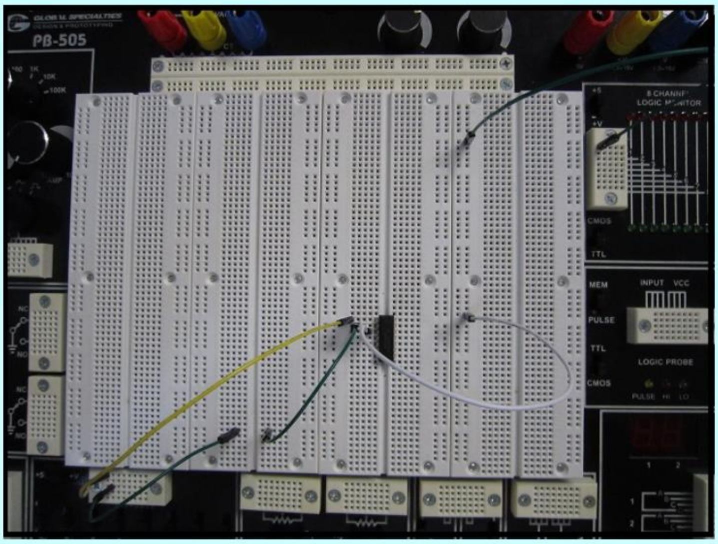


Figure 4-3: Example of a troubleshooting activity introduced in ECTE233

Since this is an important (pre-requisite for follow on courses) second year course in the first session of study, the author and the course coordinator agreed to provide some pedagogical understanding to the first experiment to complement the troubleshooting activities and give students some perspective for all future laboratory work they undertake. This decision stemmed from student comments regarding a range of courses where they experienced faults and could not understand the purpose of some activities. These comments included, “*please provide pictures to copy the construction of circuits*”, “*please test IC’s and wires beforehand*” and “*what’s the point of this task?*” In response, the first activity was changed to read:

> “*Using the data from the journal paper by Feisel and Rosa (2005) write in your logbook details about the 11 learning objectives that the ECTE233 laboratory will try and develop*”

The laboratory report assessment task was also changed to instruct students to include a section where the learning objectives of the experiment they were reporting on are discussed. These activities encouraged students to think about what they were doing from a pedagogical perspective, and as expected, there was a noticeable difference in student perspective and a substantial reduction in negative comments. However, this reduction in comments about faults could have been directly related to the new troubleshooting activities. This suggests that implementing activities based on the laboratory objectives outlined in Feisel and Rosa (2005) and making students aware of pedagogical learning outcomes benefits the student experience.

The remaining experiments remained much the same, but with some adjustments to improve the clarity and construction of an activity. For example, a laboratory has many verification activities such as, given an expression, draw a truth table, and build a circuit and compare. These activities were amended to become problem based. For example, Figure 4-4 shows a problem scenario that students must solve. The solution and approach is similar to the original verification activity, but students now gain a perspective on how they can use the logic gates in a real world application. The final change was the installation of air conditioning in the laboratory. The collective negative feedback received from the laboratory evaluations was used to gain funding for the installation.

Task 1

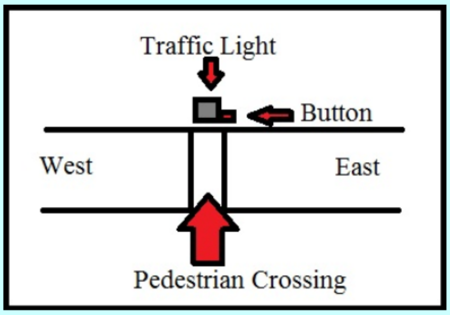
Consider the following problem:

You have been given the task to design a very simple circuit to manage a pedestrian crossing, controlled by a traffic light. The traffic light also has a sensor that can detect if cars are coming from the east or west.

This traffic light works slightly different to your normal traffic light. Its operation is as follows:

For the traffic light to turn red the pedestrian crossing button must be pressed, and traffic may only come from one direction.

The traffic light will not turn red if the button is not held down, if there is no cars in either direction, or if there are cars in both directions. A visual representation is shown below:



i) Draw a truth table for this scenario

ii) Select two chips from your labkit that will solve this problem as easily as possible. What are they?

iii) Write the Boolean expression, and draw the logic diagram for the solution

iv) Read the datasheet information to understand the operation of the ICs

v) Implement the solution on the Wishmaker

Figure 4-4: Example of a problem based activity in ECTE233 used to verify knowledge by linking it to real world situations

In 2012 the new laboratory notes were implemented and the author again observed students in the laboratory. As seen in Table 4-III, between 2011 and 2012 there was a substantial uplift in laboratory scores for each statement, but the only thing that changed was the laboratory notes and air conditioning. It was observed that once the students developed fundamental skills, they made rapid progress through the experiments and the demonstrators needed less time to troubleshoot problems with students. Again, as was with ECTE344, a common issue was the clarity of instruction for some of the activities, which when identified were easily fixed. This resulted in less negative comments from students, including those relating to the hot working conditions now that air conditioning was in use. Some comments students made:

- "*Love the labs. Well thought out labs and experiments*" Autumn, 2012
- "*An Overall great lab. Understanding more in lab then lecture*" Autumn, 2012

- “*Very well done great and helpful experience*” Autumn, 2013

This same method of modifying laboratory notes to reinforce the fundamentals and enable students to become more productive in other complex activities was implemented in three other courses (ECTE170, ECTE290 and ECTE363) with a laboratory component. Table 4-IV shows the impact that updating the laboratory notes had on the six individual survey statements across the different courses by comparing the difference in scores before and after the changes.

Table 4-IV: Increase in student satisfaction for each survey statement

	ECTE170	ECTE233	ECTE290	ECTE363
S1	11%	18%	9%	56%
S2	6%	12%	9%	69%
S3	4%	10%	9%	17%
S4	6%	23%	3%	-1%
S5	28%	13%	7%	18%
S6	20%	13%	6%	10%

As expected from the earlier case studies, rewriting the laboratory notes increased the scores for most of the six survey statements. Interestingly, S2 (which refers to the laboratory notes) does not always lead to the highest percentage of increase in student satisfaction, whereas S5, which relates to the hardware used in the laboratory, shows a substantial increase in all four cases. ECTE233 (a digital hardware course) requires a significant amount of simulation work, which is most likely reason for the big jump in satisfaction for S4.

This iterative refinement process shows how the laboratory notes (activity and clarity) influence the way students evaluate their experience in the laboratory. It also shows that the evaluations are primarily the same across the years when laboratories are run the same way. The pedagogical improvements to the experiments with the increases in evaluation scores also suggest that students can evaluate quality in the laboratory. There is also a strong relationship between the way students perceive laboratory notes and equipment/software. Chapters six and seven will continue this investigation in greater depth.

4.3.2.3. ECTE333

The ECTE233 laboratory case study revealed how changing the old and faulty Wishmaker's resulted in an uplift factor across all the laboratory statements. This effect that laboratory equipment has on the scores was also seen in ECTE333 (a microcontroller course). In 2009 students faced problems with the laboratory hardware such as random communication problems with the microcontroller interfacing with the computers. It took a number of weeks to identify the problem (unstable serial ports on the new computers that needed to be replaced), but this event allowed for an observation of the impact on the laboratory scores. As shown in Table 4-V, by comparing the 2009 score to the 2010 – 2012 scores the computers issue had a negative impact on all six statements, but mostly on the facility statements. As with ECTE344, ECTE233, and this laboratory, it is important that students perceive the equipment to be high quality and be in good working order to gain higher laboratory scores.

Table 4-V: Change in ECTE333 Laboratory Evaluation Scores

Survey Statement	2009 N=21		2010 N=24	2011 N=21	2012 N=26
S1	83%	Corrected computer issues	89%	96%	93%
S2	83%		89%	93%	93%
S3	84%		92%	96%	94%
S4	74%		92%	96%	90%
S5	73%		91%	92%	90%
S6	73%		89%	95%	88%
Score	**78%**		**90%**	**95%**	**91%**

4.3.2.4. Computers

The case studies presented here investigated major issues with regards to laboratory equipment. Across the 25 courses a number of small changes identified by student comments were acknowledged and improved, but they were not easy to identify from simply looking at the laboratory scores. The issues at times were clarified or given weight by speaking to the demonstrators or students. The effect of implementing changes can be seen by omitting relevant comments in future surveys. Most of these small issues were targeted towards the computers, the software and applications.

Across 2010 and 2011 there were a number of small complaints related to the performance of virtual machines and operating systems in other subjects than those explored earlier. These complaints were not directed towards any one specific course, but had the occasional mention across many. Some examples include:

- "*VMs creates a lag every now and again, maybe a boost in memory would help*" Autumn, 2010
- "*Speed of computers needs to be better to help in simulation*" Spring, 2010
- "*Software out of date for Win 7. Freezes a lot in VM*" Autumn, 2011
- "*Run windows 7 64bit*" Autumn, 2011

These four examples were from different subjects, but with a related theme. Virtual machines and simulators can be both processor and memory intensive. A four year asset replacement cycle was enacted to ensure that the technology did not become excessively old. It was noticeable that the software was pushing the computers to their limits, so the computers were replaced at the end of 2010; these new computers were installed with Windows 7 32bit to ensure compatibility with the software, and in the autumn, a 64bit version was tested on a select number of trial machines. These new computers had faster processors and an increase of memory (especially important to virtual machines), but the limitation of Windows 7 32bit was that the memory could not be addressed beyond four gigabytes and as a result the comments continued throughout autumn. When the operating system was upgraded in spring most of the performance based comments disappeared.

This example shows the importance of a holistic view because the small number of comments seen in evaluating individual courses did not show the extent of student frustration with the performance of the computer. This is one of the advantages of using a Laboratory Manager to oversee the laboratories and implement continuous improvement.

4.3.3. Student Perceptions of Workload

Student workload can be difficult to measure in the laboratory due to the different capability of students. It was observed in a number of courses, across a number of experiments, some students could complete an experiment in less than two hours while others could not complete an experiment in three hours and would complain about the workload. Student workload issues are generally more relevant when new experiments are implemented and the time needed to complete the activities is miscalculated. Workload issues are best observed in the laboratory but if there was a significant workload issue comments in the survey included:

- "*Less but more "learning efficient" work*" Autumn, 2012
- "*Large amount of material to cover in time. Takes away from learning experience*" Autumn, 2012
- "*Laboratory's too long, all its teaching us to do is write down numbers*" Autumn, 2012

A case study where the impact of workload issues was examined emerged when two new laboratory courses commenced in 2012, ECTE412 and ECTE423. Both courses were in the fourth and final year of the Bachelor's program in Electrical Engineering; both used a laboratory with similar equipment, the main difference being the experiments and modules used. A key component of these experiments was the LabVolt equipment which allows for the use of different plug-in modules for experiments. One of the courses was rated highly and the other poorly, primarily due to the amount of work required in each experiment; this was verified through discussions with the laboratory demonstrators.

Table 4-VI shows the difference in student evaluation for the three facility-based statements. The data shows that the scores are similar for S4 (computers), although computers are not used very much in these labs. The hardware statement (S5) and condition of the laboratory (S6) both varied by over ten per cent. The experiments were different between the two subjects, but the workload may have been a factor for S1-S3. To further verify the effect of workload, in 2013the workload was reduced with guidance from the demonstrators. The overall score of ECTE423 in 2013 rose to 92%, an increase of 28% from 2012. This data supports the work of Lizzio (2002) who found that higher student workloads lead to poorer student evaluations.

Table 4-VI: Comparison of students' evaluation of two courses that use the same laboratory and equipment

	Overall Score	S1	S2	S3	S4	S5	S6
ECTE412	85%	81%	87%	83%	80%	90%	90%
ECTE423	72%	62%	63%	69%	82%	80%	77%
Difference	**18%**	**19%**	**24%**	**15%**	**2%**	**12%**	**17%**

4.3.4. Facilities

Table 4-VII shows how students perceived the condition of the laboratories over time. University policy is that a vigorous clean only occurs before the start of the semester. In 2011 SECTE organised for an individual to undertake weekly dusting and tidying of all the laboratories and a vigorous clean at the start and middle of the semester. The 7% jump in score between 2010 and 2011 supports the possibility that the students noticed the laboratories were in a much better condition in 2011. Therefore cleanliness may play some part in student satisfaction.

Table 4-VII: Change in evaluation score for the condition of the lab 09-13

Year:	2009	2010	2011	2012	2013
Score S6:	81%	82%	88%	88%	90%

4.3.5. Qualitative Data

The quantitative analysis indicated that laboratory notes, equipment, demonstrators, and facilities help to influence student satisfaction in the teaching laboratory. Most of the survey data revolved around a five point Likert scale in order to undertake a quantitative analysis to measure and compare student satisfaction. The final question on the survey was open ended to give students the opportunity to comment on what is good and bad, and what improvements are needed. This data was inserted into NVivo and analysed. The student comments extend across the 25 laboratory courses. The following section discusses observations made beyond the case studies analysed earlier.

Over this five year period over 686 comments were made, some positive and some negative. Any comments that made direct reference to permanent academic staff are not reported in the survey data due to the condition specified in the approval of the policy by the school committee in 2008. Since the laboratory surveys were predominantly run only on sessional demonstrators, the number of comments related to academic staff was negligible, and not in relation to the laboratory. Therefore more than 686 comments were made but only 686 were recorded. With 4064 surveys conducted over the 5 year period, 17% of surveys contained a comment. This low percentage of comments can be interpreted to mean that any comments made are very important to the individual; that is, student felt strongly enough about an issue to think about it and write a comment.

To gain a deeper understanding of what mattered most to students, all the comments were separated into the seven different themes as identified throughout section 4.3, and if the comment contained multiple themes, it was separated accordingly. The seven themes are:

- **Computers including software:** The speed, reliability, hardware and operation of computers, and software that includes the operating system, internet, versioning, speed and reliability;
- **Demonstrators:** The assistance, introductions, teaching style, and interactions;
- **Electronic equipment:** The type, performance, reliability, functionality, and quantity of all non-computer related equipment related to the engineering laboratory;
- **Facilities:** This includes any non-experimental facility used or required in the teaching laboratory such as chairs, space, and air-conditioning. It also includes requests for experimental facilities outside the teaching laboratory;
- **Laboratory Design:** Comments made about the overall makeup of laboratory experiment including general comments, design of experiments, relationship to lectures, difficulty, and suitability;
- **Laboratory Notes:** The quality, clarity and depth of information required to undertake the experiments. This included supplementary resources required to complete the experiment;

- Workload: Comments in regards to the amount of work undertaken in an experiment and the impact it has on student learning.

The percentage of comments that make up each category is shown in Table 4-VIII.

Table 4-VIII: Weighting of factors raised in student feedback

Category	Percentage of Comments
Computers	11%
Demonstrators	12%
Electronic Equipment	22%
Facilities	6%
Laboratory Design	17%
Laboratory Notes	25%
Workload	7%

The data in Table 4-VIII shows that the distribution of comments under each theme is in line with the analysis of the evaluation data from the six survey statements, with the largest percentages targeted at the importance of laboratory notes and equipment to students in the teaching laboratories. Student comments about laboratory notes and electronic equipment make up almost 50% of all comments. By combining electronic equipment and computers, both important tools for undertaking the majority of experiments in SECTE, the combined total of the three categories make up 58% of all comments.

Eleven per cent of comments were in regards to the computers and software used in the teaching laboratories, with most centred on the speed of the computers, the use of virtual machines to drive different operating systems, and software configurations as well of the versioning of software. In 2009 the speed, versioning, and virtual machine problems were common, but as these issues were addressed the number of comments declined.

The electronic equipment category was the second highest, making up twenty-two per cent of the comments, most of which included the reliability, age and functionality of the equipment. Investigations into many of the claims made by students in regards to the reliability of equipment were found to be operator error, including errors made by students and demonstrators. This resulted in the need to better educate users, hence the need for developing additional resources to support learning (investigated in chapters six and seven). Age also played a significant part in student comments because students are not satisfied using equipment that looked old and in their eyes, is therefore irrelevant.

Seventeen per cent of student comments are based on the design of laboratory experiments; with the most common being the overall quality of experiments, the link between experiments and lectures, and the learning experience of the experiments. This was connected to the most commented category with twenty five per cent of the comments being laboratory notes. The quantitative analysis showed that the laboratory notes played one of the most important roles in determining student experience, as also observed in the qualitative data. The comments indicate that students want laboratory notes that are clear and have a defined goal; they become very frustrated when the task requirements can be interpreted a number of different ways, and they want access to resources that will allow them to understand the experiments.

The second lowest category commented on was student workload or the time required to complete experiments. Most of the comments were about the time or length of experiments and the impact this had on student learning. Due to the rapid pick up of laboratory issues due to student evaluations, and the relative ease in which problems are corrected, comments on workload usually only arose a session after a laboratory had been created or redeveloped. Without these evaluations the percentage of workload comments could possibly have been much higher

The category with the smallest number of comments was facilities, with only six per cent of all comments. Over 9% of the comments for facilities were related to air-conditioning, but once it was installed the number of facility based questions decreased. The other major comment regarded access of facilities outside the teaching laboratory so students could work on experiments out of class time, and as these needs were addressed the comments also decreased.

Twelve per cent of the comments were directed towards laboratory demonstrators, with most comments centred on the assistance, availability, interaction and introductions to experiments undertaken by demonstrators. Comments about ineffective demonstrators were very common in 2009 but by 2013 positive comments became standard due to the changes outlined in Chapter three. Some examples of the comments include:

- "*Demonstrators should give instructions, introductions at the start of laboratory's*"
- "*I hate laboratory's, but demonstrators made it a worthwhile experience"*
- *"A 2nd demonstrator could be useful*"
- "*More interaction should be between the demonstrators and students during the laboratory, not only at end*"
- "*laboratory demos are largely invisible & do not give the impression of having looked themselves beforehand*"
- "*Good demonstrators. Not only tell us method to solve but also the core knowledge related to the subject*"

Chapter three provided some evidence that student evaluations could to some degree measure the teaching quality of laboratory demonstrators. The survey comments strengthened the notion that they definitely influence laboratory experience. Chapter five will explore this relationship.

4.4. Summary

The quantitative and qualitative data are similar in that the changes implemented across many laboratories via the iterative refinement process have provided an insight into answering the sub-question:
What changes lead to improvements in student evaluations of the laboratory experience?

The analysis of student evaluations shows that the laboratory notes (activity and clarity) and the quality of the equipment used are the most important factors that determine laboratory experience as explored within this study; based on the chapter's focus on quality being the student experience in regards to the experiments and facilities. For example, other factors outside the definition such as quality of peers could play a role. Laboratory notes or resources with detailed instructions on how to use the hardware and software in the experiments resulted in a large increase in the evaluation score, while well-written notes of a good length provide an "up-lift" to the other evaluation criteria explored.

