The National Engineering Laboratory Survey

A Review of the Delivery of Practical Laboratory Education in Australian Undergraduate Engineering Programs

Selected Outcomes

Dr Thorsten Kostulski
Steve Murray

Labshare - December 2010

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This report is an outcome of the Labshare project undertaken by the Australian Technology Network of universities: University of Technology, Sydney, Curtin University, Queensland University of Technology, RMIT University, and the University of South Australia, under the title *National Support for Laboratory Resource Sharing*. Support for this project has been provided by the Australian Government Department of Education, Employment and Workplace Relations (DEEWR). The views expressed in this report do not necessarily reflect the views of the Australian Government Department of Education, Employment and Workplace Relations, or of the universities whose staff participated in the survey.

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Executive summary

Laboratory experiences have long been considered a core component of technical degree programs – particularly in engineering and the applied sciences. Unfortunately, the infrastructure necessary to make laboratory learning possible is usually expensive in terms of acquisition cost and maintenance. Laboratories represent a very significant component of (overly stretched) university budgets and capital investment, and are a valuable infrastructure resource. Despite this, there is almost no sharing of facilities or design expertise either between institutions or across educational sectors. Further, the current inflexible operation of, and constrained access to physical laboratories is misaligned with the increasingly complex lifestyles of students and the demands on their time. Continuing increases in student numbers and competition for floorspace have put further pressure on universities in the delivery of effective practical laboratory education. To quantify and evaluate factors that impact on the delivery of practical laboratory education, the DEEWR-funded Labshare project has conducted a national survey and also investigated the potential of laboratory resource sharing between universities.

Between August 2009 and September 2010, all 34 Australian universities offering undergraduate engineering programs participated in the survey and were visited by a researcher. The target audience were executive, academic and technical staff as stakeholders in laboratory resourcing and in the delivery of laboratory practice, which saw the participation of over 260 individuals. In particular, over 85% of all senior executives represented in the Australian Council of Engineering Deans (ACED) contributed to this comprehensive national review. Since the survey was conducted in an interview-style, it produced data of very high quality and reliability.

A large part of the different questionnaires was aimed at collecting data specific to the university, subject or laboratory facility, and at collecting the participants' opinions surrounding teaching laboratories, for example decision-making processes, development initiatives and coursework support. Resourcing trends were also evaluated, along with a subjective rating of the sufficiency of those resources for the delivery of practical laboratory education. The main points of the academic questionnaire were pedagogy and learning outcomes, which allowed participants to assess the 13 ABET objectives as suitable descriptors for the results of laboratory learning. Finally, interviewees were asked to comment on remotely accessible laboratories as a possibility to facilitate resource sharing. Following the statistical analysis of responses, a number of key outcomes were identified:

- According to executives, the reasons for having laboratories range from student motivation to the reinforcement of concepts, but also include compliance with accreditation requirements.
- Trends in laboratory resourcing reveal that almost all universities face challenges; those with large student numbers have floorspace and throughput issues, those with small numbers have funding and staffing issues.
- The main factor affecting the quality of practical sessions at many large institutions is the significant variability in the quality of demonstrators and the strong reliance on them to deliver the sessions.
- Flexible student access to facilities is increasingly important for the delivery of project-based laboratory work.
- In some cases, resourcing issues and conflicts of interest by academics (research) have forced the reduction of laboratory sessions per semester.
- Student groups in most practical sessions tend to be larger than pedagogically desirable.
- Academics rank practical sessions as the most important component of their subjects, yet they often receive less attention in subject development and assessment than other components.
- The ABET objectives have been widely accepted as descriptors of laboratory learning outcomes by Australian academics.
- Technical staff say that inflexible, specialised laboratories are most prone to under-utilisation.
- Wear and tear and the need for upgrades are the most common reason for equipment expenditure in laboratories, but are often not budgeted for on a regular basis.
- Past efforts to collaborate and share physical laboratories resource between universities and TAFE on a metropolitan scale (Melbourne) have reportedly experienced difficulties due to timetabling and commuting challenges.

The specific topic of remote laboratories has resulted in the following findings:

- The National Survey has significantly raised awareness of the need for resource sharing and the possible role of remote laboratories.
- Remote laboratories are widely deemed to offer convincing benefits in terms of flexible access, student convenience and efficient use of equipment, but still need to ascertain their pedagogic effectiveness and financial viability to be regarded a regular supplement of hands-on laboratories.
- Most universities expressed interest in learning more about remote laboratories and the sharing of equipment with other institutions, including developing their own experiments.
- Executives at several non-ATN institutions said they are planning for the adoption of some remotely accessible experiments in their coursework in the near future.

Following the survey, sharing trials of remotely accessible laboratories are currently being conducted between 10 Australian universities and are planned to continue in the near future. Experience with inter-institutional use and further developments are expected to generate additional results to address the above points and to lay the foundations for a national consortium.

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1 Introduction and Context

1.1 Background

Laboratory learning is acknowledged as being indispensable in the context of an engineering degree program [1-3]. Unfortunately, the infrastructure necessary to make laboratory learning possible is usually expensive in terms of acquisition cost and maintenance. Laboratories represent a very significant component of (overly stretched) university budgets and capital investment, and a valuable infrastructure resource - yet are often greatly underutilised and are commonly seen by students as under-resourced. Despite this, there is almost no sharing of facilities or design expertise either between institutions or across educational sectors. Further, the current inflexible operation of, and constrained access to, physical laboratories is misaligned with the increasingly complex lifestyles of students and the demands on their time. Despite some isolated efforts to address some of these issues, there has been no nation-wide, concerted approach yet to identify and analyse the challenges associated with practical engineering education at tertiary level. With this as a somewhat sobering context, any attempt to consider the applicability of a wider view of the management of laboratory resources should commence with a survey of currently available laboratories and their usage.

The Labshare project undertook to complete a nation-wide survey of the engineering faculties and/or schools at universities in Australia with the aim of compiling a record of the types of laboratories being used, their usage levels and other notable attributes. As a key deliverable, the Labshare mission includes 'National Review: To support the development of appropriate approaches, a national review will be carried out of current laboratory infrastructure, funding, educational roles, and utilisation levels within all Faculties of Engineering in Australia.'

This activity has been exhaustively accomplished through a detailed survey, the nature of which is presented in this report along with a collection of some of the survey outcomes. This document summarises a larger, more comprehensive encapsulation of the survey outcomes which include:

(1) educational objectives;
(2) commonalities which exist in usage and infrastructure;
(3) opportunities for shared laboratories.

1.2 The Labshare project

'Labshare: National Support for Laboratory Resource Sharing' is a project backed by the Australian Government's Diversity and Structural Adjustment Fund. It is a joint initiative of the Universities amongst the Australian Technology Network - the University of Technology, Sydney, Curtin University of Technology, Queensland University of Technology, RMIT University, and the University of South Australia. Labshare's mission is to create a nationally shared network of remote laboratories that will result in higher quality labs that support greater student flexibility and better educational outcomes, improved financial sustainability, enhanced scalability in terms of coping with student loads, and are developed and run by those with the greatest expertise in a particular discipline.

LABSHARE OBJECTIVES

National Review - Report on status and opportunities of engineering laboratories in Australian Universities

Pedagogic Design - Online resource kit containing guidelines on the appropriate selection, design and utilisation of remote labs

Technical Architecture - Technical interface specifications and user documentation that supports lab development

Technical Resource Development - Implemented laboratory software library

Organisational Model Design –Definition of sharing models, with appropriate formal agreements which can be used in implementing the models

Shared Lab Development – Development of at least 4 remote laboratories in different engineering discipline areas capable of supporting a minimum of 1000 students

Resource Kit Development – Starter pack of material for universities and for schools

Communication – Website development, quarterly newsletters, annual workshops, twice-yearly practical workshops

Sharing Trials – Students remotely using initial laboratories followed by experience survey and feasibility evaluation

Model Refinement

1.3 Research questions

RATIONALE

Prior to conducting the survey, estimates of infrastructure, budgets and utilisation levels could be made drawing upon techniques such as localised data collection and extrapolation, or by attempting to obtain quantitative data from sources such as DEEWR, the Australian Bureau of Statistics and similar. In order to facilitate a more precise description of contemporary laboratory practice which might be useful in terms of establishment and construction of laboratories, their intended use in support of learning and their demands upon resources, it was determined that the nation-wide survey be carried out.

POSITIONING

Comprehensive survey instruments used for data collection were carefully developed (see Part I – Survey Implementation), but were essentially directed at providing some insight into issues like the following:

What makes laboratory learning a significant part of the undergraduate engineering degree programs?

How important do academics consider practical laboratory sessions for student learning, compared to lectures and tutorials?

What techniques are being used to assess laboratory learning performance?

To what extent are resourcing problems impinging upon laboratory learning?

What influences do the demands of current professional practice bring to laboratory work?

Who should be responsible for the development of laboratory learning exercises, and what incentives, restrictions and motivations play a role in this?

Who is seen as being responsible for determining a budget for laboratory development and maintenance?

Who is currently involved in delivering practical lab sessions to students, and who should be?