Experiments that are not clear in terms of the activity students are required to perform, that do not provide information about the equipment/software used, or are too long for the duration of the laboratory tend to have lower evaluation scores, and also tended to drag the other evaluation criteria down as well. Information about the equipment/software is important because if students cannot understand how to use the equipment or lack troubleshooting skills, they may believe it is faulty and then perceive the entire laboratory to be low in quality, an effect noticed in qualitative comments about some experiments.

Including a laboratory exercise or resource on fault-finding/troubleshooting can improve the laboratory experience and reinforce the notion that things do not always work in engineering. Problems encountered in laboratory exercises are seen as skill building that will add to student satisfaction. Having good hardware/software in the teaching laboratory is equally important because just as user error can lead to negative misconceptions about equipment and perceptions of a low-quality laboratory, so can faulty equipment or unusable software.

The changes carried out in the laboratory in some cases have added to learning by considering the laboratory learning objectives outlined in Feisel and Rosa (2005) in addition to the course learning outcomes. In these cases it was observed to have been of great benefit to student learning. Students now perceive this change is providing them with better skills for their future and as a consequence, has helped increase student evaluations. This is explored further in chapter eight.

Learning in a clean environment can be taken for granted. This study has also suggested that students notice when they are learning in a better environment, and therefore this chapter has provided evidence of the changes that can be made to improve student experience. This study has also provided further justification via the qualitative feedback to understand how student evaluations of laboratory demonstrators can influence their laboratory experience. This is explored in chapter five. This study also indicated that additional learning resources can help to improve student evaluations; this is covered in chapters six and seven.

CHAPTER 5: INSTRUMENT BIAS AND THE RELATIONSHIP BETWEEN DEMONSTRATORS AND LABORATORY EXPERIENCE

5.1. Introduction

In chapter three, it was confirmed using an iterative refinement process that as demonstrators are trained and supported, student evaluation scores increased. This suggests that on average, students can identify and report a quality experience. Likewise, chapter four also indicated through an iterative refinement process, that as the experiments and facilities improved, student evaluations scores also increased; this again suggests that students can identify and report a quality experience. It is commonly assumed that the teacher is highly influential in determining the outcome of student evaluations. However, what is not well understood is how much influence does a great teacher have in making a poorly designed and equipped laboratory become a great learning experience? Since the iterative refinement process was used concurrently to improve the quality of laboratory teaching assistants and the experiments and facilities, it is important to understand how these measures are related.

To complicate matters further, a laboratory may be run by more than one teaching assistant, which raises the question, what influence do different teaching assistants play in student experience in the laboratory? Having multiple teachers in the classroom is known as team based teaching (TBT), and as stated in chapter two, the advantages of TBT are more support in the classroom, students can interact with a variety of personalities and teaching styles, and students can seek assistance from the teacher they find most effective. To increase knowledge in this area it is important to understand how teaching assistants are allocated in a TBT format. For example, is having two highly experienced teachers any different from having one experienced teacher and one in training? Understanding this would lead to greater efficiency in resourcing the teaching staff associated with a teaching laboratory.

Moreover, as outlined in chapter two, the survey instrument must be valid. Chapter three explored the face validity of the survey instrument, while this chapter will explore the structural validity by confirming whether or not the evaluation questions can be grouped into scores. It will also investigate discriminant validity by identifying the impact of bias on the evaluations, and also determine the relationship of the instrument to learning. Convergent validity is about whether multiple measures are related and this will be tested by examining the relationship with learning in chapter eight. There are many possible factors that could influence a student evaluation including class size, physical appearance, the time of day, as well as the weather and gender. Some unwanted influences can be difficult to measure and determine, such as the impact of an individual's physical appearance.

This chapter will commence by examining common factors found in the literature that can influence student evaluations such as: class format (does TBT help alleviate any negativity of large class sizes?); course level (do evaluations improve with each course level, especially in years when electives are chosen?); and, gender (the influence of male and female teachers). These factors will be compared against student evaluations of laboratory demonstrators, student evaluations of the laboratory experience (the experiment and facilities), and the number of demonstrators used. A relationship will then be determined to understand how these three factors influence each other. Other influences are explored in section 5.2.5.

This chapter presents the method and the results to answer the sub-questions:
1) What forms of influence can be found in the survey instrument?
2) What is the relationship between student evaluations of teaching and the laboratory experience?

5.2. Influencing Factors and Hypothesis

In an ideal world it would be expected that the SET would be free of influence and be a reflection of student learning, but the thousands of SET research studies suggest otherwise (Spooren et al., 2013). Common influences found in the literature that impact a SET when used in the laboratory include class format, course level, and gender.

5.2.1. Class Format

Class format refers to the number of demonstrators in the laboratory; it is used to compare the difference between a small laboratory class with one demonstrator or a larger class with several demonstrators. While in many instances class size depends on the equipment, in situations such as in a computer laboratory, large classes are achievable and are generally more efficient, especially in terms of timetabling. The assignment of these parameters usually cannot be controlled by the laboratory demonstrator so understanding the role class size plays and the impact TBT has on student evaluation is important. Class size is defined as the number of students participating in a single laboratory session.

Literature studying the effect that class size has on SETs tends to show it has some impact (Shapiro, 1990, Watkins, 1990, El Ansari and Oskrochi, 2006, Johnson et al., 2013). A small number of studies have shown that class size has little impact on SET (Lin, 1992, Zabaleta, 2007), whereas several studies involving large datasets found class size has a significantly negative correlation with SET scores. This includes a study by Narayanan et al. (2014) covering 983 business and engineering courses, Johnson et al. (2013) covering 3938 courses and 549 unique engineering instructors, and Watkins (1990) with 20,000 ratings from over 200 courses. In terms of student learning, Bandiera et al. (2010) found that on average class size did not have much of an effect, except for the smallest and largest classes. A large negative effect was found in smaller classes from 1-19 students compared to 20-33 students, the most common size of laboratory classes conducted in this study. The relationship between the SET and student learning was also investigated by Galbraith et al. (2012) who studied the relationship between 116 business related courses and found that the larger the class, the less probability of SET predicting achievement in student learning.

In this study the student to staff ratio was designed to be constant with approximately one demonstrator for every fifteen students. When team teaching was required, an experienced demonstrator would be partnered up with a less experienced demonstrator. Considering this consistent student to teacher ratio, irrespective of class size, and that an experienced and inexperienced demonstrator would work together, the following hypotheses were tested:

H1a: Class size does not have an effect on demonstrator teaching scores in a team based teaching format

H1b: Class size does not have an effect on laboratory experience scores in a team based teaching format

5.2.2. Course Level

When most students start an undergraduate degree in Australia, they have little understanding about the learning experience at university. With age and experience, it is often observed that the students (excluding mature age entry students) mature throughout the degree. In this study, some core courses to specific disciplines commence in the third year, while the fourth year consists of many discipline specific electives. As a result, student motivation may increase with course level. This has led to numerous studies that have investigated whether or not course level has any effect on SET. The complexity of such an analysis was highlighted by Cranton and Smith (1986) who investigated five different departments and found that the relationship differed across the departments.

Studies outside engineering, such as psychology courses (Blackhart et al., 2006) and business courses (Scherr and Scherr, 1990) have shown that course level has almost no effect on SET, whereas major engineering based studies (Johnson et al., 2013, Narayanan et al., 2014), indicate the opposite. In particular, the study by Narayanan et al. (2014) who compared engineering and business, found that the effect of course level was greatest for engineering. A sample of 3,185 business, economics, accounting, and statistics students by Badri et al. (2006) also indicated that a relationship between course level and SET existed. Considering the literature in terms of engineering the following hypotheses were tested:

H2a: Higher level courses receive higher demonstrator teaching scores in the laboratory, regardless of team based teaching format

H2b: Higher level courses receive higher laboratory experience scores, regardless of team based teaching format

5.2.3. Gender

The gender of the instructor and/or student, and the relationship with SET has also been widely investigated, but the findings reached very mixed conclusions. A recent investigation by MacNell et al. (2015) into student ratings of online teaching staff, where the real gender of staff is not known, found that the SET was biased against females. This was determined by having a male and female instructor participate in multiple online discussion forums, using both a male or female name in different sessions. However, due to the small sample (N=72) and design of the experiment, researchers have questioned the validity of the finding (Benton and Li, 2014). Other gender bias studies have also found that males give significantly lower SET scores to females (Basow and Silberg, 1987, Centra and Gaubatz, 2000), male instructors receive higher SET scores regardless of the gender of the student (Basow and Silberg, 1987, McPherson et al., 2009), and male instructors received equal ratings from males and females (Centra and Gaubatz, 2000).

A wide ranging study of literature by Aleamoni (1999) found that most studies have established that gender does not play a biasing role in SETs. Some of the studies that have found such a conclusion includes a study of four universities in Pakistan (Hameed et al., 2014), a controlled social experiment (Feldman, 1993), and a large scale study of a Spanish program (Zabaleta, 2007).

The large scale engineering studies found that male instructors do receive higher SET ratings and female instructors were not held to a higher standard (Johnson et al., 2013), and male instructors in engineering received higher ratings, unlike those in a business college (Narayanan et al., 2014). This study investigates this bias further by comparing male and female instructors in a mixed TBT format. Considering the mixed literature and engineering studies, the following hypotheses are tested:

H3a: Male instructors receive higher demonstrator teaching scores, regardless of team based teaching format

H3b: Laboratories with male instructors receive higher laboratory experience scores, regardless of a team based teaching format

5.2.4. Relationship: Teaching vs Laboratory Experience

The final hypothesis and goal of this study is to investigate the relationship between student evaluations of teaching and laboratory experience (the quality of the experiments and facilities). As reported in the literature reviewed earlier, substantial research has been undertaken to investigate the SET, and separate research has been carried out to investigate student's perception of the quality of university facilities and laboratories (Douglas et al., 2006, Deshwal et al., 2012, Gonsai et al., 2013, Nikolic et al., 2015, Vial et al., 2015). What needs more attention is an understanding of how student perception of teaching quality relates to their perception of a quality laboratory experience. This is important because the *"quality of the classroom life is significant in shaping students' feelings and attitudes to their classmates and teachers"* (Che Ahmad et al., 2013, pg. 368). If universities can quantify this relationship, they will be better able to allocate resources to maximise student experience and learning outcomes, and also maximise efficiency and monetary gains. Therefore, the following hypothesis is tested and then used to quantify the relationship between the teaching team:

H4a: There is a positive relationship between demonstrator teaching scores and laboratory experience scores

5.2.5. Limitations

This study does not attempt to investigate all factors that can influence the SET. Other effects already investigated in literature include bias against minority and nonnative English speakers (Plank and Chiagouris, 1997, Hamermesh and Parker, 2005, Reid, 2010, Bavishi et al., 2010); age discrimination (Stolte, 1996, Arbuckle and Williams, 2003); physical attractiveness (Langlois et al., 2000, Hamermesh and Parker, 2005); and the difficulty of achieving high grades (Braga et al., 2014). These influences and many other possible influences such as the weather and time of day are not in the scope of this study.

5.3. Method

A simultaneous evaluation of teaching and laboratory experience occurred during 2012 – 2014, with ethics approval number HE14/156. This consisted of 2519 survey responses across six teaching semesters. Evaluation surveys are only conducted in laboratories that are run by (casual/sessional) laboratory demonstrators. The same laboratory demonstrator is used in a laboratory throughout the semester, so the results of this study may differ for a permanent faculty due to differences in teaching experience and knowledge of the course and structure. Laboratories that may have been influenced by individuals such as permanent faculty have had their evaluations removed from this study due to the focus of this research on sessional staff. This resulted in 2,161 survey responses being evaluated in this analysis. A lecturer in statistics from the university was used to help develop the following statistical methodology.

A typical engineering course consists of a lecture, tutorial, and laboratory per week. Most courses have duration of one semester per year, with two courses being run, and evaluated twice in the year. Many courses have multiple and repetitive laboratory classes because the maximum laboratory class size possible due to equipment constraints is 45 students. Again, due to equipment constraints, some laboratory class sizes could be as small as 10-15 students. The demonstrators usually have no input into the delivery, material, and learning objectives associated with the experiments.

Having repeated laboratories within a single course with consistent factors such as assessment, structure, experiment, and facilities, while having different or the same laboratory demonstrators, provides the framework for a rigorous multi-level analysis.

A combination of laboratories with different and same demonstrators undertaking repeat classes was desired as the multi-level approach factors in these differences. Most SET based research studies are not multi-level because the comparisons are made between different courses and/or the same courses over a number of years. This method has the limitation of many more variables due to uncontrollable differences between subjects or years. Since the conditions in multiple laboratory classes are consistent, and multiple demonstrators are used, the analysis can be carried out between laboratory classes of the same course as well as between courses. A simplistic representation of the differences in the comparisons made between single and multi-level approaches is shown in Figure 5-1.

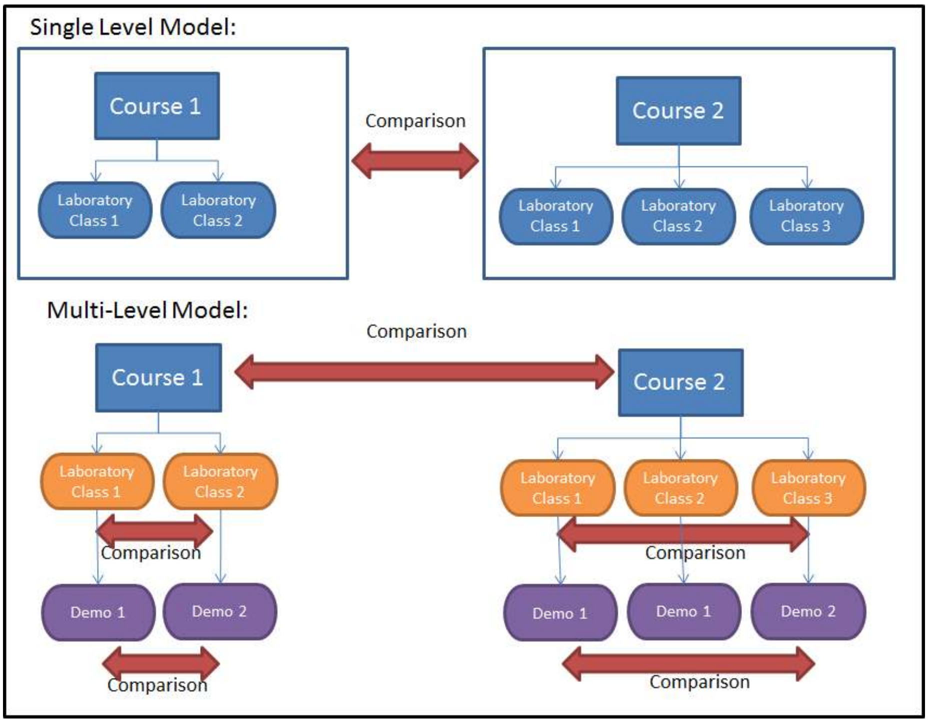


Figure 5-1: A simplistic representation of the difference between single and multi-level statistical approaches

This scenario of having students within a laboratory class, and laboratory classes within a course, is a typical example of hierarchal data, for which typically a multi-level model, with levels students, laboratory classes and courses, is used for the statistical analysis (Berkhof and Kampen, 2004). Another typical example in educational literature is pupils within classes and classes within schools (Moerbeek, 2004). Not accounting for the hierarchal structure of the data might lead to incorrect statistical results because standard errors would be either under or overestimated (Moerbeek, 2004). The statistical platform R (R Core Team, 2013) and the R package lme4 (Bates et al., 2014) was used for the statistical analysis, in which the fixed effects (usually differences in the means) and p-values of the multilevel model will be presented. A multivariate Wald test based on a multi-level approach is applied. In some cases when multiple hypotheses are tested at once, the Bonferroni method of correction by multiplying the p-value with the number of hypotheses and comparing this adjusted p-value with the significance level (Abdi, 2007) is applied.

The data is also compared via a non-hierarchal analysis. To assess the effect of a factor with more than 2 levels, One-way ANOVA and p-values from Welch's t-test are applied, but the latter should be considered as unreliable because it does not account for the hierarchal structure of the data collected in this study. That means the results of Welch's t-test and ANOVA are presented only for comparison purposes because all the studies outlined in Section 5.2 do not use a multi-level model. This difference in design highlights the significance of this research by providing a stronger statistical analysis. The conclusions will always be based on a multi-level approach based at the standard 5% significance level.

The data for the statistical analysis was obtained from a paper based survey instrument outlined in chapters three and four. For some laboratories in a TBT format some demonstrators may be evaluated more than once, but across multiple sessions, demonstrators involved in teaching a course may have repeated or changed. Since a multi-level analysis is used this did not matter because in any given teaching semester, for any given course, the experiment and facilities are constant. This means an easy comparison between demonstrators is achievable. Twenty-five laboratory courses were analysed, including the number of multiple evaluations shown in Table 5-I. This data includes the number of laboratory classes, laboratory courses, and student sample evaluated in each teaching semester across the three years. Table 5-II outlines the gender and ethnicity of the laboratory demonstrators, and shows that male and international demonstrators were heavily used across the three year period.

Table 5-I: List of courses and number of laboratory classes surveyed towards the end of each semester.

Course Code	Course Name	2012 Sem 1	2012 Sem 2	2013 Sem 1	2013 Sem 2	2014 Sem 1	2014 Sem 2
ECTE222	Power Engineering 1	2		3		3	
ECTE233	Digital Hardware	2		1		4	
ECTE301	Digital Signal Processing	1		1		1	
ECTE333 A	Microcontroller Architecture and Applications Part A	1		0		0	
ECTE344	Control Theory	2		2		3	
ECTE363	Communication Systems	3		3		2	
ECTE401/901	Multimedia Signal Processing	1		2		1	
ECTE412/912	Power Electronics and Drives	1		2		3	
ECTE423/923	Power System Analysis	1		2		3	
ECTE433/933	Embedded Systems	2		1		1	
ECTE170/172	Introduction to Circuits and Devices		3		3		3
ECTE182	Internet Technology 1		1		1		1
ECTE203	Signals and Systems		1		2		1
ECTE212	Electronics		2		2		1
ECTE290	Fundamentals of Electrical Engineering		4		2		4
ECTE323	Power Engineering 2		2		2		3
ECTE324	Foundations in Electrical Energy Utilisation		2		2		1
ECTE333 B	Microcontroller Architecture and Applications Part B		1		1		1
ECTE364	Data Communications		1		2		1
ECTE432/932	Computer Architecture		1		0		0
ECTE465/965	Wireless Communication Systems		1		1		1
ECTE469/962	Queuing Theory and Optimization		0		3		2
ECTE903	Image and Video Processing		1		1		0
ECTE906	Advanced Signals and Systems	1	1	1	1	2	0
ECTE955	Advanced Laboratory	2	1	1	1	1	1
	Total Laboratory Classes Surveyed	19	22	19	24	24	20
	Total Courses Surveyed	12	14	11	14	11	12
	Total Survey Responses Analysed	316	432	245	419	368	381

Table 5-II: Demonstrator and survey characteristics

Semester	No. of Courses	Male	Female	Australian Citizen	International	Survey Responses Analysed
Semester 1 2012	12	17	7	1	23	316
Semester 2 2012	14	24	8	2	30	432
Semester 1 2013	11	14	6	1	19	245
Semester 2 2013	14	19	10	3	26	419
Semester 1 2014	11	19	9	4	24	368
Semester 2 2014	12	16	7	3	20	381
Number of unique demonstrators evaluated		41	15	5	51	

As outlined in Chapters three and four, operational management of the laboratory is allocated to the designated course coordinator (permanent faculty) who is responsible for the design, assessment, and running of the laboratory. Laboratory demonstrators were allocated by the author, as laboratory manager. Considerations in allocation include experience, work load, and the skills required. In larger classes, when a teaching team was needed, inexperienced laboratory demonstrators were partnered with experienced ones (a master/apprentice model). The only exception being for first year courses, due to the importance that the first year has on student retention (Pendergrass et al., 2001, Daempfle, 2003, Karataş et al., 2016). Due to an assumption that the two best demonstrators are needed in the laboratory to try and ensure a great first year experience, only the most highly valued (in terms of reputation and evaluation scores) teaching assistants were used. This assumption highlights the importance of this study in resource allocation; that is, does only one demonstrator need to be exceptional, with the other used more effectively in another class?