Are there any significant differences in laboratory practice between large and small, metropolitan and regional universities?

With respect to resourcing, what have been the trends in staffing, floorspace, laboratory development and maintenance over the past decade?

What are the views on various degrees of commercially-based ‘outsourcing’ of laboratory practice?

How critical are group sizes in laboratory sessions, and what would academics and demonstrators see as an optimal number?

How do academics determine and assess the learning outcomes from practical sessions?

What role can remotely accessible laboratories play?

How are they perceived by participants, especially in comparison to hands-on laboratories?

How is the level of interest in establishing a sustainable remote laboratory community in Australia?

PART 1

Survey Implementation

2 Methodology and Data Collection

This chapter establishes a framework for the implementation of the national review as a survey and provides rationales for the selection of the target audience, survey administration and various aspects of the survey instrument design.

2.1 Scope

The specific scope of this investigation is already reflected in the research questions presented in Chapter 1. Firstly, within this project, participation was limited to the Australian tertiary sector, i.e. universities. However, many of the above research questions may also be applicable to other sectors, and future studies involving VET institutions and secondary schools may follow. Engineering disciplines are considered fundamentally practice-based and have a mandatory requirement for experimentation with laboratory equipment and hardware for accreditation. Therefore, focussing on engineering faculties and schools (including a small overlap with applied sciences and industrial design) appears reasonable. Besides, virtually all coursework-related, practical laboratory work (other than research) takes place in undergraduate years, which also includes associate degrees (e.g. BEngTech), where available. This further restricts the scope to Australian undergraduate engineering programs. The only engineering disciplines which are intentionally excluded from the review are purely software-based programs, which require little (if any) experimentation with hardware.

It was determined that a review in the style of a formal survey would be most suitable for this context. Other possible methods, such as a literature review or the analysis of publicly available records, often bear the risk that the feasibility of the respective approach cannot be determined till very late in the review. Besides, survey administration plays a major role in the consideration of data quality (see Section 2.3.1).

2.2 Target audience

The range of topics covered in the research questions leads to the conclusion that input from a variety of university staff is required, with the exception of those with administrative and research-only responsibilities. Due to the logistical complexity of including student feedback from a large number of universities, students do not form part of the target audience in this particular review. The following staff groups were specifically identified as candidates:

EXECUTIVE STAFF

Depending on the organisational structure of each university, faculty or school, executives (pro-vice chancellors, deans, heads of school or similar) bear budget responsibility and drive the strategic vision of their organisational unit. Therefore, they directly or indirectly control the resources for laboratories. They are usually complemented by associates (e.g. deans, teaching & learning) and directors of coursework, all of who may have influence on the operation of practical coursework components to varying degrees. Consequently, it is mandatory to include their opinion in the survey.

ACADEMIC STAFF

Academic staff members are instrumental in selecting appropriate laboratory experiments for their students, designing suitable lessons and in many cases also for delivering/assessing the practical course component. This requires both technical and pedagogic expertise. Together with tutors and demonstrators, this target audience is usually expected to work closest with the students.

TECHNICAL STAFF

The involvement of technical support staff in laboratory coursework can vary considerably, depending on their specific responsibility. Technical officers and some laboratory managers often fulfil the role of preparing the laboratory equipment for student use, performing maintenance, designing and manufacturing new experimental apparatus and also regularly conducting laboratory sessions in interaction with students. Technical managers and coordinators have insight into laboratory resourcing (staffing, capital investment, maintenance and floorspace) and organisational issues, which is of great interest in the context of this review.

The selection of these three target audiences mandates that each of their responsibilities is addressed separately. The design of the survey instrument is therefore required to identify which questions can be answered by which target audience, and to what extent an overlap in those survey questions is desirable.

2.3 Survey administration

2.3.1 Selection of implementation mode

The choice of the most suitable mode of implementation is critical for the success of a survey. Of all available options, such as online survey, mail-out survey, telephone interview and face-to-face interview, the latter was eventually selected after careful consideration. For the best data consistency, this required a single researcher to visit each institution personally and to conduct separate, individual interviews with each participant. Although this was the most elaborate and labour-intensive of all options and took significantly longer to conduct, superior data quality, high flexibility, high completion rate and establishment of relationships with the participants were convincing reasons for this approach. Besides, it was considered important to go beyond meetings and questionnaires and to visit as many coursework laboratories as possible in order to integrate first-hand experience into the survey.

2.3.2 Practical implementation

Following the identification of appropriate executive contacts at all Australian universities offering engineering degrees, participation in the survey was invited in mid-2009 through a letter from the Dean of Engineering and IT at UTS, as this is the lead Labshare institution. A positive response was followed up through the coordination of visitation dates and the selection of survey participants from faculty/school executive, academic staff and technical support staff. The coordination typically involved communication with a nominated delegate from the institution, during which a number of meetings were requested. Executive participants were typically pre-selected by the survey administrator, subject to availability of key staff. For practical reasons, it was left to the delegate to nominate suitable interviewees from amongst the academic and technical staff and to create the overall agenda. It was clearly communicated that participating staff members should be spread across all offered engineering disciplines, and that they should also have an active involvement in practical laboratory sessions with coursework students. This procedure imposes some constraints on the interpretation of the data, which is further covered in Section 2.5.

Questionnaires were provided to the delegate ahead of the visit for further distribution to the nominated survey participants for transparency reasons. It was also clearly stated that all data collected is confidential to the research team and would only be disclosed in amalgamated form. Preparation by participants was encouraged but not mandatory, and any pre-filling of the questionnaire was reviewed during the meeting for better consistency of the survey responses. Following the style of a face-to-face interview, the questionnaire was completed by the survey administrator according to the participant's answers and free-form comments.

Visits to each university were conducted over a 1 - 3 day time frame, depending on the size of the engineering program, in order to allow for a broad representation of disciplines and interview types. All survey interviews took place over a 13-month period, between mid-August 2009 and mid-September 2010.

2.4 Survey instrument design

With research questions, scope, target audience and methodology defined, the survey instrument was developed in the form of a paper-based questionnaire for maximum flexibility. The design process was conducted by the survey administrator and guided and facilitated through the involvement of an expert statistician and survey designer. Input was also sought from other project stakeholders, and all questionnaires have undergone several review cycles before their external release.

2.4.1 Survey structure and length

Due to the partial dissimilarity of objectives for the three survey types (executive, academic and technical), each questionnaire has a different length and follows a slightly different structure. Table 1 lists the section titles, and the number of questions per section is clearly indicative of the focus for each type.

Besides the classification by topic, all questions in the academic and technical questionnaires can also be logically divided into questions referring to the individual, or to one or more subjects (or facilities, respectively) that the interviewee is involved in. This separation is important for data analysis and further explained in Chapter 4.

The executive survey is designed to be completed in about 30 minutes, while the academic and technical surveys are expected to be finished in about 60 minutes. Due to the likelihood of discussions and additional comments occurring during the course of the interview, the requested meeting time was about 50% longer than the typical survey completion time.

TYPE	LABEL	SECTION TITLE	NO. OF QUESTIONS
Executive	A	General Questions	15
	B	Remote Laboratories	6
Academic	A	Your Academic Activities	4
	B	Practical Laboratory Sessions	6
	C	Design & Development of Laboratory Experiments	7
	D	Pedagogic Aspects	12
	E	Remote Laboratories	8
	F	General Comments	1
Technical	A	General Laboratory Information	4
	B	Laboratory Utilisation	8
	C	Laboratory Maintenance and Development	15
	D	Pedagogic Aspects	6
	E	Remote Laboratories	8
	F	General Comments	1

Table 1: Structure of the executive, academic and technical questionnaires

It must also be pointed out that even within a survey type, it is not expected that each participant would be able to answer all questions. For example, a technical coordinator would typically be very knowledgeable about resourcing and laboratory expenditure, while a technical officer supporting practical sessions would be able to give better answers regarding the interaction with students. Consequently, this presumption requires the survey administrator to be selective about the subset of questions to complete in each individual interview.

2.4.2 Quantitative and qualitative questions

An important factor in survey design is to consider how responses will be eventually analysed, and what question type would be most helpful in achieving this aim while allowing respondents to give answers which have not been pre-defined by the survey designer.

Conclusions derived from **quantitative** answers are often deemed more accessible than from qualitative answers, which require a degree of interpretation. Given the substantial length of each questionnaire, the majority of questions has therefore been formulated requiring pre-classified, quantitative answers (e.g. multiple choice, ranking) or numeric answers for a more efficient and reliable analysis. A typical example would be a statement which requires a response according to the Likert scale (agree/disagree). Since the survey is administered as an interview, quantitative answers can be easily annotated by hand, complementing the pre-defined (and often restrictive) nature of quantitative questions. Quantitative answers are also more suitable for conditional stochastic analysis, and many of the results presented in Part II rely on this data type.

Questions requiring **qualitative** answers are often helpful where a-priori classification of answers is either not possible or not practical, or where the creativity of the respondent is meant to be encouraged. For example, significant differences in administrative structure, size and operation of universities mandates a flexible approach towards some questions, especially those involving subject names, laboratory equipment and experiment titles. Consequently, in this case it is more practical to record free-form answers first before classifying the data during the analysis phase. Other typical qualitative data collected in this survey comprises annotations, qualifications of quantitative answers and comments, which have led to the identification of interesting observations (cf. Chapter 10).