Across all laboratory courses the ratio of teaching assistants to students was aimed at being one to 15, therefore on average, if a laboratory consists of 15 students, one laboratory demonstrator is used, if 30 students' two laboratory demonstrators are used, and if there are 45 students, three demonstrators are used. A breakdown of the number of courses that used the three different class formats is shown in Table 5-III. The type of format depended on student numbers as well as timetable and equipment constraints. The number of courses sampled using three demonstrators was low, which limits the significance of data under this TBT format.

Table 5-III: Number of courses that used a class format of 1, 2 or 3 demonstrators

Semester	One Demonstrator	Two Demonstrators	Three Demonstrators
Semester 1 2012	7	4	1
Semester 2 2012	5	6	3
Semester 1 2013	5	6	0
Semester 2 2013	6	7	1
Semester 1 2014	7	3	1
Semester 2 2014	3	8	1
Number of unique courses *(a course can be represented in multiple columns)*	16	16	5

5.3.1. Student Evaluation Instrument

The teaching allocations were assigned such that the most experienced demonstrator would lead the class, assume overall responsibility, and also provide an introduction to the students. In this study this demonstrator is referred to as DEM1 (demonstrator 1). When a TBT format is required the second and third demonstrators assist and follow the instructions of DEM1. The second and third demonstrators are referred to as DEM2 and DEM3, and are listed in the evaluation instrument in terms of their order of experience. The six survey questions outlined in chapter three were used to evaluate DEM1 and five questions (Q2-3) are used for DEM2 and DEM3, and the difference of one question relates to the introduction delivered by DEM1. The survey of laboratory experience was also outlined in chapter four. It consisted of three statements (S1-3) that evaluated student's perception of the experiment, referred to as LAB1. Three statements (S4-6) were used to evaluate the equipment and facilities, referred to as LAB2. The survey responses for the demonstrator and laboratory experience were converted to a weighted average score as described in chapters three and four for comparison purposes.

The survey questions were analysed to understand how the data could be cross compared. For the demonstrator survey questions, the smallest correlation is 0.3324, which is still highly significant ($p<0.0001$), similarly for DEM1, DEM2 and DEM3, the smallest correlations are 0.9053 (p-value <0.0001), 0.9794 (p-value<0.0001), and 0.9778 (p-value<0.0001).

The next step was to confirm the number of components/factors within each learning domain to determine how the questions and statements could be grouped to produce a score. The default method of determining factors is via Kaiser Criterion by observing if the eigenvalues are greater than one. However, literature suggests that it should not be the only criterion because it tends to over extract factors (Lance and Vandenberg, 2009), therefore four different checks were used, the Kaiser Rule, parallel analysis, optimal coordinates, and the acceleration factor.

For DEM1, DEM2, and DEM3, the methods suggest only one underlying factor. The largest and 2nd largest eigenvalues were 4.73 and 0.108 for DEM1, 3.94 and 0.02 for

DEM2 and 3.94 and 0.023 for DEM3. Based on the Kaiser rule (Child 1990), these findings all suggest one underlying factor. Other methods such as parallel analysis and optimal coordinates also suggest only one factor using the R package "psych" (Revelle 2015). Similar to Johnson, Narayanan, and Sawaya (2013) we used the average score of all questions to maintain interpretability.

The six laboratory experience questions had eigenvalues of 3.43, 1.11, 0.497, 0.39, 0.28 and 0.28. Using the R package "psych" (Revelle 2015), the Kaiser rule, parallel analysis and optimal coordinates all suggest two underlying factors (Child 1990). Factor loadings and "varimax" rotation was used to assess the groupings of the factors. Factor 1 has loadings of 0.87 (Q1), 0.86 (Q2) and 0.83 (Q3), whereas factor 2 has loadings of 0.77, 0.85 and 0.86, with all other loadings being below the cut-off value of 0.3. The Bi-plot of a principal component analysis is shown in Figure 5-2 to demonstrate that Q1, Q2, and Q3 are clustered, as are Q4, Q5, and Q6 as highlighted by the red arrows and numbers. Since the factor loadings are approximately equal (around 0.85) we used the average of Q1,Q2,Q3 scores and the average of Q4,Q5,Q6 scores as the two variables of interest, denoted by LAB1 and LAB2 in order to maintain interpretability, just like Johnson, Narayanan, and Sawaya (2013) did for one factor. To ensure reliability the standardised Cronbach's α (R package "psych") was calculated for all scores of interest. The values are: 0.85 (EXP), 0.82 (FACIL), 0.99 (DEM1), 1.00 (DEM2), 1.00 (DEM3) and are all above 0.70, a common cut-off value for validity.

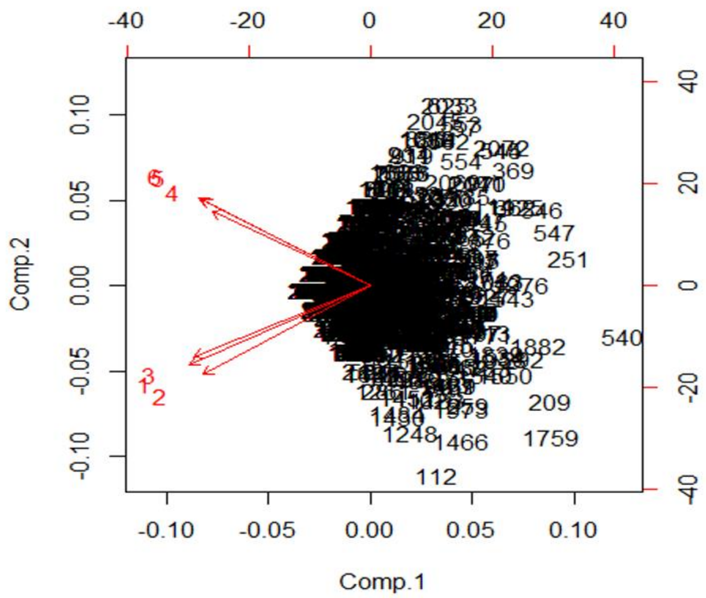


Figure 5-2: Bi-plot of laboratory survey responses indicating that the questions can be separated into two clusters

5.3.2. Limitations

Each laboratory class has one, two, or three demonstrators. This means that 2,161 student responses are available to evaluate laboratory experience, but fewer responses are available for a particular demonstrator. Due to the different sample sizes, it would be more likely to obtain significant results for laboratory scores rather than demonstrator scores. In addition, only a small sample was available for the case of three demonstrators (as indicated in Table 5-III). The study was conducted in a school of electrical, computer, and telecommunications engineering and different disciplines may have different outcomes. Similarly, it is important to note that different approaches or pedagogies to laboratory learning may be prevalent across disciplines, universities, or countries. The school has a large percentage of international students and international teaching assistants, so different combinations of student cohorts, student quality, levels of communication, as well as different social attitudes towards race and gender could also alter the findings. These limitations are in addition to the possible forms of bias mentioned throughout section 5.2.

5.4. Results

Class format:

H1a: Class size does not have an effect on demonstrator teaching scores in a team based teaching format

H1b: Class size does not have an effect on laboratory experience scores in a team based teaching format

H1a and H1b were to confirm whether class size had no effect on teaching or the laboratory experience scores in a team based teaching format with a constant student to staff ratio. Each laboratory class has approximately 15 (1 demonstrator), 35 (2 demonstrators) or 45 students (3 demonstrators). Table 5-IV shows that H1a and H1b are supported by the analysis based on a multi-level model, because the mean differences between scores are not significant at the 5% significance level.

Table 5-IV: Data confirming that class size has no effect in a TBT format

Score	Multi-level Model effect / p-value	Welch t-test effect /p-value	Conclusion
LAB1			
15 vs 35	-0.058109637	-0.443297427	H1a supported
15 vs 45	3.3665 / 0.2466	3.0232 / 0.0137	
35 vs 45	- 3.4230 / 0.2150	3.3195 / 0.0042	
LAB2			
15 vs 35	-0.255850999	-0.126266196	H1a supported
15 vs 45	2.2555/0.1868	2.3730 / 0.0216	
35 vs 45	-17.39096683	2.4801 /0.0122	
DEM1			
15 vs 35	-0.812268484	-13.93205128	H1b supported
15 vs 45	0.5578 / 0.8114	0.4022 / 0.7057	
35 vs 45	1.1061 /0.6332	1.4889 /0.1474	
DEM2			
15 vs 35	--	--	H1b supported
15 vs 45	--	--	
35 vs 45	1.445 / 0.4764	2.677 /0.0037	
DEM3			
15 vs 35	--	--	H1b supported
15 vs 45	--	--	
35 vs 45	1.033 / 0.6984	1.1961 / 0.3573	

Course level:
H2a: Higher level courses receive higher demonstrator teaching scores in the laboratory, regardless of a team based teaching format
H2b: Higher level courses receive higher laboratory experience scores, regardless of a team based teaching format

H2a and H2b were to confirm whether higher level courses had a positive effect on teaching or the laboratory experience scores. The effect of course level (1st year, 2nd year, 3rd year and 4th year courses) was investigated, and the results of possible influence of course level (COURSE) are shown in Table 5-V. The makeup of the courses was represented in Table 5-I with the first digit of each course representing the course level. All 4th year courses surveyed contained postgraduate coursework students (900 level), so 400 and 900 level courses are treated as the same level.

Table 5-V: Possible bias of course level

Score	Multi-level Model Wald statistic, p-value	One way ANOVA F statistic, p-value
COURSE on LAB1	W=1.625, p=0.6537	F=6.893, p=0.0001
COURSE on LAB2	W=2.821, p=0.4200	F=2.530, p=0.0556
COURSE on DEM1	W=14.67, p=0.0021	F=19.625, p<0.0001
COURSE on DEM2	W=8.765, p=0.0325	F=28.429, p<0.0001
COURSE on DEM3	W=6.232, p=0.1008	F=10.499, p<0.0001

The results from Table 5-V show there is an effect on DEM1 and DEM2 (significant), but no effect on LAB or DEM3 (using the multi-level approach). Interestingly, the single level approach has an effect on all tests, highlighting the importance of selecting the appropriate statistical model. To investigate how levels compare to other levels, Table 5-VI shows the effects (differences in mean) and p-values for every pair of course levels. The p-values are based on the multi-level approach. In general, H2b must be rejected because there is no clear direction. For example, DEM1 4th year courses scored lower than 1st and 3rd year, but higher than 2nd year. Third year courses scored much higher than 2nd year courses (even after a Bonferroni correction for multiple testing is applied, i.e. multiple p-values by 6 and compare with 0.05). For DEM2, after a Bonferroni correction, there are no significant differences, except third year courses scored higher than 2nd year. Overall, as there is no clear pattern so H2a and H2b are rejected.

Table 5-VI: Differences in mean for every pair of course level

	DEM1 effect	DEM1 p-value	DEM2 effect	DEM2 p-value
2nd vs 1st	-4.5215	0.0154	-3.931	0.1203
3rd vs 1st	0.5487	0.7651	2.9851	0.2827
4th vs 1st	-2.1288	0.2447	0.1821	0.9401
3rd vs 2nd	5.0702	0.0003*	6.9160	0.0045*
4th vs 2nd	2.3924	0.0837	4.1129	0.0443
4th vs 3rd	-2.6775	0.0460	-2.8031	0.2322

Gender:

H3a: Male instructors receive higher demonstrator teaching scores, regardless of team based teaching format

H3b: Laboratories with male instructors receive higher laboratory experience scores, regardless of team based teaching format

H3a and H3b were to confirm if the male demonstrators had a positive effect on teaching or the laboratory experience. The makeup of male and female demonstrators is shown in Table 5-II, with the female demonstrators on average representing 43% of teaching staff. To test whether a male instructor has an effect on LAB scores, we calculated the average proportion of male instructors (PROPMALE). This proportion has values of 0, 1/3, ½, 2/3 and 1. For example 1/3 indicates 1 out of 3 demonstrators are male. We then tested whether the coefficient associated with PROPMALE is significant, and then whether the gender of DEM1, DEM2 and DEM3 affects the LAB scores. To test H3b, we tested whether 'male' demonstrators received higher demonstrator scores. Table 5-VII shows the results, with none of the tests indicating any significance. Therefore H3a nor H3b are not supported.

Table 5-VII: Analysis to determine if male demonstrators receive higher scores than females

Score	Multi-level Model effect / p-value	Welch t-test/LM effect /p-value	Conclusion
PROPMALE on LAB1	-0.1384 / 0.7605	0.0200 / 0.4102	H3a not supported
MALE DEM1 on LAB1	-1.3522 / 0.8183	-0.9861 / 0.9236	H3a not supported
MALE DEM2 on LAB1	0.0925 / 0.4789	0.7659 / 0.2087	H3a not supported
MALE DEM3 on LAB1	1.3848 / 0.3578	-0.1032 /0.5272	H3a not supported
PROPMALE on LAB2	-0.1139 / 0.8363	-0.0892 / 0.8887	H3a not supported
MALE DEM1 on LAB2	-0.4585 / 0.6888	-0.4401 / 0.7689	H3a not supported
MALE DEM2 on LAB2	1.4558 / 0.1138	1.4954 / 0.0353	H3a not supported
MALE DEM3 on LAB2	0.0774 / 0.4838	-0.0416 / 0.5137	H3a not supported
MALE DEM1 on DEM1	0.4200 / 0.3665	0.6556 / 0.1534	H3b not supported
MALE DEM2 on DEM2	-1.0651 / 0.7425	-0.4239 / 0.6972	H3b not supported
MALE DEM3 on DEM3	-1.0292 / 0.6480	-2.6075 / 0.9774	H3b not supported

Relationship:

H4a: There is a positive relationship between demonstrator teaching scores and laboratory experience scores

The main goal of this study, expressed in H4a, was to confirm if a positive relationship exists between the teaching and laboratory experience scores. To investigate the relationships between LAB ratings and demonstrator ratings (DEM1, DEM2 and DEM3), we need to take into account that only some classes have only i) DEM1, some have ii) DEM1 and DEM2, and some iii) DEM2 and DEM3 (when the lead demonstrator does not need to give a class introduction) and some iv) DEM1, DEM2 and DEM3. We considered these cases separately using the multi-level model analysis. The number of courses representing these cases is shown in Table 5-III.

Table 5-VIII shows the results for case i), Table 5-IX for case ii), Table 5-X for case iii) and Table 5-XI for case case iv), and they all show a strong positive relationship between the LAB1 scores and demonstrator scores. For example, Table 5-VIII shows that an increase in one unit of the DEM1 score results in an increase of 0.5451 in the LAB score. Table 5-IX, X and XI has a similar pattern, but they also show the DEM1 scores are more important than DEM2 scores, and the DEM2 scores are more important than DEM3 scores, except for scenario iv), which indicates the DEM3 scores could be more important than DEM2 scores. Table 5-VIII shows the DEM3 scores are not significant, which could be due to low sample size for scenario iii). The same analysis was repeated between LAB2 scores and demonstrator scores. A very similar outcome was found for LAB2 scores across all four scenarios. Table 5-XII shows the relationship for scenario iv) between LAB2 scores and the three demonstrator scores. These results confirm that DEM1 has the largest influence on laboratory experience scores and is therefore most important.

Table 5-VIII: Relationship with only DEM1

	Estimate	**Standard Error**	**t-value**	**p-value (2-sided)**
Intercept	35.3687	2.1368	16.55	<0.0001
DEM1	0.5451	0.0225	24.17	<0.0001
	Level 1 (students)	Level 2 (class)	Level 3 (Courses)	
Variance-Estimates	132.13	20.691	6.061	R^2=0.3616

Table 5-IX: Relationship with only DEM1 and DEM2

	estimate	Standard Error	t-value	p-value (2-sided)
Intercept	28.1943	2.7814	10.137	<0.0001
DEM1	0.3790	0.0384	9.859	<0.0001
DEM2	0.2486	0.0378	6.562	<0.0001
	Level 1 (students)	Level 2 (class)	Level 3 (Courses)	
Variance-Estimates	114.217	4.667	7.844	R^2=0.4908

Table 5-X: Relationship with only DEM2 and DEM3

	estimate	Standard Error	t-value	p-value (2-sided)
Intercept	26.7086	4.6322	5.766	<0.0001
DEM2	0.4087	0.0767	5.328	<0.0001
DEM3	0.2547	0.0701	3.595	0.0003
	Level 1 (students)	Level 2 (class)	Level 3 (Courses)	
Variance-Estimates	114.62	12.01	6.45	R^2=0.4653

Table 5-XI: Relationship with DEM1, DEM2 and DEM3

	estimate	Standard Error	t-value	p-value (2-sided)
Intercept	15.3720	7.1941	2.137	0.0326
DEM1	0.2931	0.1085	2.700	0.0069
DEM2	0.2783	0.1192	2.334	0.0196
DEM3	0.2177	0.1324	1.644	0.1002
	Level 1 (students)	Level 2 (class)	Level 3 (Courses)	
Variance-Estimates	114.94	0.00	12.68	R^2=0.4873

Table 5-XII: Relationship between LAB2 scores and demonstrator scores

	estimate	Standard Error	t-value	p-value (2-sided)
DEM1				
Intercept	57.3383	1.9690	29.12	<0.0001
LAB2	0.3594	0.0213	16.86	<0.0001
DEM2				
Intercept	58.5487	2.4239	24.15	<0.0001
LAB2	0.3539	0.0254	13.92	<0.0001
DEM3				
Intercept	47.8763	4.5387	10.548	<0.0001
LAB2	0.45720	0.0471	9.702	<0.0001

These results also show that DEM-ratings are not fully explaining the LAB1 ratings, as R2 the proportion of the variance ranges from 0.36 to 0.49 and shows that 36%-49% of the variance of the LAB1 scores is explained by demonstrator scores. The highest values are obtained when more than two demonstrator scores are available;

which shows that the ratings of all three demonstrators jointly contribute to an accurate prediction of laboratory scores.