2.4.3 Focus group tests and revision

Prior to the official release of the survey, all questionnaires were internally tested with focus groups in several iterations. In each version, practical and conceptual weaknesses were identified and revised, if appropriate.

2.5 Limitations of survey implementation

Obviously, certain organisational, financial and time constrains have put limits on the implementation of the review. While the survey cannot claim to be exhaustive in its objectives, it certainly is very comprehensive in terms of university involvement and coverage of topics. Within these boundaries, the following practical limitations must be pointed out:

As previously mentioned, key executive staff members were usually pre-selected by the survey administrator (cf.Section 3.2). Since each university contributed to the survey through at least one, but mostly multiple executive surveys, it can be claimed that the responses are largely representative of Australian engineering universities as a whole. However, due to the variation in executive participation per institution, it cannot be claimed that each university is proportionally represented in the survey according to staff or student numbers.

Academic and technical staff members were not randomly selected, but nominated by their own institution, which is unavoidable due to practical considerations. Also, similar to the executive case, the number of participants per institution varied, which skews the share of contribution to the overall results between universities. This leads to the conclusion that survey participants in these two groups do not statistically represent all academics in Australian engineering programs.

However, drawing data from a non-random sample of participants is not expected to affect the quality of results, since it is not known that any bias has been introduced through this approach. It will also be shown in Part II that the sample of participants is large and diverse enough to support conclusive findings.

3 Participation

In total, 59 individual days of survey visits produced 261 meetings and the completion of 210 questionnaires across all three categories. The remaining meetings (51) were held without a formal completion of the questionnaire, however all comments with relevance to the survey objectives have been incorporated as qualitative observations in Chapter 10.

3.1 University participation

100%, that is all 34 universities offering tertiary engineering qualifications in Australia, responded to the invitation, as listed in Table 2. The 'Org' column indicates at which organisational level the survey was conducted (F=Faculty, S=School). Grouped by state/territory, the table also includes the official head count numbers of students enrolled in engineering and technology-related courses at undergraduate level (bachelor and associate degrees) in 2008, as more recent data was unavailable at the time of publication. These figures represent full-time, part-time, on-campus and distance mode students, but not those at international locations (outside Australia). The number of undergraduate engineering students ranged from 3 to over 5,000 with a mean of 1,635 and a median of 1,109.

According to official DEEWR statistics, the total number of undergraduate engineering students was 50,914 in 2006 and rose by to 55,584 in 2008, which is an increase by over 9% in 2 years. Assuming that this trend has continued over the past 2 years, this figure is likely to have exceeded 60,000 in 2010.

Within these universities, organisational structures vary greatly. Nominal 'Faculties of Engineering' only exist at 4 Australian universities, while engineering is usually combined at faculty level with either 'Science', 'Built Environment' or 'Information Technology' disciplines at all other institutions with large student numbers above the median (ca. 1100+ students), with Griffith University being the only exception. Engineering disciplines offering courses for less than the median are organised in schools or even sub-units, except for the Australian National University. In order to keep the National Survey focussed on engineering disciplines only, as opposed to broadening it into related fields, interviews were conducted on the most appropriate organisational level. 50% of all universities participated at faculty-level, the remainder

LOCATION	UNIVERSITY	ORG.	STUDENT HEAD COUNT (DEEWR 2008)
ACT	Australian National University	F	664
	University of Canberra [1]	S	3
NSW	Macquarie University	S	74
	The University of New South Wales	F	5,020
	The University of Sydney	F	2,517
	University of Newcastle	F	1,968
	University of New England	S	30
	University of Technology, Sydney	F	3,081
	University of Western Sydney	S	913
	University of Wollongong	F	1,407
NT	Charles Darwin University	S	141
Qld	Central Queensland University	S	803
	Griffith University	S	1,203
	James Cook University	S	522
	Queensland University of Technology	F	2,094
	The University of Queensland	F	3,172
	University of Southern Queensland	F	3,010
	University of the Sunshine Coast	S	34
SA	Flinders University	S	249
	The University of Adelaide	F	2,396
	University of South Australia	F	2,007
Tas	University of Tasmania (incorporating AMC)	S	1,015
Vic	Deakin University	S	614
	La Trobe University	S	340
	Monash University	F	3,311
	RMIT University	F	3,920
	Swinburne University of Technology	F	3,258
	University of Ballarat	S	261
	The University of Melbourne	F	3,332
	Victoria University	S	980
WA	Curtin University of Technology	F	3,859
	Edith Cowan University	S	540
	Murdoch University	S	400
	The University of Western Australia	F	2,446
	TOTAL	**17F, 17S**	**55,584**

Table 2: Participating universities by state/territory with corresponding and undergraduate engineering student enrolments (head count estimates).

1 Engineering programs (other than software/network engineering) were suspended in 2003, and are expected to be re-introduced in 2011. Expected numbers are reportedly around 150 students.

at school-level. In the vast majority of cases, this approach is consistent with the organisational unit represented in the Australian Council of Engineering Deans, ACED.

Within this report, the terms ‘large university’ and ‘small university’ are used as indicators of student enrolment numbers in engineering disciplines only. The terms do not intend to reflect any other aspect of the school, faculty or university; neither do they imply any form of ranking or qualification.

3.2 Individual participation

Due to the variation in the organisational structure and the breadth of engineering disciplines at each university, the total number of participants per category also varied with each institution. Generally, large universities are represented by more interviews in total, and also through a higher number of executive surveys completed at various levels (e.g. PVC, dean, head of school, director etc.). For smaller universities, most executive interviews were conducted at school-level (head of school/deputy, head of department etc.) and were usually limited to one or two meetings per visit. Academic and technical surveys were conducted according to the nomination of the university.

Over 80% of all meetings resulted in the formal completion of the questionnaire, while free-form comments were recorded in the remaining cases. A breakdown of meeting and survey numbers according to category is illustrated in Figure 1. All 34 universities are represented by at least one meeting or interview in each category.

3.2.1 Executive staff

The executive category produced the widest spread of participants with decision-making responsibility, as shown in Figure 2. It must be noted that the classification was performed according to the official, formal position name. Reclassified in the sense of ACED, where heads of school of smaller institutions constitute ‘deans’, meetings with 29 out of 34 ‘deans of engineering’ were conducted, with 24 surveys completed. These numbers lead to the conclusion that the survey has been able to capture the opinions of over 85% of the engineering leadership at Australian universities, along with other executive input.

While all quantitative survey responses by executives were analysed with equal weight in this report, regardless of position, comments and qualifications of answers were usually considered in the context of their overall responsibility.

3.2.2 Academic Staff

Similarly, the classification of academic participants also occurred according to their formal position, as depicted in Figure 3. Two-thirds of all survey responses in this category were obtained from experienced academics holding the position of senior lecturer or higher, which can be interpreted as being representative of many years of technical and pedagogic expertise.

3.2.3 Technical staff

Finally, the technical staff group is represented through participants at coordination/managerial level, typically with significant responsibility for staffing, material and/or budget at faculty/school level. Laboratory managers usually look after areas and major assets within a discipline and may also have staff responsibility. Technical officers are typically more likely to be directly involved with specific technical equipment and also in coursework. Figure 4 demonstrates that all positions are well represented in the survey. In particular, the participation of 15 coordinators and senior managers in the survey especially allows insight into resourcing and major issues.

It should be noted that the classification of a participant as ‘technical’ (within the scope of this survey) did not depend on any formal level of qualification and, in fact, ranged from certificate level to PhD and associate professor, depending on the primary function performed.

In conclusion, the above figures prove that the overall participation in the National Review has been exhaustive on an institutional level, and very comprehensive within each of the survey categories. For anonymity as well as for practical reasons, all answers within one category were amalgamated prior to analysis.