5.5. Discussion

The first hypothesis was to determine how class size affects student evaluations scores when using a team based teaching format. Literature suggests that class size does impact on student evaluations (Shapiro, 1990, Watkins, 1990, El Ansari and Oskrochi, 2006, Johnson et al., 2013), and since the ratio of teachers to students was relatively constant, no impact was suspected when using team based teaching. The results show that based on a multi-level model where the mean differences between scores for different classes are not significant at the 5% significance level, class size had no impact on the evaluation scores of teaching staff and laboratory experience. This provides weight to the benefit of teaching teams and a master/apprentice model for demonstrator training.

The literature also suggests that course level can influence student ratings, especially in engineering (Badri et al., 2006, Johnson et al., 2013, Narayanan et al., 2014). Analysis of the results suggest that this influence was not present regardless of the class format and differences in the mean and corresponding p-values for every pair of course levels showed no clear pattern in any direction. Therefore, student ratings of demonstrators and laboratory experience did not increase with course level. However, the 3rd and 4th year results were greater than the 2nd year results; which tends to suggest that those years in which students participate in more discipline specific courses, their evaluation is more favourable.

The findings in the literature regarding the effects of teacher gender on student evaluations are mixed; some suggest there is no effect (Aleamoni, 1999, Feldman, 1993, Hameed et al., 2014), while others, including large engineering studies, did (Basow and Silberg, 1987, McPherson et al., 2009, Johnson et al., 2013, Narayanan et al., 2014). The study shows that none of the tests indicated a significant correlation, regardless of class format, and demonstrator gender had no real influence on student evaluations scores.

The final hypothesis was to investigate the relationship between student evaluation scores on teaching and laboratory experience in order to quantify the importance of the laboratory demonstrator and also understand how to apply this effectively in a TBT class format. Laboratory experience was divided into two components based on the factor analysis; one focussed on the experiments and the other on the facilities. The results show that the lead demonstrator has the greatest influence on the laboratory experience score, regardless of whether one, two, or three demonstrators are used. As expected, in a laboratory with one demonstrator their influence is the highest, with an increase in one unit of the DEM1 score resulting in an increase of 0.5451 of the LAB1 score.

In a team based teaching format, a lower but still important influence is shown for the other two demonstrators, which suggests the importance of selecting high quality demonstrators and providing laboratory specific training to positively influence laboratory evaluation scores. It also shows the importance of using the best possible lead demonstrator. With the major influence being held by the lead demonstrator findings also suggest that using a master/apprentice model in a TBT format will not have a major impact on student laboratory experience as long as the lead demonstrator is of high calibre. This is an important finding because it should give those who allocate teaching staff the confidence to use TBT to help train less experienced demonstrators. Moreover, researchers evaluating the success of changes to laboratory experiments or facilities can now quantify the impact that teaching staff have in their research design.

These results also show that while laboratory demonstrators have a large part in influencing laboratory experience, only 36% to 49% of the variance is explained by demonstrator scores, and therefore we suggest that other factors contribute at least 50% to variation in student evaluations of laboratory experience. The remaining unexplained variation could be due to factors collected in the study, factors that could be observed but were not collected and other factors that are not observable. For instance, demonstrator age and ethnicity was not included, but it could reduce the unexplained variance. Factors associated with laboratory experience are also very important. In chapter four it was found that laboratory notes (activity and clarity), quality of equipment, and student workload within the allocated laboratory timeslot influenced the laboratory experience scores.

5.6. Conclusion

This chapter investigated the use of student evaluations in order to comprehend the influences associated with the survey instrument in regards to team based teaching in an engineering teaching laboratory. Evaluations were conducted on laboratory teaching assistants and analysed using a multi-level model. This chapter also showcased the importance of using multi-level statistical models to analyse student evaluations due to the contrasting findings of single level models. Seven hypothesises were tested:

H1a: Class size does not have an effect on demonstrator teaching scores in a team based teaching format - *supported*
H1b: Class size does not have an effect on laboratory experience scores in a team based teaching format - *supported*
H2a: Higher level courses receive higher demonstrator teaching scores in the laboratory, regardless of a team based teaching format - *rejected*
H2b: Higher level courses receive higher laboratory experience scores, regardless of a team based teaching format - *rejected*
H3a: Male instructors receive higher demonstrator teaching scores, regardless of team based teaching format - *rejected*
H3b: Laboratories with male instructors receive higher laboratory experience scores, regardless of team based teaching format - *rejected*
H4a: There is a positive relationship between demonstrator teaching scores and laboratory experience scores - *supported*

The TBT approach found no significant influence in terms of class format, course level, and demonstrator gender, indicating there is an acceptable level of discriminant validity. Structural validity was also confirmed by understanding how the questions and statements could be grouped into scores. This is in addition to the confirmation of face validity in chapter three. Further validation of the survey instrument will be examined in chapters seven and eight by examining the relationship with learning and investigating for convergent validity.

A key conclusion is that team based teaching is a valuable method of enhancing the laboratory learning experience. As expected, the lead demonstrator has the most influence on laboratory experience when one, two, or three teaching assistants are used. With this influence quantified, staff conducting teaching allocations should be encouraged to use the master/apprentice model by partnering very experienced demonstrators with less experienced ones. However, when the laboratory class increased (45 plus) the influence from each demonstrator became more equal, probably because the lead demonstrator has less time to make contact with all the students.

CHAPTER 6: LABORATORY RESOURCES

6.1. Introduction

Chapter three used an iterative refinement process to examine the benefits of providing additional resources for experiments and equipment to help train and prepare demonstrators for teaching. Similarly, chapter four outlined through an iterative refinement process how such resources improved the laboratory experience scores from student evaluations. The research found that additional resources that help students understand the experiments, the equipment, and develop laboratory skills, provided an uplifting factor to student evaluations. From these positive outcomes came a further study to investigate this impact in greater detail. The findings can aid in understanding if students use such resources to better target the development of such resources, helping to improve the student experience. As a result, this chapter presents the method and results needed to answer the sub-question:

Do students use and appreciate additional laboratory resources?

6.2. The Training Laboratory

An online multimedia resource database for both demonstrators and students called the Training Laboratory was developed to try and improve laboratory experience and learning. It is important to gain an insight into the design and usefulness of this resource.

6.2.1. Laboratory Demonstrators

The idea that sparked the development of this Training Laboratory was the need to improve the training delivered to teaching assistants who are known as laboratory demonstrators. As outlined in chapter three, training laboratory demonstrators is important to provide a quality learning experience for students. In the school, most teaching assistants are international PhD students whose theoretical knowledge is very high, but who often lack practical skills. This included knowing how to use the equipment and how to correctly troubleshoot problems. This problem had to be rectified because the laboratory is important means of developing cognitive, psychomotor, and affective skills (Salim et al., 2013). As a result, a website which contained tutorial videos, text and picture information, and manuals that the laboratory demonstrators could use as preparation material was created.

6.2.2. Prerequisite Student Knowledge

The engineering department is a popular destination for international students, comprising a large proportion of the student ratio in the third and fourth years. Since many international students enter mid-way through the electrical, computer or telecommunications degree, it became apparent they were good at theoretical learning but their practical skills were lacking and they, like the laboratory demonstrators, struggled in the laboratory.

In Australia, multiple pathways are also causing a similar issue; students can obtain advanced credit for courses from studies obtained from other universities or colleges (Millman, 2013). In addition, the coursework program for double degrees or other mixed programs means students undertake courses in a nonstandard order, so the resources developed in the Training Laboratory allow students to catch up pre-requisite laboratory skills.

6.2.3. Laboratory/Resource Design

Designing laboratory experiments takes time to become effective and increase student satisfaction. Additionally, developing supplementary material like video guides is time consuming but beneficial for learning (Mason et al., 2013). The traditional method of developing laboratory notes is an independent process whereby each course coordinator or course teaching team, teaches and also provides resources to complete the laboratory. This method suggests that productivity can be low because course coordinators may duplicate the resources or instruction. A second problem existed if hardware or software is changed resulting in the need to update the resources. A third problem was it was often hard to cater for students who do not have the prerequisite skills. Finally, advanced students can become bored and lose interest in an experiment if it is too simple and only repeated existing skills. It is better to share resources across courses and avoid repetitive learning by directing students to the online resources.

6.2.4. The Internet

A lot of the resources currently available on the internet are free and useful in teaching the skills used in the laboratory. With powerful search engines such as Google, and extensive video resources on YouTube, students already have a number of pathways to teach themselves practical skills that may be deficient (Lee and Lehto, 2013). Finding information in this manner is a very important skill for engineers to have, and learning should always encourage this independent searching, but there are times when resources need to be ad free, quick to navigate to, and delivered in a specific way.

6.3. Implementation

The Training Laboratory website was developed in 2011 and first used by students in 2012. The content is structured into four categories; Equipment, How to Guide (Hardware), How to Guide (Software), and Troubleshooting. It includes written instructions, videos, user manuals, and links to external resources. Over time, more resources have been developed or linked, to provide students with a one stop shop for developing laboratory skills. The main page of the Training Laboratory can be seen in Figure 6-1.

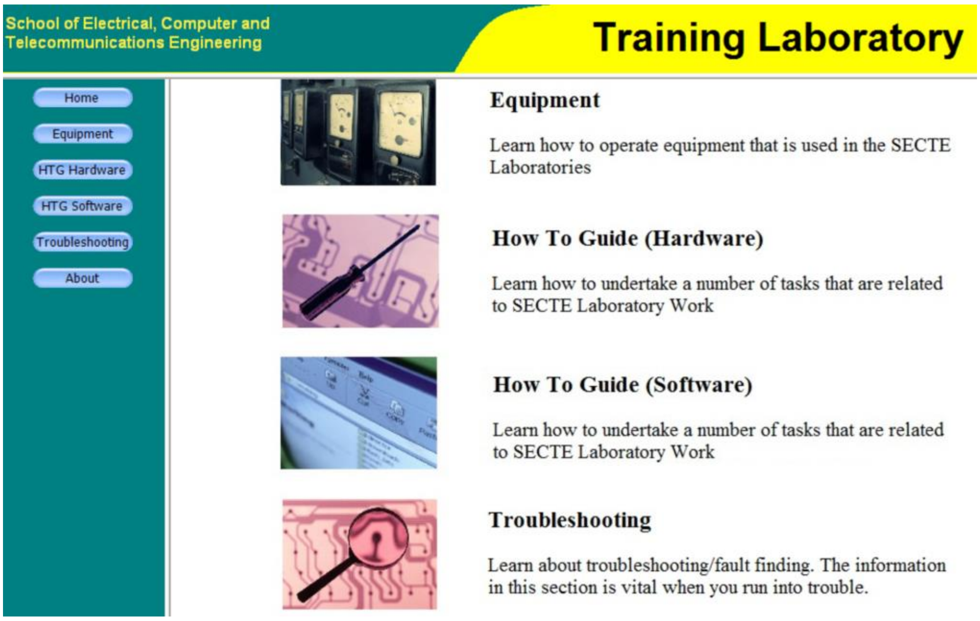


Figure 6-1: The Training Laboratory Website

Each individual resource took a number of days to develop, especially the video resources. It took time to develop a plan, undertake the recording, and then edit the video. If a company or website had a well-established training resource, a link was provided to prevent unnecessary duplication. The decision as to what resources are required, and how to design them, was determined by talking to experienced laboratory demonstrators and observations in the laboratory to identify common questions and common mistakes made by students.

6.4. Research Design

Within the iterative refinement process outlined in chapter four, a study was carried out on three second year courses to understand how students used and perceived the Training Laboratory. Ethics approval for this study was conducted under HE14/156. The first course was on Digital Hardware (ECTE233) run in the first semester of the second year, and the second course was on Electronics (ECTE212) run in the second semester of the second year of study. The digital hardware and electronics courses are undertaken by students studying computer, electrical, mechatronics, and telecommunications engineering. The third course also ran in the second semester of second year; it was as an introductory electrical engineering servicing course for students studying other engineering degrees such as civil, environmental, materials, mechanical, and mining engineering.

In 2011, while designing the resources for the Training Laboratory, and before implementation, a qualitative study was undertaken to observe how the students and demonstrators interacted with the resources, the experiments, each other, and other demonstrators. The observations focussed on the hurdles students faced in undertaking the experiments and the support provided by the demonstrators. This was to provide direction as to what resources needed to be created and how they could be integrated within the experiments to provide support. The Training Laboratory was added to ECTE233 and ECTE290 in 2012 and to ECTE212 in 2013; observations were then made to see if the interactions had changed.

In 2014 a quantitative study was undertaken to measure how usage changed over time, with the hypothesis that usage would reduce with each experiment in a course. This was carried out via a large course wide study where students enrolled in ECTE233 filled in a survey at the end of the first, second, and last experiments. The survey question that related to the Training Laboratory asked "*What was the main purpose of using the Training Laboratory*?" focussed on measuring the number of students using the resource for equipment, troubleshooting or other means.

The second quantitative study was to investigate student use of the Training Laboratory across all three courses. At the end of the last experiment a survey was given to students to gain an understanding on usage across various courses and how the resource impacted on student satisfaction. This investigation also looked at how usage differed between local Australian students (Domestic Students), and foreign students (International Students), who had arrived in Australia to study for one to four years of a bachelor degree. The survey questions related to the Training Laboratory asked the questions:

1) "*What was the main purpose of using the Training Laboratory?*"
2) "*If the resource was REMOVED how would your overall satisfaction for undertaking the experiments change?*"

This research was limited in that it was only undertaken in one engineering department, at one university, and with a limited number of courses, so the results may vary with different disciplines, universities, and student cohorts. Moreover this analysis was carried out with three courses that had a similar experimental approach, so the findings could differ if other approaches such as recipe styles are used.

6.5. Results and Discussion

6.5.1. Quantitative Analysis

The first study was used to understand how much students used the Training Laboratory between the first experiment and the last experiment, with the hypothesis being there would be a rapid decrease. Table 6-I shows the student responses across the three experiments including the test for statistical significance (SS) and comparative error. The analysis shows that there was a substantial drop off in usage between the first (6.1%) and second experiment (15.3%) but this difference was not statistical significant. Usage at the last experiment dropped to 18.5% of students and this was statistical significant compared to the first experiment, providing some support to the hypothesis.

Table 6-I: Responses for the 1st, 2nd and 6th experiments to the question, "What was the main purpose of using the Training Laboratory?"

Answer Options	First Experiment	SS FvsS (Error)	Second Experiment	SS SvsL (Error)	Last Experiment	SS FvsL (Error)
a) To learn how to use the equipment	30.6%	No (8.94)	30.5%	No (16.13)	29.2%	No (16.99)
b) To learn how to troubleshoot	2.0%	*Yes (6.91)*	11.9%	No (10.13)	6.2%	No (7.05)
Both a and b equally	59.2%	No (18.61)	40.7%	No (17.34)	41.5%	No (18.24)
Other	2.0%	No (5.12)	1.7%	No (6.07)	4.6%	No (6.43)
Did not use the resource	6.1%	No (11.37)	15.3%	No (13.17)	18.5%	*Yes (11.58)*
Response (N =100)	***49%***		***59%***		***65%***	

The second quantitative study was to examine how students were using the resource across three different courses. Table 6-II summarises how the students claimed they used the resource across the three courses. A statistical test was undertaken to compare usage differences between the domestic and international students. This was not done for the servicing subject as the international response was too low.

Table 6-II: Responses after the last experiment to the question, "What was the main purpose of using the Training Laboratory?"

	Digital Hardware			Electronics			Electrical (Servicing)
Answer Options	Domestic Students	International Students	Chi-Square (p-value)	Domestic Students	International Students	Chi-Square (p-value)	All Students (International response low)
a) To learn how to use the equipment	25.9%	45.5%	7.82* (.005)	46.1%	22.2%	9.39* (.002)	42.9%
b) To learn how to troubleshoot	7.4%	0.0%	5.46* (.019)	11.5%	0.0%	9.95* (.001)	2.4%
Both a and b equally	38.9%	54.6%	5.13* (.023)	30.8%	55.6%	12.79* (.003)	50.0%
Other	5.6%	0.0%	3.70 (.054)	0.0%	0.0%		0.0%
Did not use the resource	22.2%	0.0%	21.66* (001)	11.5%	22.2%	3.54 (.059)	4.8%
Response	***66%*** (54/81)	***58%*** (11/19)		***51%*** (26/51)	***47%*** (9/19)		***15%*** (42/287)

The data between domestic and international students was separated, except for ECTE290. Of the 42 responses, only two were from international students, which was too small for any meaningful comparison. Since this is a servicing course where students have no prior exposure to an electrical laboratory, it was expected that they would make substantial use of this resource. The data shows that the students made substantial use of the resource, with usage above 75% across the three courses. It also suggests that students used the resource to gain an understanding of the equipment and to improve their troubleshooting skills. Usage was greatest for ECTE290, which was expected because students had no experience in an electrical laboratory; only five per cent did not use the resource. The data also shows that there is a significant difference in usage between the domestic and international students.

This supports the findings in chapter four which found that providing such resources in a laboratory environment improved student experience. While the data in Table 6-II provided evidence that students used the resource in the classroom, the data in Table 6-III shows how such resources can affect student satisfaction.

Table 6-III: Responses after the last experiment to the question, "If the Training Lab resource was REMOVED how would your overall satisfaction for the experiments change?"

Answer Options	**Digital Hardware**	**Electronics**	**Electrical (Servicing)**
Overall satisfaction would significantly improve	1.5%	0.0%	0.0%
Overall satisfaction would improve	9.2%	2.9%	0.0%
Overall satisfaction would NOT change	32.3%	25.7%	16.7%
Overall satisfaction would decrease	40.0%	45.7%	57.1%
Overall satisfaction would significantly decrease	7.7%	20.0%	26.2%
Undecided	6.2%	5.7%	0.0%
Response (N =100, N = 70, N = 287)	***65%***	***54%***	***15%***

Students in the three courses were asked how their satisfaction with the experiments would change if the resource was removed. For ECTE233 47.7% of students claimed their satisfaction would decrease, while for ECTE212 and ECTE290 it was 65.7% and 83.3% respectively. These figures reflect the amount of resources a student might need to use from the Training Laboratory. This data supports the findings in chapter four that appropriate laboratory resources can increase student evaluations.

6.5.2. Participant Observer Notes

Chapter four described how an iterative refinement process was used to investigate the impact of changes in the laboratory. This was accomplished by observing students before and after the Training Laboratory was incorporated into the laboratory notes for each course. Before implementation students regularly stopped when they found the experiments difficult, especially with early experiments and for international students. The international students struggled to complete experiments because they were coming into a laboratory not only having to understand the learning objectives, but also to try and understand how to use equipment that was foreign to them. It was soon noted that learning in the laboratory was not very effective for those new to the equipment. The laboratory demonstrators were also busy trying to explain how the equipment worked, as well as provide help with the learning objectives, all of which resulted in many students waiting a long time for help, which was very unproductive.