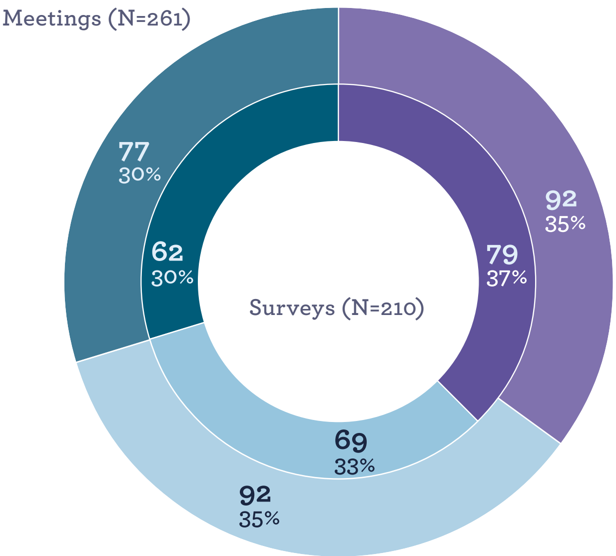


Figure 1: National Review participation in meetings and survey by category

- Executive
- Academic
- Technical

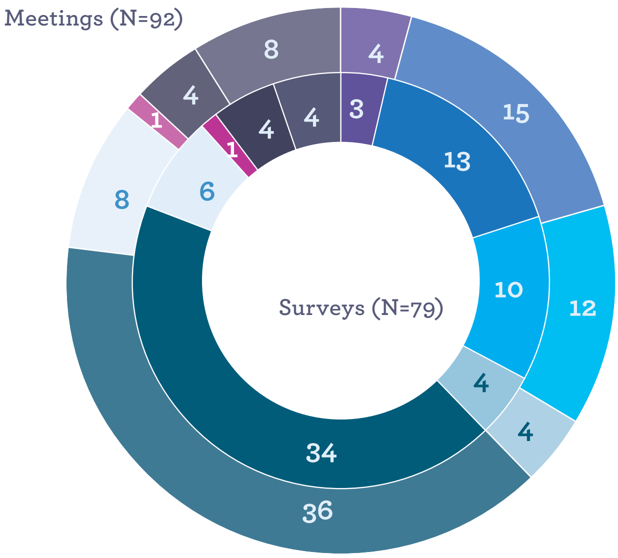


Figure 2: Executive staff participants in meetings and survey by position

- Pro-Vice Chancellor (incl. Deputy)
- Dean, Executive Dean
- Associate Dean (Teaching & Learning)
- Associate Dean (other than ADTL)
- Head of School
- Head of School (Deputy/Associate)
- Head of Department
- Director of Coursework/Disclipine
- Director or Manager (other)

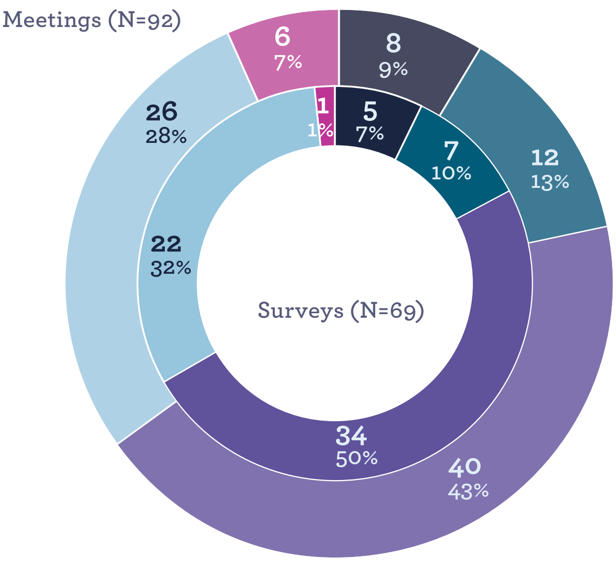


Figure 3: Academic staff participants in meetings and survey by position

- Professor
- Associate Professor
- Senior Lecturer
- Lecturer
- Other

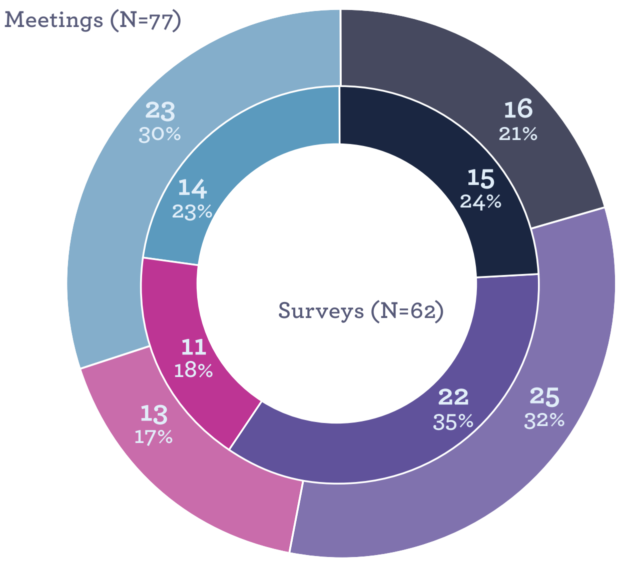


Figure 4: Technical staff participants in meetings and survey by position

- Lab Coordinator, Senior Technical Manager
- Lab Manager/Supervisor
- Senior Technical Officer
- Technical Officer

4 Analysis Procedure

The selected, practical survey implementation as interviews with hand-written records mandates certain steps in the analysis procedure. Firstly, the anonymity of the participants must be guaranteed so that no individual response can be linked to a person during transcription, analysis or publication, except by the survey administrator. Only the cover sheet of each questionnaire contains personally identifiable data, which are cross-referenced to a unique, numeric code. All response pages were labelled with this code and physically separated from the cover sheet before the transcription by other project staff commenced.