Implementing the Training Laboratory also required training the laboratory demonstrators to use it effectively for teaching purposes. Observations were made in laboratory classes with demonstrators trained to use the resource as an aid to learning. If the laboratory demonstrators were asked a question that was covered in the Training Laboratory, the first step was to point the students to the relevant resource. For example, consider the scenario where students cannot measure the current in a circuit with a digital multimeter, the laboratory demonstrator would show the students the resources available to learn how to use a digital multimeter and how to take electrical measurements. This was followed by asking the students if they had reviewed the information contained within the resource.

In most cases the students did not explore the available resources, or if they had this would help them remember. The laboratory demonstrator would ask the students to review the resource, and they would return in five minutes to check if they had gained the required level of understanding. This gave the laboratory demonstrator more time to spend with the rest of the class, rather than investing a large amount of time teaching fundamental skills. Upon returning to the students, if the appropriate level of understanding had still not been reached, the laboratory demonstrator would identify the issue and help guide the students to the necessary level of understanding.

This process resulted in a significant increase in learning productivity because student awareness of the resources grew, and the demonstrator would always start by pointing them to the resource, they began to use it more often when they ran into trouble. A direct result of this was that students were no longer sitting and waiting for help as much as they had previously done, and the demonstrators had more time for all the students.

As expected, the Training Laboratory was of greatest use to international students who do not start in the first year of an undergraduate program (equal benefit in first year courses). A repeated observation in a number of different laboratories was that the resource provided international students with an opportunity to better use laboratory time. Entering the laboratory for the first time was no longer a juggle between coming to terms with foreign equipment/software and concentrating on the learning objectives of the experiment.

Productivity in the laboratory was observed to be the best when the resources were tied to pre-laboratory activities. Differences in student preparation became noticeable because those that used the resource progressed through the experiments faster, and resorted to the troubleshooting resources without direction when needed. Students that made little use of the resource wasted time understanding the fundamentals and lacked direction when it came to troubleshooting. When these students struggled they tended to seek assistance from the demonstrator rather than work out how to use the resources to find a solution. It usually took the demonstrator several attempts to put the students into a routine whereby they would seek out resources for themselves, before asking for help.

6.6. Conclusion

Both the quantitative and qualitative analysis conducted in this chapter confirms the findings in chapter four, that additional resources that help support learning in the laboratory improved student evaluations. The question this chapter tried to answer was:
Do students use and appreciate additional laboratory resources?

The study found that students used the resource more in the earlier experiments rather than the later. Usage was centred on both learning about the equipment and troubleshooting. A statistically significant difference in usage was found between the domestic and international students suggesting that the resource may support the laboratory experience in different ways. The study also found that for most students student satisfaction would have declined if the resource was unavailable, supporting the notion that such resources help improve student evaluation scores and are therefore appreciated. The classroom observations suggest that the resource changed interactions with the demonstrators and that learning productivity increased with less students stopping and waiting for assistance when a particular solution could be found within the resource. Further analysis of the use of resources and the impact on the student experience is examined in chapter seven.

CHAPTER 7: RESOURCES AND LEARNING

7.1. Introduction

It has become evident throughout this thesis that using an iterative refinement process to develop resources can improve student evaluations conducted in the laboratory. Chapter three outlined how such resources can be used to improve the training of laboratory demonstrators. Chapter four showed how student evaluations can be improved by designing experiments with clear instructions and with resources that help to develop understanding. Chapter six outlined that students use such resources to support their knowledge of hardware and software, and to develop troubleshooting skills. This chapter outlines a case study of an iterative refinement process that acted upon negative student evaluation data to improve a third year telecommunications laboratory. The chapter provides a detailed example of how the data was used to identify the problem and put in place actions to improve student evaluation scores of the laboratory experiment and facilities. A key action was the development of additional resources. As part of this case study, an attempt was made to answer if learning also improved through the following the research question:
Do additional laboratory resources improve learning?

7.2. Background

This study was undertaken in the School of Electrical, Computer and Telecommunications Engineering (SECTE) at the University of Wollongong (UOW) under ethics approval number HE13/129. Those students undertaking an electrical, computer or telecommunications degree must complete the third year undergraduate telecommunications course ECTE363. The number of international students undertaking the course is approximately 45-55% (depending on the year).

This particular laboratory was first used for teaching purposes in the early 1990s. In the intervening years, it has been modified to concentrate more on digital communication techniques rather than analog techniques. This resulted in a skewing of the laboratory difficulty to the point that material covered in the initial laboratory (necessary to understand the laboratory infrastructure) was no longer part of the laboratory experiments. Not surprisingly, this was a major cause for the dissatisfaction expressed by recent student cohorts inside and outside this laboratory.

As outlined in chapters four and six, courses with supplementary material available on well organised web sites, saw a significant increase in student evaluations. For example, in 2009 the control laboratory was modified so that experiments were demonstrated using web-based video instructions and background lectures which students could access from their own computers at any time. No such material had been previously available for the laboratory component of this telecommunication course.

Due to the success of other courses that used online laboratory notes with multimedia modules, it was decided to re-design this course in a similar fashion, believing that the extra multimedia material would assist both students and demonstrators to better understand the laboratory concepts.

The telecommunications course ECTE363 was based on the telecommunications instructional modelling system (TIMS) used to allow undergraduate students to inter-connect a variety of different interchangeable boards that simulate telecommunication signals and system. This includes digital modulation and de-modulation systems. TIMS can also be used to simulate analog communication systems. The laboratory implemented in the 1990s included both types of experiments. TIMS is used in many tertiary institutions throughout the world. A software simulator for TIMS is also available for institutions that cannot afford to provide a physical TIMS laboratory for their students (Emona TIMS, 2016). The provider of the TIMS system also provides documentation showing sample experiments for student activities using the equipment.

7.3. Laboratory Redevelopment

7.3.1. Reflection

Repeated student evaluations of the laboratory component and the laboratory demonstrators in 2009 and 2010 were negative (71% and 67%, respectively for the laboratory). The course coordinator was concerned with this data and decided to work with the Laboratory Manager to implement changes. The course coordinator taught in one of the laboratory classes in autumn 2010, and having developed material for the original laboratory in the mid- 1990s, was concerned that the students had little of understanding of what was required, how they were meant to complete the experiments, and what the learning objectives were. Moreover, students were taking a long time to complete experiments and only made progress with a lot of help from the demonstrator.

The laboratory also suffered from having no initial tutorial experiments introducing the equipment, before students had to carry out digital experiments. Students had access to TIMS reference booklets during laboratory sessions, which outlined the operating characteristics of each module. When students arrived at the laboratory, they were given an initial introduction from the demonstrator and were then expected to carry out the experiments outlined in the laboratory notes (studying either in groups or alone). An examination of the experimental procedures outlined in the laboratory notes provided by TIMS indicated that the notes were accurate and quite descriptive. However, the authors of these notes indicated that they expected that preliminary experiments would be carried out before attempting more technically complex material, and because the experiments changed over from analog to digital over the years, scaffolded learning was no longer in place.

Formal and informal feedback by students and demonstrators suggested that students from all backgrounds, even when successfully carrying out the experiments, could not show they had gained any deep understanding of telecommunication system design. Even students who managed to get the TIMS equipment to function correctly admitted they were not sure why it functioned from an engineering perspective.

In consultation with students, demonstrators, literature, and other staff, a number of changes were agreed. These included developing extra multimedia educational material for demonstrators and students; creating a laboratory web-site to showcase the resources, and creating a training DVD for demonstrators to improve training on the TIMS equipment and experiments

7.3.2. Multimedia Website

One primary area of focus when developing resources was for students to become familiar with TIMS and grasp its fundamental operating principles. Despite students being in their third year of an undergraduate engineering program, they had not previously used the TIMS units.

A video tutorial was therefore created to introduce the setup, operation, and manipulation of the TIMS equipment; this tutorial included how to use measuring equipment such as an oscilloscope, and how to read the signals produced throughout the TIMS equipment. The tutorial was based on the need to reinsert the scaffolded learning removed during the transition from analog to digital experiments. The tutorial was made available via the newly created laboratory website, as shown in Figure 7-1. Students are now required to view the tutorial video before entering the first laboratory session. Furthermore, to ensure that students spent their extra time preparing for the first laboratory, an e-learning quiz was developed; from a database of 28 questions they were asked eight questions, with only one attempt at each, and the results contributed to their laboratory assessment.

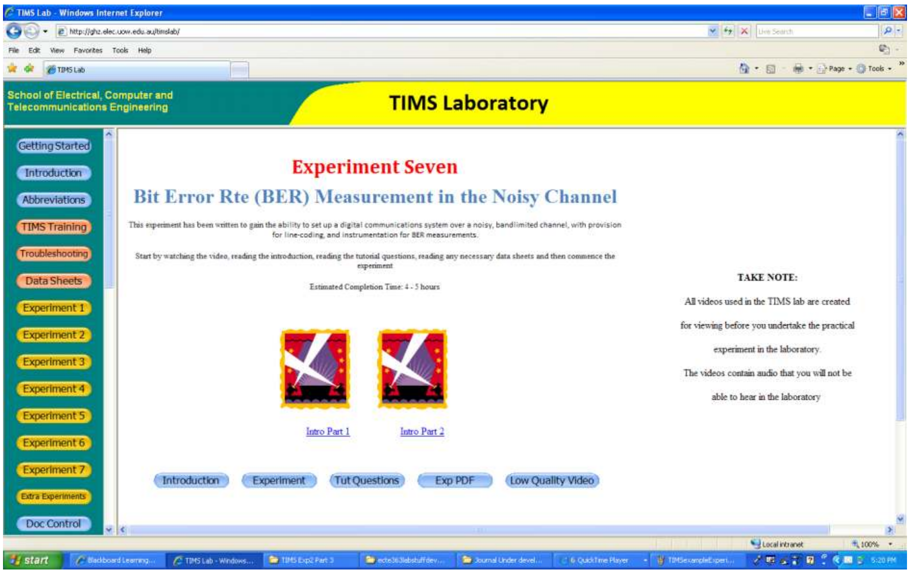


Figure 7-1: Snapshot of Experiment 7 Web site for the revised Telecommunications Laboratory

Video introductions for compulsory experiments were also created. This took about 10 hours of filming and about 20 hours of editing. The assistance provided by the videos in how to undertake the experiment gradually decreased as the students developed competencies in each experiment.

In addition to the introductory video, resources that explained the operating characteristics of different interchangeable TIMS cards (known as modules) were also created. This information was previously available only in the laboratory via a limited number of resource books, but it is now available for students to view before entering the laboratory, thus allowing them to prepare in advance. This information was also hyper-linked within the laboratory instructions of each experiment for quick reference.

Additional online resources were also created for the other electronic equipment in the lab that is used in conjunction with TIMS. This includes instruction manuals on how to use the equipment and troubleshooting guides. These resources are also integrated into a shared online resource called the ‘Training Laboratory’ which was outlined in chapter six.

The order of the experiments was also changed to ensure that the more technically difficult laboratory experiments followed the easier experiments to ensure a scaffolding of knowledge. The first experiment was the only analog experiment but it covered FM, while the preceding experiments were digital, covering topics such as PRBS, line coding, eye patterns, and noise.

7.3.3. Demonstrator Resource

As outlined in chapter three, multimedia resources helped to train laboratory demonstrators, which resulted in increased student evaluation scores. In an attempt to improve demonstrator knowledge, a DVD resource was created from the hours of raw video developed for the introductory videos. The DVD enables the laboratory demonstrators to understand learning outcomes determined by the design, not by their own interpretation. The goal was that better trained demonstrators would be able to provide more effective support to students. The demonstrators were required to watch the relevant segment of the DVD before undertaking the experiment.

7.4. Method

The success or failure of the multimedia resources to improve student evaluations and learning was evaluated during autumn 2011 via a three pronged approach. The first required the demonstrators to keep a log of their experiences for each experiment. Two laboratory demonstrators were used in autumn 2011, neither of which had taught the subject previously. As a part of the log, they had to answer twelve questions that explored student experience; these questions are outlined in Table 7-I. The second approach was to observe the impact the changes had on the student evaluation scores that was outlined in chapters four and five. The third approach was to assess any impact the changes had on assessment results and if this correlated with the observations of learning conducted by the demonstrators.

7.5. Results and Discussion

7.5.1. Demonstrator Observations

The two laboratory demonstrators were required to keep a log of their teaching experience. The questions and a summary of results from the demonstrator log are shown in Table 7-I. The two demonstrators were aligned with their observations.

Table 7-I: The twelve questions asked for each laboratory session from each demonstrator

Question (From your experience in the laboratory.....)	Exp 1	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6
Did the students do much preparation beforehand for the experiment?	Majority	Yes	Yes	Yes	Yes	Yes
Did you think the students watched the introductory videos before their lab?	Yes	Yes	Yes	Yes	Yes	Yes
Were they watching the introductory videos during the lab?	Yes	Yes	Yes	Yes	No	Yes
Did the introductory videos show too much or too little?	About right	About right	About right	About right	About right	About right
Did the students refer to the data sheets on the website?	Yes	Yes	Yes	Yes	Yes	Yes
How long did it take the students to finish the experiments?	120 - 150min	180+ min	90 - 150min	90 - 180min	90min	180+ min
Were the students able to follow the instructions without much trouble?	Yes	No	Yes	Yes	Yes	Challenging
Were the experiments too easy or too difficult to do or just right?	Average	Difficult	Average	Average	Easy	Difficult
Was there enough modules, wires etc? If not explain	Yes	Yes	Yes	Yes	Yes	Yes
Was there any mistakes in the notes/videos that need to be corrected? If so explain	Yes	No	No	No	No	No
Did the students really learn anything from the lab?	Yes	Many struggled	Yes	Yes	Yes	Yes
Anything else that you believe is necessary to comment about to help us improve the lab?	Good start	Some concepts too advanced	n/a	n/a	n/a	Only a few completed

The responses from the demonstrators indicated that students attempted to prepare for the laboratory, especially the first one, because it was an assessment task. In some cases they did not complete all the preparations but at least they had begun. They also used the new videos before and during the laboratory session.

To improve time management, the demonstrators monitored the time taken for each laboratory. For most students, experiment one, the FM modulator, took from 120 to 150 minutes; experiment two took 3 hours, but some students did not complete the laboratory, and even with the laboratory videos, found this experiment difficult to understand.

The demonstrators reported that students had no difficulty with experiment three, which was completed within 90 to 150 minutes; experiment four took between 90 to 180 minutes; experiment five took at least 90 minutes; and experiment six took all of three hours. In fact by the time the students reached this experiment, some were concerned about the upcoming laboratory exam and were spending up to an hour reviewing/practicing earlier experiments. No students attempted experiment seven, an optional experiment.

The demonstrators reported there were no obvious mistakes in the videos or the revised laboratory notes (with one very minor exception in the initial laboratory). With the exception of experiment two, they found the laboratory material satisfactory and indicated that they felt that the students were learning relevant material and gaining a good understanding of telecommunication system design. This was a substantial improvement compared to previous observations, providing an indication that an increase in grades could be expected. They also felt on the whole, that the videos were well targeted.

7.5.2. Student Evaluations

Student surveys had been carried out on the telecommunications laboratory from 2009 to 2013. The design of the statements and evaluation procedure is outlined in chapter four. Table 7-II shows the survey statements, and the responses.

Table 7-II: Laboratory survey responses 2009 through 2013

Survey Question	2009 n=34	2010 n=15		2011 n=42		2012 n=43	2013 n=33
S1) I have a great overall impression of the laboratory component for this subject	57.65%	49.33%	Redevelopment of laboratory	77.14%	Swap of experiments two and five	84.65%	84.85%
S2) The contents of the laboratory notes provide me with enough information to successfully complete the required exercises	60.59%	45.33%		76.67%		86.51%	83.64%
S3) The experiments undertaken in this laboratory are worthwhile learning experiences	67.06%	65.33%		76.19%		83.26%	85.45%
S4) The computers in the laboratory are suitable for the work required	87.65%	89.33%		88.57%		86.51%	92.12%
S5) The electronic equipment other than the computers in the lab are suitable for the work required	74.12%	74.67%		88.10%		84.19%	88.48%
S6) The laboratory is in good condition	77.65%	80.00%		88.10%		86.51%	90.91%
Average Score	**70.78%**	**67.33%**		**82.46%**		**85.27%**	**87.58%**

The survey shows that the ratings correlate with the changes made to the laboratory, and the data can be divided into three different stages. The years 2009 and 2010 show student ratings before the redevelopment, with consistently low scores across the board. The only exception their rating of the computers, probably because computers only play a very small role in the laboratory, word processing, spreadsheets, and the web.

In 2011, the redeveloped laboratory was deployed with the new online multimedia resources. The experiments were the same, compared to 2009 and 2010, and the laboratory equipment and instruments also remained the same. However, in 2011 an increase in scores occurred for all survey statements, apart from the suitability of the computers. In part, this improvement could be due to the multimedia resources used for learning, and the DVD training resource could also have played a part in providing more effective demonstrators.

Of real interest was the 18% increase in student ratings of the electronics equipment, whereas the TIMS unit, the modules, and the measuring instruments remained the same. This provides further evidence that by better understanding what the equipment does and how it operates, students gain a better appreciation of the laboratory environment.

The feedback obtained in 2011 indicated that experiment two was too advanced and experiment five was easy, so in 2012, experiments two and five were swapped to provide better scaffolding. Between 2011 and 2012, the three experiment based statements (S1, S2, and S3) was the source of further improvement in the survey instrument; this further indicates the importance of correctly scaffolding learning in the laboratory, and the impact this has on student evaluations. It also shows the importance of an iterative refinement process carried out over a long period of time, and even when changes are made, further improvements can generally be found.

No changes were made to the laboratory for 2013, and as expected, many student responses were close to those obtained in 2012. Overall the data suggests that by having laboratory notes and resources that provide scaffolded learning, and greater understanding of the equipment, student experience is greater. This supports the findings outlined in chapter four.

7.5.3. Demonstrator Evaluations

Student evaluations of demonstrator evaluations were also examined. The statements and scores are shown in Table 7-III. Demonstrator names are masked for privacy reasons, and each demonstrator is assigned a number.

Table 7-III: Demonstrator survey responses 2009 through 2013

Year:	2009	2010	2010	2011	2011	2012	2012	2013	2013	2013
Survey Question **Demonstrator:**	**Dem01**	**Dem02**	**Dem03**	**Dem04**	**Dem05**	**Dem04**	**Dem05**	**Dem05**	**Dem06**	**Dem06**
Q1: At the start of each laboratory does the casual demonstrator give you a satisfactory introduction to the laboratory?	55.88%	70.67%	61.33%	90.91%	88.57%	88.00%	86.15%	78.67%	90.00%	88.89%
Q2: Is the casual demonstrator well prepared for the subject?	77.65%	77.33%	63.11%	85.45%	89.38%	87.33%	92.31%	89.33%	97.50%	93.33%
Q3: Does the casual demonstrator communicate the subject matter clearly?	74.71%	74.67%	56.00%	81.82%	87.50%	88.67%	90.77%	88.00%	90.00%	91.11%
Q4: The casual demonstrator appears to be interested in assisting me to learn?	81.76%	85.33%	52.00%	83.64%	87.50%	92.67%	93.85%	92.00%	92.50%	93.33%
Q5: Is the casual demonstrator helpful in responding to questions or problems?	82.94%	80%	60.44%	85.45%	87.50%	91.33%	92.31%	93.33%	95.00%	91.11%
Total Score:	74.59%	77.60%	58.57%	85.45%	88.09%	89.60%	91.08%	88.27%	93.00%	91.56%

Six different laboratory demonstrators were used during the four year period, of which five were Chinese international research students and one was from the

Middle East; they all spoke a comparable level of English. There was a dramatic difference in evaluations from 2011, the year the laboratory was redeveloped. All the survey responses improved, providing further support to the importance of having resources to aid learning in the laboratory. Interestingly the communication scores improved, although the ability to communicate was similar. One explanation could be that students had gained more knowledge from the videos and other resources, and thus were better able to understand the experiments and the accompanying explanations. In addition, the DVD resource for the demonstrators could have given them more confidence and clarity with the experiments. These resources could also have meant that fewer conversations were needed between student and demonstrator.

7.5.4. Learning

The impact of the new multimedia resource was also analysed via student assessments. This was first done via the laboratory exam which asked students to draw a block diagram of a telecommunications system, build the system using the TIMS hardware, and then carry out measurements. They also had to analyse the difference between the measured values and the theoretical values of the system.

The logs from the laboratory demonstrators reported that during the laboratory exam in autumn 2011, it appeared that the students knew how to connect, manipulate and troubleshoot the modules and measuring equipment. The students were also observing appropriate signals on the oscilloscopes. That is, they observed an increase in cognitive and psychomotor skills. This alone was a large improvement on 2009 and 2010 where many students were very confused using the TIMS systems. This was the driver for the changes implemented.

The assessment marks from the laboratory exam in 2011 also showed an improvement compared to 2010, but since an academic staff member left, access to the individual marks has been lost, and no accurate analysis or commentary can be provided. Final assessment marks for the subject are shown in Table 7-IV. In 2011, the laboratory component was worth 25% of ECTE363. Many factors play a role in determining the final grade, but the improvement in grades between 2010 and 2011 may suggest that improvements to the laboratory played some part. However, this link is weak and this experience paved the way for the approach used in chapter 8 to measure learning.

Table 7-IV: Student final grades 2010 and 2011

Year	Mean	SD	Students	HD	D	C	P	PC	F
2011	69.11	12.32	83	14%	27%	22%	33%	2%	2%
2010	64.4	14.25	95	13%	15%	22%	41%	2%	7%

7.6. Conclusion

This case study outlined a number of changes to a third year telecommunications laboratory based on iterative refinement methodology. At the heart of the changes was the development of a number of resources to aid students in learning and laboratory demonstrators in training. The redevelopment involved:

- Developing an online laboratory resource
- Creating a video tutorial
- Producing video introductions for each experiment
- Producing a training DVD for the laboratory demonstrators
- Providing TIMS datasheets online
- Providing resources to help understand and use the equipment and resources used in the laboratory
- Providing scaffolded learning

The question this chapter tried to answer was: *Do additional laboratory resources improve learning?* The addition of this extra online multimedia teaching material in early 2011 improved the evaluation scores and appears to have improved the student learning within the telecommunications laboratory. This is inferred through the demonstrator logs and the improvements in the assessment outcomes, for the student cohort between 2010 and 2011. However, this measurement for learning is inclusive and not ideal with a more effective study forming the basis of chapter eight. More importantly, this infers that the students seemed to have improved learning experiences and probably outcomes.

CHAPTER 8: STUDENT EVALUATIONS AND LEARNING

8.1. Introduction

This chapter explores the relationship between student evaluations and perceived learning and laboratory exam performance across the cognitive, psychomotor, and affective domains. This builds upon some of the known weaknesses in an attempt to measure learning in chapter seven. In this respect, quality is considered to be an improvement in both student learning and their experience. Outlined in the literature review in Section 2.1 was a set of thirteen learning objectives designed for the laboratory (Feisel et al., 2002). Salim et al. (2013) combined learning objectives with learning across the cognitive, psychomotor and affective domains to develop an instrument to measure the learning objectives of a laboratory. This instrument is used to examine whether or not the student evaluation instrument in this thesis does more than just measure how students feel about their laboratory experience.

8.2. Method

The laboratory components of two engineering courses in 2015 were selected for this study, which was carried out under ethics approval number HE14/156. The first course (ECTE233) was a second year digital hardware laboratory which contained simulation and practice based learning. With most experiments the students would commence by simulating various integrated circuits (ICs) and purpose built circuits using Multisim (National Instruments, 2016). This would then be followed with physically constructing the circuits using digital ICs. The course had six experiments of three hour durations, conducted fortnightly over the session. A laboratory practical examination was held during the official examination period, the first time such an examination had been undertaken for this course.

The second course (ECTE363) was a third year telecommunications laboratory where all the experiments focused on using TIMS (hardware for simulating telecommunications signals and systems), as outlined in chapter seven. There are no software components in this course. The course has five, three hour long laboratory sessions which are conducted fortnightly over the semester. The students were expected to complete at least five different experiments, followed by a laboratory exam during the sixth session. The laboratory experiments were used to introduce many concepts that were not covered in lectures or tutorials.

At the start of the first laboratory session for both courses a self-assessment was undertaken. Students were asked to rate their knowledge on a scale from zero to five, with zero reflecting no knowledge to five reflecting extreme confidence. Students who agreed to participate in the research were requested to include their student number for identification. At the end of the last laboratory session (sixth laboratory session for ECTE233 and fifth for ECTE363) the same self-assessment activity was repeated. During the second last laboratory session, laboratory and sessional teacher surveys were carried out, and students who participated were asked to include their student number for identification.

The data for the self-assessments, student evaluations, and laboratory exam were matched using student numbers and then the responses were de-identified for analysis. A total of 125 complete responses were matched across the two subjects as summarised in Table 8-I.

Table 8-I: Student Participation

Course	No of Students	Completed at Least One Component	Data Match to All Four Components
ECTE233	114	106	73
ECTE363	64	61	52

ECTE233 consisted of one small laboratory class with one demonstrator and three large classes with two demonstrators. ECTE363 consisted of five small laboratory classes with one demonstrator. Sessional laboratory demonstrators were assigned to diversify the teaching experience across the laboratory classes. A summary of the laboratory class information is shown in Table 8-II with each demonstrator assigned a different number. The student self-assessments were undertaken using a modified MeLOLW survey shown in Table 8-III.

Table 8-II: Laboratory Demonstrator Allocation and Class Size

Course	Demonstrator/s	Class Size
ECTE233	Dem01	15
ECTE233	Dem01, Dem02	29
ECTE233	Dem03, Dem04	37
ECTE233	Dem05, Dem06	35
ECTE363	Dem07	11
ECTE363	Dem07	15
ECTE363	Dem08	7
ECTE363	Dem08	16
ECTE363	Dem09	15

Table 8-III: Self-Assessment Questions

Measure	MeLOLW	ECTE233 Adapted	ECTE363 Adapted
Cognitive 1	Improve knowledge and theory learned in class	Understand the operation of digital IC's and other digital hardware?	Understand the operation of TIMS hardware?
Cognitive 2	Help verify theory learned in class	Design circuits (physical or simulation) to verify the operation of digital hardware?	Verify telecommunications theory via TIMS equipment?
Cognitive 3	Improve ability to use formulas in solving problems / questions related to theory	Use Boolean algebra to simply circuits?	Use TIMs equipment to solve problems?
Cognitive 4	Improve ability to use the correct unit for the measured values	Read and understand IC datasheets?	Read and understand TIMS datasheets?
Cognitive 5	Help to develop basic statistical technique (i.e. draw graph and chart)	Draw a truth table or timing diagram for a digital circuit?	Draw graphs, signals and charts related to telecommunications?
Cognitive 6	Improve understanding about safety in the lab	Understand lab safety for a digital hardware lab?	Understand lab safety for a telecommunications lab?
Cognitive 7	Improve ability to analyse / discuss experimental result	Analyse truth tables and timing diagrams?	Analyse/discuss the results from a telecommunications experiment?
Cognitive 8	Improve ability to write the conclusion of the experiment	Write a conclusion for an experiment?	Write a conclusion for an experiment?
Cognitive 9	Improve ability to write laboratory report	Write a lab report?	Write entries into a logbook, in a professional manner?
Psychomotor 1	Improve ability to conduct experiments	Correctly conduct an experiment on digital hardware?	Correctly conduct an experiment on TIMS hardware?
Psychomotor 2	Improve ability to select appropriate instruments	To select appropriate instruments for both the input and output of your digital circuit?	To select appropriate instruments for both the input and output of your TIMS circuit?
Psychomotor 3	Improve ability to plan experimental work	Plan experimental work on digital hardware?	Plan experimental work on TIMS hardware?
Psychomotor 4	Improve ability to construct circuits	Construct a working digital circuit?	Construct a working TIMS circuit?
Psychomotor 5	Improve ability to connect instruments	Connect meters, displays and other instruments to a digital circuit?	Connect meters, displays and other instruments to a TIMS circuit?
Psychomotor 6	Improve ability to operate the instrument (i.e. select proper range)	Use a Wishmaker/Prototyping board?	Operate instruments (TIMS, CRO etc.)?
Psychomotor 7	Improve ability to take the reading of the instruments	Ability to take the readings of the output of digital circuits?	Ability to take the readings from the CRO?
Affective 1	Improve team working skill	Solve digital hardware problems with others?	Solve telecommunications problems with others?
Affective 2	Improve communication skill	Communicate (written and orally) a digital hardware solution?	Communicate (written and orally) a telecommunications solution?
Affective 3	Improve ability to learn independently	Solve digital hardware problems on your own?	Solve telecommunications problems on your own?
Affective 4	Improve ethics (i.e. plagiarism, copy other students results)	Consider ethical issues in the digital hardware laboratory?	Consider ethical issues in the telecommunications laboratory?
Affective 5	Improve creativity	Creatively use digital hardware to solve a problem?	Creatively use telecommunications hardware to solve a problem?
Affective 6	Learn from failure	Learn from failure (when your circuit does not work)?	Learn from failure (when your circuit does not work)?
Affective 7	Improve motivation	Motivate yourself to learn about digital hardware in the laboratory?	Motivate yourself to learn about telecommunications hardware in the laboratory?

The original MeLOLW instrument contained nine measures for the cognitive domain and seven for each of the psychomotor and affective domains. After reviewing each measure within each domain it was decided to alter the wording to better position the statements within the context of the laboratory experiments the students were undertaking. The laboratory component of each course has slightly different learning objectives.

Adjustments to the MeLOLW questions were made to be compatible to the learning objectives of the two courses. The wording of the questions was also changed from being generalised to being specific to avoid any ambiguity for the students. For example in digital circuits there is no unit of measurement, simply one or zero. The greatest changes occurred for the cognitive domain. The modified and original questions were shown in Table 8-III. Students were asked, "*How would you rate your ability to…*" for each measure on a scale from 0 – I have no idea at all to 5 – I am extremely confident.

8.3. Results and Discussion

The first analysis was to check the reliability of the survey after the questions were modified. This was achieved by comparing Cronbach's alpha coefficients to those of the MeLOLW instrument to determine whether or not they remained acceptable. As Table 8-IV shows, the coefficients of the modified instrument in the first and last experiment are high and comparable to MeLOLW. A value greater than 0.70 is considered appropriate, and shows there is some flexibility in the wording of the measures.

Table 8-IV: Cronbach's Alpha Coefficients for Learning Instrument

Learning Domain	MeLOLW	Modified First Experiment	Modified Last Experiment
Cognitive	0.901	0.83	0.83
Psychomotor	0.853	0.89	0.86
Affective	0.774	0.88	0.87

MeLOLW data from Salim et al. (2013)

The next step was to confirm the number of components/factors within each learning domain to determine how the questions can be grouped. The default method of determining factors is via Kaiser Criterion by observing whether the eigenvalues are greater than one. However, literature suggests that it should not be the only criterion because it tends to over extract factors (Lance and Vandenberg, 2009). Therefore, four different checks were used; Kaiser Rule, parallel analysis, optimal coordinates, and acceleration factor. Table 8-V lists the results of underlying factors behind each score.

Table 8-V: Factor Analysis of the Learning Instrument

	First Experiment				Last Experiment			
Learning Domain	**Kaiser Rule**	**Parallel Analysis**	**Optimal Coordinates**	**Acceleration Factor**	**Kaiser Rule**	**Parallel Analysis**	**Optimal Coordinates**	**Acceleration Factor**
Cognitive	2	2	2	1	2	2	2	1
Psychomotor	1	1	1	1	1	1	1	1
Affective	2	1	1	1	1	1	1	1

Table 8-V indicates that three of the tests (Kaiser, Parallel and Optimal) show that the cognitive domain has two factors present (two groupings of questions). This is shown in both the self-assessment activities. To determine the two factors a principle component analysis was undertaken. This is shown in Figure 8-1, which suggests that measures eight and nine for the cognitive domain are separate to measures one to six. After reading the questions, this is highly possible because questions eight to nine differ due to their concentration on writing skills.

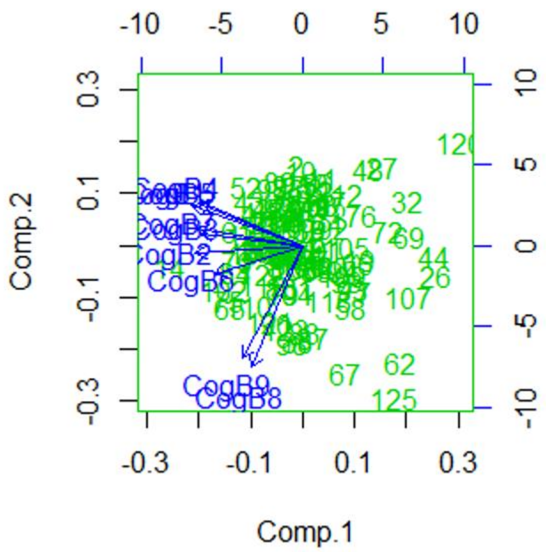


Figure 8-1: Principle Component Analysis of Cognitive Domain

After completing the factor analysis, the relationship between perceived learning and student evaluations was examined. Perceived learning was measured by comparing the difference between perception of learning from the self-assessment carried out at the start of the first experiment and the self-assessment of the last experiment. Note here that this measure is not an indication of actual learning because there were no assessment tasks at the time of the surveys, and the students were probably not really aware of actual learning when completing the evaluations. The relationship was investigated using:

- L: All six laboratory evaluation questions outlined in chapter four
- L1: Only questions one to three of the laboratory evaluation focused on the experiments
- L2: Only questions four to six of the laboratory evaluation focused on laboratory facilities
- D1: The lead laboratory demonstrator questions outlined in chapter three
- D2: The assistant laboratory demonstrator (where applicable)

The student evaluations were converted into a weighted-average score to allow for easy comparison. Full details of the evaluation scores can be found in chapters three and four. Table 8-VI shows the relationship between the perceived learning students gained across the three learning domains and the student evaluations. The table shows the effect of 1 score increase of each learning domain compared to L, L1, L2, D1 and D2. The values that are significant at the 5% level and are indicated by the asterisks and red text. The significant relationships were between the increases in perceived learning across the cognitive and psychomotor domains and student evaluations of laboratory experiments. The student evaluations of the laboratory facilities or demonstrators had no significant relationship. Moreover, changes in the affective domain also had no relationship on student evaluations. However, this sample only covers two laboratory courses with a total of 125 students, so the level of significance could increase with a larger sample, but this does provide some evidence of the importance of cognitive and psychomotor learning to influence high satisfaction for laboratory experiments.

Table 8-VI: Relationship between Learning and Student Evaluations

Factor	L	L1	L2	D1	D2
DiffCog	3.095* (0.024)	4.167* (0.016)	2.021 (0.187)	-2.065 (0.309)	2.539 (0.487)
DiffAff	1.370 (0.325)	1.957 (0.265)	0.783 (0.613)	-2.581 (0.206)	2.054 (0.490)
DiffPsy	2.197* (0.046)	2.834* (0.042)	1.560 (0.205)	-0.659 (0.686)	-0.151 (0.953)

The factor analysis indicated that the cognitive domain has two factors. The first is based on analytical skills (Q1-7), and the other on writing skills (Q8-9). Table 8-VII shows the relationship between the cognitive domain and student evaluations across these two factors. The data indicates that only the analytical skills influenced student opinion of the laboratory experiments.

Table 8-VII: Effect of Factors in the Measurement of Cognitive Learning

Factor	L	L1	L2	D1	D2
DCog Q1 to Q7	0.340* (0.031)	0.452* (0.021)	0.222 (0.205)	-0.331 (0.151)	0.216 (0.620)
DCog Q8 and Q9	0.382 (0.543)	0.529 (0.502)	0.2329 (0.741)	1.459 (0.115)	0.885 (0.574)

The final test was to compare student self-assessment to the performance of the laboratory exam. Table 8-VIII shows this relationship by comparing the exams separately and simultaneously. A negative sign indicates a decrease in laboratory score. The data suggests that the only relationship that exists between students perceived learning for analytical skills is within the cognitive domain. In this comparison the psychomotor skills are no longer significant. This is a common phenomenon and is important because the effect on laboratory exams tends to be due to an improvement in cognitive skills, not psychomotor skills. In Q1 to Q7 the increasing difference in cognitive skills leads to an increase in the laboratory exam score, whereas for Q8 and Q9 the increase leads to a decrease in the laboratory exam score. This suggests that the particular lab exams only tests students' analytical skills and therefore an increase in 'writing' skills does not help in doing well in the laboratory exam.

There were a number of problems associated with the laboratory exams. The ratio of equipment to students is often a problem, which means that many repeat sessions of the laboratory exam is needed. While the exam questions changed slightly with each repetition, the message soon spread about what was in the exam. An analysis of the lab exam cohorts showed that the mean laboratory exam mark for both courses increased in each subsequent running of the session. The ECTE233 exam was highly skewed towards full marks because students either knew or did not know the fundamentals, whereas the distribution of marks in the ECTE363 exam was greater. The other major problem about comparing the laboratory exam marks is that students cram beforehand, and therefore the level of knowledge can differ substantially when student evaluations are taken. As a result the data in Table 8-VIII can only be used as a very rough guide.

Table 8-VIII: Self-Assessment vs Laboratory Exam Performance

Factor	Lab Exam - separately	Lab-Exam simultaneously
DiffCogQ17	*1.301 (<0.001)*	1.520 (>0.001)
DiffCogQ89	-3.090 (0.006)	-2.8417 (0.011)
DiffAff	3.637 (0.147)	-0.2143 (0.947)
DiffPsy	4.670 (0.019)	-2.112 (0.4610)

8.4. Conclusion

This study investigated how the perceptions of learning across the cognitive, psychomotor, and cognitive domain influenced student evaluations in the laboratory. A modified MeLOLW instrument was used and verified as a reasonable measure of perceived learning across the three domains. Factor analysis found that two factors were present within the nine learning measures contained within the cognitive domain. While the study was only conducted across two courses with a small sample, the evidence suggests that student evaluations of the laboratory experiments are influenced by student’s perceived analytical skills gained in the cognitive domain and psychomotor skills. Expanding this study to increase the sample size may lead to more significant relationships being found. This supports the findings in chapter four which showed that the laboratory experiment (activity and clarity) played an important role in student satisfaction. No relationship with perceived learning was found with the laboratory facilities and demonstrators.

Compared to laboratory exam performance, the data suggests that the student evaluations are only related to their analytical skills within the cognitive domain. However, this research found a number of issues in relation to measuring exam performance in a laboratory setting. Student evaluations are very complex and this data is only one small jigsaw piece in a very large puzzle. More research is needed on more courses to obtain a more definitive understanding, and more research is required on how to measure real learning in the laboratory; this in itself is work required in another dissertation.

Finally, since no perceived learning was discovered in the affective domain, this provides for future research opportunities, particularly an investigation into the questions used in the survey, such as, were the questions appropriate for measuring affective skills associated with the laboratory? Future research could possibly investigate the design of experiments and how different styles have an impact on affective skills.

CHAPTER 9: MAPPING THE PROCESS FLOW OF HOW STUDENT EVALUATIONS CAN BE USED TO IMPROVE QUALITY IN THE LABORATORY

Chapter three and four introduced two survey instruments to measure student evaluations of the teaching staff and laboratory experience. An iterative refinement process was used to improve the training of laboratory demonstrators, laboratory experiments, facilities and resources. Chapter five undertook a statistical analysis of the data to investigate possible bias and to understand the relationship between laboratory demonstrators and laboratory experience scores. Chapter six continued the work from chapter four to further investigate the impact of additional learning resources. Chapter seven provided a case study of an iterative refinement process together with an attempt to explore any improvements to learning. Chapter eight built upon the lessons learnt in chapter seven to undertake a statistical analysis of the data to determine the relationship between student evaluations and perceived learning across the cognitive, psychomotor, and affective domains. The findings from each chapter can be linked together to understand how each variable interacts. This chapter will discuss how the variables are related and mapped to build a process flow which illustrates how student evaluations can be used to improve quality in the laboratory. This is a major contribution to research because no such modelling for perceived learning in the laboratory currently exists.

9.1. Teaching Evaluations

Chapter three outlined a survey instrument used to evaluate laboratory demonstrators, after which a rigorous training and mentoring program was applied using an iterative refinement process. The training and support structure aligned closely with the recommendations made in the Australian Council of Deans of Science report on teaching in the laboratory (O'Toole et al., 2012), so it was generally expected it would lead to an improvement in teaching quality and improved student evaluations. However, concrete evidence to determine whether such changes would be revealed via student evaluations is not available. Chapter three shows that students are on average, well able to evaluate teaching performance, with evaluation scores increasing with demonstrator training and mentoring. This finding aligns with the work of Marsh (1987), Aleamoni (1999) and Stehle et al. (2012). As a part of laboratory training, video resources were developed to provide explanations on equipment, software, and fault finding. As further evidenced in chapters six and seven, the video resources not only helped students to understand the experiments, it also helped the demonstrators. The videos also became a tool that the demonstrators used to direct student questions, encourage self-directed learning; and increase their productivity, enabling them to move between students at a faster pace. These findings are mapped as shown in Figure 9-1. The laboratory demonstrator evaluations can be improved by training, mentoring, and resources that improve understanding in the laboratory.

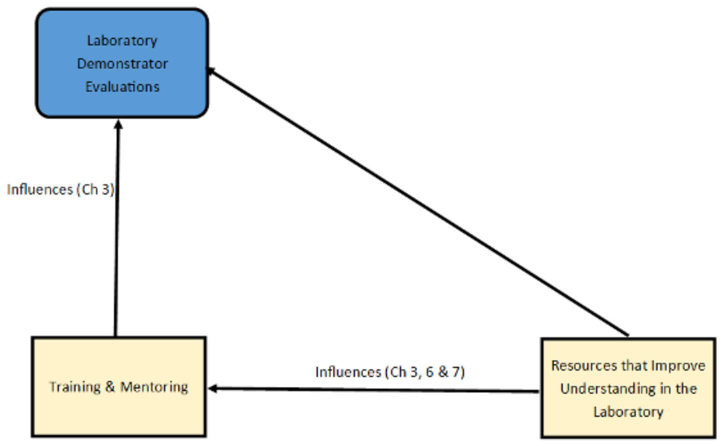


Figure 9-1: Processes involved with increasing demonstrator evaluation scores

9.2. Laboratory Evaluations

Chapter four presented a survey instrument used to evaluate student opinions on laboratory experiments and the facilities used within the laboratory. As expected, the research reported in chapter four showed there is a strong relationship between the evaluation of experiments and facilities; especially the type of activity students perform and the clarity of instructions. This finding supports the work of Gallardo et al. (2007), Boxall and Tait (2008) and Stanisavljevic et al. (2013). Ensuring that experiments are interesting, that they linked to the development of skills that students consider useful to real world applications, and which combine simulation and practice in a pedagogically beneficial way resulted in improvements in the evaluation scores for experiments. The experiments should provide a learning path for students to understand how to identify problems and troubleshoot accordingly. As shown in section 4.3.2, teaching troubleshooting skills improved the evaluation scores, and when experiments are difficult and have no direction on what corrective actions to take, evaluation scores were generally lower.

Chapter four also provided evidence that clarity of instruction was also a key influencer in the evaluations. Students have high expectations of the quality of material they receive from teaching staff, but they were quick to complain if the notes include spelling mistakes, references to wrong information, wrong sequences of instructions, and grammatical errors. As discussed in section 4.3.2 using online notes is an easy way to quickly rectify mistakes and improve clarity issues immediately after being detected. Most importantly however, clarity is linked to the ability of students to extrapolate the aim of the task and what they are required to do. As a result, evaluations scores may decrease when they sense a lack of direction or become confused.

As previously reported by Howard and Boone (1997) and Lizzio (2002) student workload plays a factor in student evaluations because they do not want to feel pressured to race through all the activities. Chapter four showed that they want to feel like they are learning something from the laboratory and not simply copying down numbers. This generally comes from underestimating the amount of time a student would take to understand and complete the experimental tasks. As discussed in section 4.3.2, the use of pre and post laboratory activities can be used to shift some of the workload away from the scheduled laboratory time. For example, students can spend time before the laboratory to simulate the activity and class time to construct the required circuits and systems.

Hardware and software issues can have a major influence on laboratory evaluations, but this can also be due to infrastructure problems that are out of the control of teaching staff (Deshwal et al., 2012, Gonsai et al., 2013). This type of problem can be reduced or eliminated by effective laboratory management (Smith, 1988, Voss et al., 2005). As was observed in section 6.5, other times this is due to a lack of student understanding of how the equipment or software operates, or it can be fixed with troubleshooting techniques. Chapters four, six, and seven outline how through the use of resources that improve understanding of laboratory equipment and troubleshooting, laboratory evaluations can be improved. Multimedia resources were used to address misconceptions with prerequisite knowledge and provide students with links that aided self-directed learning.

A major challenge with the laboratory study program, as discussed in chapter six, is the multitude of entry paths into the degree or study paths. While prerequisite knowledge is generally focused at the theory level, the assumed knowledge required for laboratory activities can be overlooked, because many international students entering the program with third and fourth year subjects may have never used standard electronic equipment such as a multimeter or oscilloscope. Chapters six and seven support the use of multimedia resources which can help such students obtain the knowledge they need to complete experiments. This results in students gaining more from the laboratory experience by concentrating on the learning objectives and not on how to use or troubleshoot the equipment. This supports the findings of other studies (Lewis, 1994, Wells et al., 2012, Lee and Lehto, 2013) that found a positive relationship between videos and student satisfaction.

The findings from these studies were used to create the map presented in Figure 9-2, which shows that laboratory evaluations can be increased by improving the design and clarity of experiments, adding resources that improve understanding, and applying an effective managerial structure to ensure that all hardware and software problems are eliminated before the start of session or are rectified quickly.

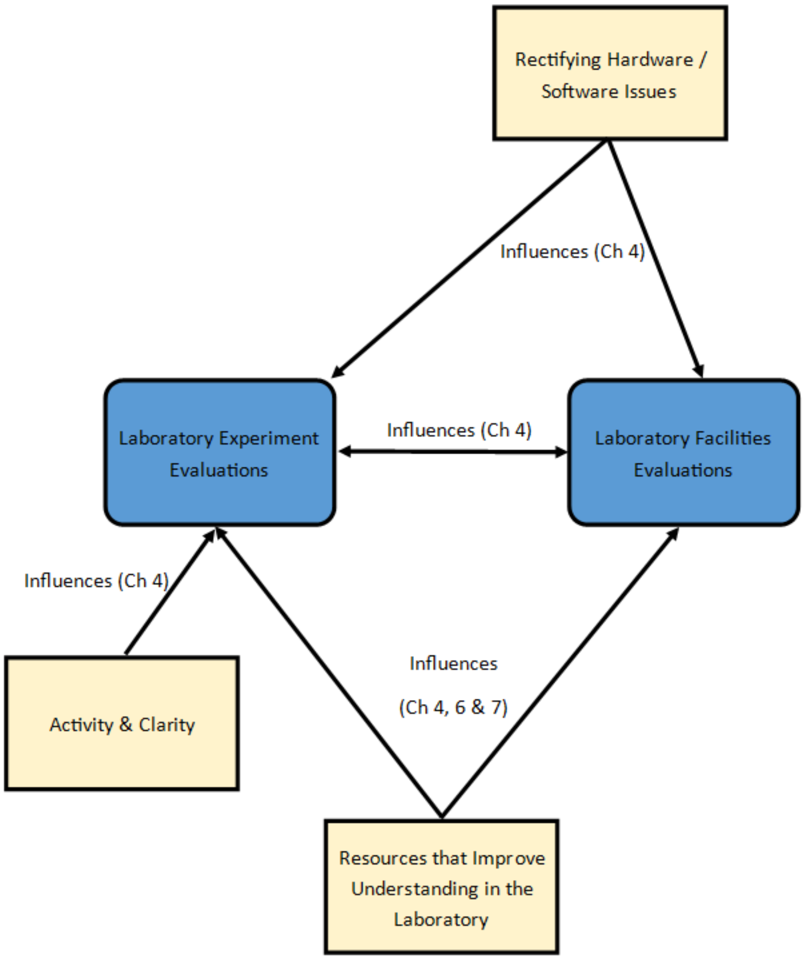


Figure 9-2: Processes involved with increasing laboratory experience scores

9.3. Bias, Demonstrator and Laboratory Relationships

Chapter five explored whether three major forms of unwanted influence were evident in the student evaluations: class size when using one, two, or three laboratory demonstrators; course level by investigating the difference between first, second, third and fourth year courses; and the gender of the demonstrator. There was no significant meaningful level of influence found, resulting in no links between the influencing factors and the demonstrator, experiment and facility evaluations. These findings support the work of Aleamoni (1999), Blackhart et al. (2006) and Zabaleta (2007).This is not to say there is no unwanted influence in the evaluations, but factors such as the weather, time of day, and ethnicity of the demonstrator were not measured and they could play a role.

The relationship between laboratory demonstrators and laboratory evaluations was also explored in chapter five. This was to determine how much influence the demonstrators have in determining how students perceive the experiment and facilities. There is no literature that has quantified this relationship. In section 5.5 the study found that demonstrators account for between 36 and 49 per cent of the variance in evaluation scores. As expected, the lead demonstrator had the greatest impact on the evaluations, regardless of there being one, two, or three demonstrators in the laboratory. However, as class size increased the impact of the lead demonstrator decreased, probably due to the lower exposure they have to all students as the class size increases. The mapping of these findings is presented in Figure 9-3, and indicates that laboratory demonstrator evaluations play an important role in how students perceive laboratory experiments and there is no strong influence with class format, course level, and gender.

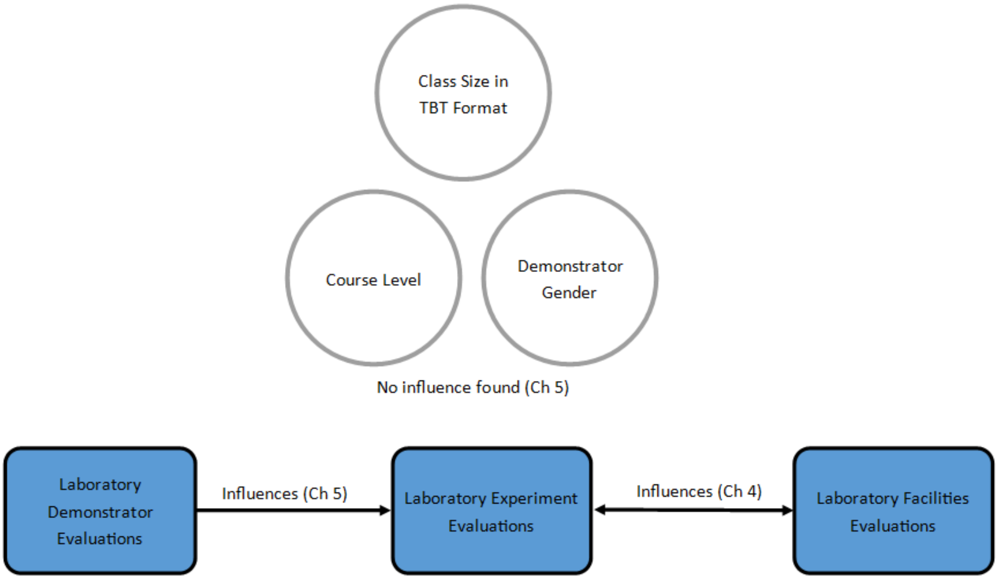


Figure 9-3: The relationship between bias, demonstrators, and laboratory experience

9.4. Evaluations and Learning

To complete the process mapping, the student evaluations were compared to perceived learning across the cognitive, psychomotor, and affective domains in chapter eight. This was to determine whether or not perceived learning played any role in student evaluations. Research in this area is divided, with strong evidence claiming no link (Carrell and West, 2010, Braga et al., 2014) and other finding a link (Gibbs and Coffey, 2004, Mason et al., 2013), while Stehle et al. (2012) claimed that the laboratory had the best conditions to determine whether a link was present. While most studies concentrate on comparing assessment tasks, this was one of the first to compare perceived laboratory learning across three domains. Section 8.3 found there is no link between student evaluations and the affective domain. With the laboratory being a place to 'learn by doing' it was expected that a link could be made with the psychomotor domain. There is a link between perceived learning and the laboratory experiment evaluations, that is, when students believed their psychomotor ability improved they rated the laboratory experiments higher. This relationship was not present for the demonstrator and laboratory facility evaluations. Learning measured through the laboratory exam did not show a relationship with the psychomotor domain, but it was related to problems in designing the exams to measure psychomotor skills and in the logistics of running the exam. Substantial research is needed to determine solutions to efficiently measure psychomotor skills when dealing with large student cohorts.

The data in section 8.3 showed that perceived learning in the cognitive domain could be split into analytical and writing skills, so the evaluations were measured separately across these two factors. The analysis found that the analytical skills perceived by the student, and confirmed in the laboratory exam, were linked to the laboratory experiment evaluations. No relationship was found for the demonstrator and laboratory facility evaluations, and no relationship was made to the writing skills, something expected due to the analytical nature of laboratory work. These findings were mapped and are presented in Figure 9-4. They show that the laboratory experiment evaluations have a relationship to perceived learning across the psychomotor and cognitive domains.

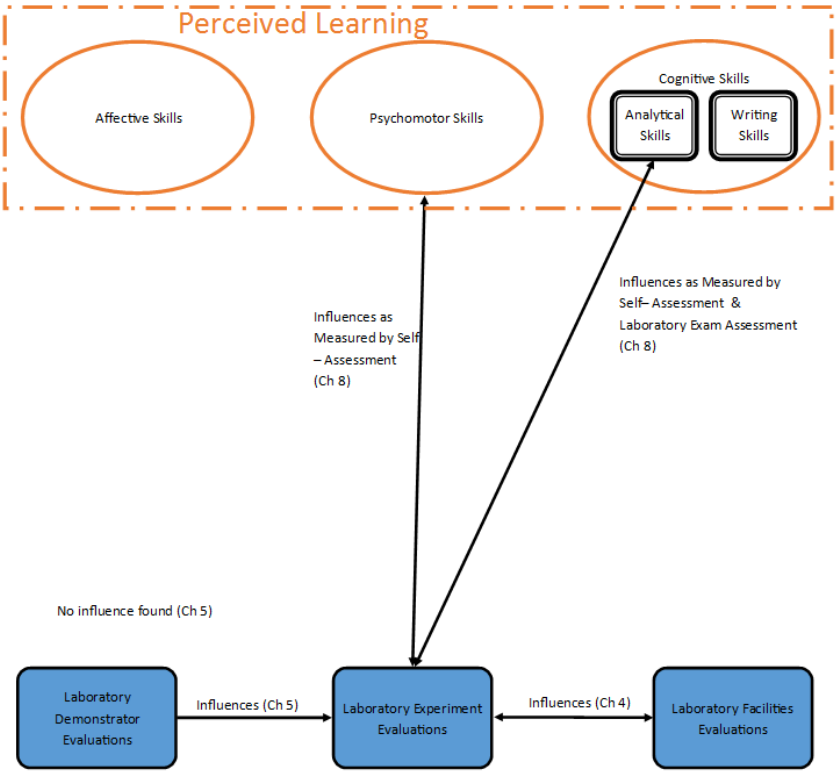


Figure 9-4: The relationship between perceived learning and student evaluations

CHAPTER 10: CONCLUSION

The purpose of this study was to gain a better understanding of student evaluations to address the question:

Can student evaluations provide data that can be used to guide improvements in the quality of laboratory experiences?

This laboratory based study was one of the first of its type to be carried out across a large number of courses over an extended period of time. As a result, the contribution to knowledge gained from this thesis includes:

- A confirmation that evaluation data can be used to guide improvements in the quality of laboratory experiences
- A confirmation that on average students can identify a quality laboratory experience
- Evidence that student evaluations in the laboratory are influenced by perceived learning across the cognitive (analytical only) and psychomotor domains
- A process map of the interconnections between laboratory demonstrators, experiments, facilities, resources and training
- An understanding of how student evaluations scores can be positively influenced, and how they can be influenced to increase perceived learning
- A confirmation that following the laboratory demonstrator training recommendations outlined in the report for the Australian Council of Deans of Science (O'Toole et al., 2012) leads to higher demonstrator evaluations
- A set of recommendations for laboratory experiments

This thesis examined the importance of providing a quality education in order to give future students and the country, a competitive advantage. This thesis found that defining what quality in education is, and who has the right to determine what quality is, is a very complex matter. This thesis considered quality to be an improvement in both student learning and their experience with demonstrators, experiments and facilities. One debated way of measuring quality is by allowing students to judge whether a quality service has been provided. This has led to thousands of research studies on student evaluations with the outcome still inconclusive.

This research studied the findings of many student evaluation studies that focussed on an evaluation of the lecturer. This approach can assume that all the knowledge gained during a course is obtained from the lecture, and ignores the input from teaching staff or activities in tutorials and laboratories. Therefore, understanding student evaluations in a laboratory environment is limited because most evaluations involve measuring student opinions of specific experiments or activities that have been trialled in an individual course. What was missing is data that looked across many courses at the same time. The studies that did look at many laboratories at once generally looked at one point in time to discover what students wanted at a particular point in time.

To gain a better understanding of student evaluations and its relationship to learning, multiple research questions were studied and reported on in this thesis. These research questions provide a snap shot of the complexity of the student evaluation instrument, and how it can be used to improve learning. This process map, presenting the complex matrix of connections can be seen in Figure 10-1, and discussed in detail in chapter nine.

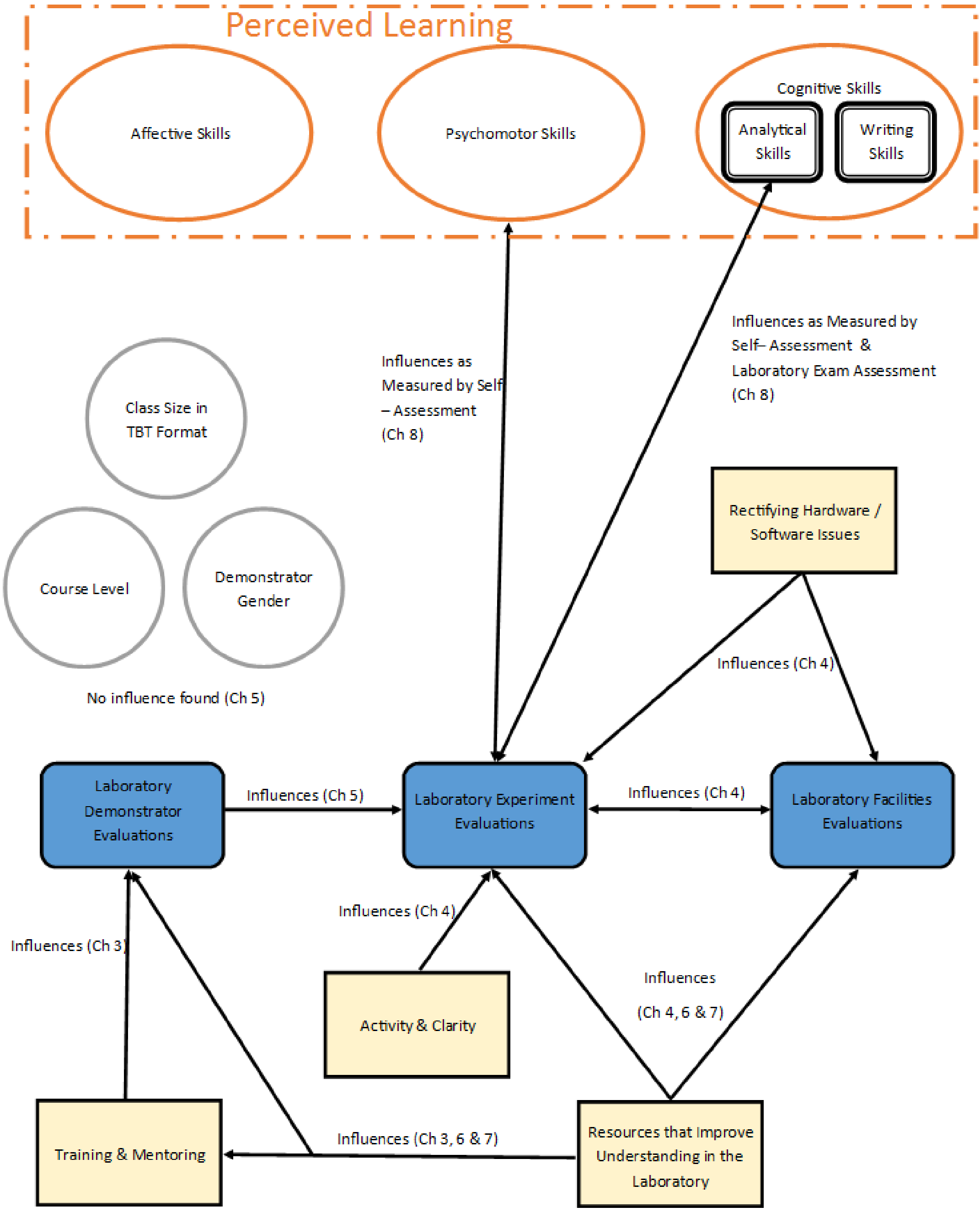


Figure 10-1: Process map of the interconnections between laboratory demonstrators, experiments, facilities, resources and training

10.1. Summary of Findings

The first research sub-question was:

Does training lead to an improvement in student evaluations?

Based on the improvement in student evaluations over a five year period, the research suggested that training does improve student evaluations. Using feedback from the student evaluations to help improve teaching effectiveness, it does suggest to some degree that students can judge teaching quality within the laboratory, and the evaluation data can be used to help improve quality. It also showed that resources that improve understanding in the laboratory helped in training the demonstrators.

The second research sub-question was: *What changes lead to improvements in student evaluations of the laboratory experience?*

An analysis of student evaluations showed that the laboratory notes (activity and clarity) and the quality of the equipment used are the most important factors that determine the laboratory experience. Laboratory notes or resources that provide significant detail on how to use the hardware and software in the experiments yielded a large increase in evaluation score. Well-designed experiments can provide an "up-lift" to other evaluation criteria explored.

Chapter five presented two sub-questions: *1) What forms of influence can be found in the survey instrument? 2) What is the relationship between student evaluations of teaching and the laboratory experience?*

The study found no evidence of unwanted influence in the survey instrument using a team teaching approach based on class format, course level, and gender of the laboratory demonstrator.

Most importantly, this study showed the significantly positive relationship between the student evaluation of a laboratory demonstrator, and the student experience in the laboratory. This was examined by having one, two, or three demonstrators in the laboratory, and as expected, the lead demonstrator always had the most influence.

The fourth sub-question was: *Do students use and appreciate additional laboratory resources?*

The study found that students used the resource to understand how the equipment and software worked, and how to troubleshoot when they ran into trouble. Such resources help create a level playing field for students who may not have experience using such software and hardware. It also helps the laboratory demonstrators facilitate learning and encourage self-directed learning. The study confirmed the findings within the second sub-question that such resources play an important role in improving student satisfaction in the laboratory.

The fifth research sub-question was: *Do additional laboratory resources improve learning?*

The addition of this extra online multimedia teaching material in early 2011 appears to have significantly improved the student experience within the telecommunications laboratory. This is inferred through the demonstrator logs, the improved student experience surveys, and improvements in the assessment outcomes for the student cohort between 2010 and 2011. Some unmeasurable improvement in learning was observed that led to the research of the last sub-question.

The sixth and final sub-research question was: *Is there a relationship between student evaluations and learning in the laboratory?*

This was the most important question in order to understand whether or not student evaluations are doing more than just making students feel happier about their experience. The findings found that student evaluations of the laboratory experiments were influenced by how they perceived the analytical skills gained in the cognitive domain, and the psychomotor skills. This supports the study in chapter four which found that laboratory experiments (activity and clarity) played an important role in student satisfaction. No relationship with learning was found with the laboratory facilities and demonstrators, but as the process map shows, they have an indirect influence because the demonstrators and facilities influence the laboratory experiment evaluation. Expanding this study to increase the sample size may lead to more significant relationships being found.

When compared to laboratory exam performance, the data suggests that student evaluations are only related to their analytical skills within the cognitive domain. However, this research found a number of issues in relation to measuring learning in a laboratory setting, thus opening up the need for future work.

Enough evidence emerged from the six research sub-questions to answer the research question of this thesis; it strongly suggests that student evaluations, when *examined collectively* can identify issues within the laboratory that need further investigation. These evaluations do not provide a full story because an in-depth analysis is still needed, but they do help point out what is working and what does not work.

The interconnection of processes required to improve student evaluations is very complex, which explains the need for such substantive research into this area. However, it seems that the overlying experience of students and learning in the teaching laboratory can be measured via their opinions about laboratory experiments. Therefore, student evaluation data can be used to guide improvements in the quality of laboratory experiences.

10.2. Recommendations

Through the findings from this dissertation, a major contribution is the development of a number of recommendations that can be used to help engineering departments develop high quality laboratories. Key recommendations from this dissertation include:

- Map all the laboratory courses against the thirteen laboratory objectives outlined in Feisel et al. (2002). This will help determine the balance between physical and simulated/virtual/remote laboratories.
- In one of the first laboratory courses students undertake, have an activity in the first experiment that makes students read the thirteen laboratory objectives outlined in Feisel et al. (2002) and reflect upon them.
- When designing assessment tasks, consider activities that measure learning in the psychomotor domain.
- Consider supporting scheduled laboratory time with appropriate pre and post laboratory activities in order to remove workload pressures and encourage experimentation.
- When designing a laboratory experiment, some questions to consider:
    - Is the learning path scaffolded?
    - Does the learning path consider students that may undertake courses in a non-standard order (focused on laboratory learning and not theoretical learning)?
    - Are there activities that teach or reinforce fault-finding/troubleshooting, reading manuals, models or datasheets?
    - Do the experimental activities involve inquiry based learning?
    - Do some of the activities relate to real world applications?

    - Are there resources for the equipment or software students are going to use readily available? (e.g. user manuals or YouTube videos)
    - Have the laboratory notes been tested to check for mistakes and clarity of instruction?
- Use laboratory management solutions to ensure laboratory equipment and facilities are in good condition and have been upgraded to a predetermined asset replacement cycle
- Develop a laboratory demonstrator training program based on the recommendations outlined by O'Toole et al. (2012)
- Consider using a team based teaching approach by pairing experienced and inexperienced demonstrators for succession planning
- Conduct regular student evaluations in the laboratory, ensuring that the findings are assigned to an individual (preferable a laboratory manager). Solutions must be appropriately followed up, executed, and communicated to students

10.3. Further Research

The findings in chapter eight highlight the issue of the difficulty of measuring learning in the teaching laboratory. While cognitive ability is important, as per the laboratory learning objectives, it is not the only learning domain that should be measured. The laboratory is a place not only to learn and reinforce knowledge, but to gain new skills by doing and improve confidence.

The findings suggest that substantial research should be invested in determining efficient methods in assessing psychomotor and affective skills. While self-assessment does indicate an improvement in learning, it may not be an accurate measure. Currently the greatest issue with measuring the psychomotor and affective skills is the large amount of resources needed, and the amount of time needed for this assessment.

While this thesis produced a process map of student evaluations, it was limited to one department of engineering, in one institution, in one country. The findings from this study would gain further weight should they be reproduced in other departments, institutions, and countries.

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Appendix A: Standard Student Evaluation Form

University of Wollongong

School of Electrical, Computer and Telecommunications Engineering
Laboratory Survey

Please answer the following questions in regards to your experience in the Laboratory

Subject: ECTE:____________ Day:__________ Time:__________ Odd/Even

Part A. Laboratory

I have a great overall impression of the laboratory component for this subject?

☐ Strongly **Agree**	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly **Disagree**

The contents of the laboratory notes provide me with enough information to successfully complete the required exercises?

☐ Strongly **Agree**	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly **Disagree**

The experiments undertaken in this laboratory are worthwhile learning experiences?

☐ Strongly **Agree**	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly **Disagree**

Part B. Facilities

The computers in the laboratory are suitable for the work required?

☐ Strongly **Agree**	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly **Disagree**

The electronic equipment other than the computers in the lab are suitable for the work required?

☐ Strongly **Agree**	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly **Disagree**

The laboratory is in good condition?

☐ Strongly **Agree**	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly **Disagree**

Part C. Casual Demonstrator Performance

Only answer this section for casual staff members and not academic staff

Name Casual Demonstrator A: ____________ **Name Casual Demonstrator B:** ____________ **(if applicable)**

At the start of each laboratory does the Casual Demonstrator give you a satisfactory introduction to the laboratory?

Casual A	☐ Strongly Agree	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly Disagree

Is the Casual Demonstrator well prepared for the subject?

Casual A	☐ Strongly Agree	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly Disagree
Casual B	☐ Strongly Agree	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly Disagree

Does the Casual Demonstrator communicate the subject matter clearly?

Casual A	☐ Strongly Agree	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly Disagree
Casual B	☐ Strongly Agree	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly Disagree

The casual demonstrator appears to be interested in assisting me to learn?

Casual A	☐ Strongly Agree	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly Disagree
Casual B	☐ Strongly Agree	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly Disagree

Is the casual demonstrator helpful in responding to questions or problems?

Casual A	☐ Strongly Agree	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly Disagree
Casual B	☐ Strongly Agree	☐ Agree	☐ Neutral	☐ Disagree	☐ Strongly Disagree

Constructive Feedback:

Appendix B: HREC Approval HE13/129

UNIVERSITY OF WOLLONGONG

In reply please quote: HE13/129

28 March 2013

Dr Peter Vial
SECTE
University of Wollongong
peter_vial@uow.edu.au

Dear Dr Vial

I am pleased to advise that the Human Research Ethics application referred to below has been **approved.**

Ethics Number:	HE13/129
Project Title:	Surveys of Laboratories for content modification and demonstrator training to be used in two research papers
Researchers:	Dr Peter Vial, Mr Sasha Nikolic, Dr Parviz Doulai, Dr Montserrat Ros, Dr David Stirling, Dr Christian Ritz
Approval Date:	28 March 2013
Expiry Date:	27 March 2014

The University of Wollongong/Illawarra Shoalhaven Local Health District Social Sciences HREC is constituted and functions in accordance with the NHMRC *National Statement on Ethical Conduct in Human Research*. The HREC has reviewed the research proposal for compliance with the *National Statement* and approval of this project is conditional upon your continuing compliance with this document.

A condition of approval by the HREC is the submission of a progress report annually and a final report on completion of your project. The progress report template is available at http://www.uow.edu.au/research/rso/ethics/UOW009385.html. This report must be completed, signed by the appropriate Head of School, and returned to the Research Services Office prior to the expiry date.

As evidence of continuing compliance, the Human Research Ethics Committee also requires that researchers immediately report:

- proposed changes to the protocol including changes to investigators involved
- serious or unexpected adverse effects on participants
- unforseen events that might affect continued ethical acceptability of the project.

Please note that approvals are granted for a twelve month period. Further extension will be considered on receipt of a progress report prior to expiry date.

If you have any queries regarding the HREC review process, please contact the Ethics Unit on phone 4221 3386 or email rso-ethics@uow.edu.au.

Yours sincerely

A/Professor Garry Hoban
Chair, Social Sciences
Human Research Ethics Committee

Ethics Unit, Research Services Office
University of Wollongong NSW 2522 Australia
Telephone (02) 4221 3386 Facsimile (02) 4221 4338
Email: rso-ethics@uow.edu.au Web: www.uow.edu.au

Appendix C.1: HREC Approval HE14/156

UNIVERSITY OF WOLLONGONG

Final Approval letter after response to review
In reply please quote: HE14/156

30 May 2014

Ms Sasha Nikolic
SECTE
Bldg 35 Room 135
University of Wollongong NSW 2522

Dear Ms Nikolic

Thank you for your response dated 26 May 2014 to the HREC review of the application detailed below. I am pleased to advise that the application has been approved.

Ethics Number:	HE14/156
Project Title:	Investigate student satisfaction and knowledge transfer of learning activities to be used in two or three research papers
Researchers:	Ms Sasha Nikolic, Dr Montse Ros, Mr Peter Vial
Approval Date:	29 May 2014
Expiry Date:	28 May 2015

The University of Wollongong/Illawarra Shoalhaven Local Health District Social Sciences HREC is constituted and functions in accordance with the NHMRC *National Statement on Ethical Conduct in Human Research*. The HREC has reviewed the research proposal for compliance with the *National Statement* and approval of this project is conditional upon your continuing compliance with this document.

A condition of approval by the HREC is the submission of a progress report annually and a final report on completion of your project. The progress report template is available at http://www.uow.edu.au/research/ethics/human/index.html. This report must be completed, signed by the appropriate Head of School, and returned to the Research Services Office prior to the expiry date.

As evidence of continuing compliance, the Human Research Ethics Committee also requires that researchers immediately report:

- proposed changes to the protocol including changes to investigators involved
- serious or unexpected adverse effects on participants
- unforseen events that might affect continued ethical acceptability of the project.

Please note that approvals are granted for a twelve month period. Further extension will be considered on receipt of a progress report prior to expiry date.

If you have any queries regarding the HREC review process, please contact the Ethics Unit on phone 4221 3386 or email rso-ethics@uow.edu.au.

Yours sincerely

Dr Mark Rix
(Acting) Chair, Social Sciences
Human Research Ethics Committee

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Appendix C.2: HREC Approval HE14/156 Amendment

UNIVERSITY OF WOLLONGONG

AMENDMENT APPROVAL
In reply please quote: HE14/156
Further Enquiries Phone: 4221 3386

19 October 2015

Ms Sasha Nikolic
SECTE
Bldg 35 Room 135
University of Wollongong NSW 2522

Dear Ms Nikolic

I am pleased to advise that the amendment requested to the following Human Research Ethics application has been approved.

Ethics Number:	HE14/156
Project Title:	Investigate student satisfaction and knowledge transfer of learning activities to be used in two or three research papers
Researchers:	Ms Sasha Nikolic, Dr Montse Ros, Mr Peter Vial, Mr Thomas Goldfinch, Professor Timothy McCarthy, Mr Thomas Suesse
Amendments:	Additional Researcher: Mr Thomas Goldfinch, Professor Timothy McCarthy, Mr Thomas Suesse
Amendment Approval Date:	16 October 2015
Application Expiry Date:	**28 May 2016**

Please remember that in addition to reporting proposed changes to your research protocol the HREC requires that researchers immediately report:

- serious or unexpected adverse effects on participants
- unforseen events that might affect continued ethical acceptability of the project.

The University of Wollongong/ Illawarra and Shoalhaven Local Health Network District (ISLHD) Social Science HREC is constituted and functions in accordance with the NHMRC National Statement on Ethical Conduct in Human Research.

A condition of approval by the HREC is the submission of a progress report annually and a final report on completion of your project. The progress report template is available at http://www.uow.edu.au/research/rso/ethics/UOW009385.html. This report must be completed, signed by the appropriate Head of School and returned to the Research Services Office prior to the expiry date.

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