4.1 Transcription and classification

Despite the careful balance of quantitative and qualitative questions, the flexibility that the questionnaire provided (in favour of superior data quality) led to a highly laborious transcription process. The decision was therefore made to split the transcription into several phases:

Transcription of all data (quantitative, qualitative and comments) from paper into a spreadsheet

Extraction of quantitative data for statistical analysis in SPSS

Manual evaluation of qualitative data and comments

This procedure required the definition of separate variables for each response and comments made, and eventually roughly 1,300 variables (incl. flags) were identified for all three questionnaire types together. The total number of entries transcribed (quantitative and qualitative responses, flags and free-form comments) was approximately 88,000.

4.2 Quantitative data

Those variables that were statistically analysable (i.e. multiple choice responses, rankings, numerical answers) were extracted from the spreadsheet and prepared for SPSS. A corresponding template was created in SPSS, including variable descriptors, as a basis for statistical analysis.

Besides, several questions could not be classified prior to obtaining actual responses from the survey, such as subject names and laboratory equipment descriptions. Those responses were therefore manually evaluated first to determine the best possible classification system (e.g. by discipline, major etc.), then new class variables were defined and subsequently statistically analysed. The advantage of this approach is that far more discipline and subject-related data is quantitatively accessible than by qualitative (manual) analysis only, see below.

All raw and post-classified quantitative data was finally imported into SPSS and statistically analysed through cross-tabulation, descriptives and frequencies. The SPSS analysis was conducted by an experienced statistician, who also prepared the fundamental reports as the basis for the selected topics in Chapter 5.

4.3 Qualitative data

Qualitative data is considered any response that is 'unstructured' and can therefore not be directly statistically analysed without an intermediate, interpretive step, such as free-form answers (e.g. subject names), qualifications of multiple choice responses (e.g. separation of student numbers into on/off-campus), comments and free-form responses. The frequent use of highly specific, technical terms not commonly found in databases for qualitative (unstructured) data analysis lead to the conclusion that automatic analysis for this data type is not viable, hence most qualitative data was evaluated manually, with the exceptions given in Section 4.2.

Preliminary results of selected aspects of the survey, mostly of qualitative nature, were initially released mid-2010[4].

PART 2

Selected Results

5 Executive Perspective

The executive survey focuses on a number of selected topics with relevance to decision-making and resourcing. Depending on the type of question, the source of the primary data is either quantitative or qualitative. The presentation of statistics and free-form responses is followed by an interpretation and discussion.

5.1 Goals of practical laboratory sessions

This section investigates the goals that executives hope to achieve by including practical coursework experiments in the engineering programs offered by their university.

(EA.1) Why are practical laboratory experiments part of your engineering courses?

245 individual answers were received from 75 executive participants. The 10 most commonly given ones can be classified and paraphrased as:

Theoretical learning needs to be reinforced in the real world (concepts, validation of theory)

Practical sessions provide students with an alternative learning approach

Students need to experience and understand engineering equipment (learning-by-doing)

Engineering is a practical discipline which requires engineering students to be trained in the real world, with exposure to real issues

Engineers Australia requires practical sessions for course accreditation

Industry demand: work-ready graduates, credibility in the work place

Engineers are kinaesthetic learners

Better student engagement and participation, experiments make studying more exciting

Practical sessions are a tradition: every engineering course has them

Opportunity for discovery and experimentation

From this list, the following primary objectives of practical coursework experiments can be extracted:

(1) Reinforcement of theoretical concepts;
(2) Exposure to and experience with real-world equipment in preparation for professional practice;
(3) As a motivating factor in achieving better learning outcomes; and
(4) Compliance with 'tradition' and accreditation requirements.

While the first three objectives are clearly student-focussed, the fourth appears to be driven by external factors. An interesting statement was made by a senior executive in regard to an often quoted requirement by Engineers Australia: 'The accreditation process is outcome-focussed and does not explicitly prescribe the inclusion of practical laboratory sessions.' This is by no means a contradiction; the comment only suggests that certain alternatives to laboratory sessions may also lead to the desired learning outcomes and therefore to accreditation. The strong support for laboratories is also clearly manifested through the following responses (questions EA.3).

In addition, one participant commented with respect to the second statement that '...faulty equipment is very frustrating for students', and another said that '...the demonstration of concepts usually does not require calibration'.

The commonly identified goals and the largely undivided responses to the two questions above indicate that engineering executives are fully aware of

(EA.3) STATEMENT:	Strongly Agree	Mostly Agree	Neutral	Mostly Disagree	Strongly Disagree	N
a) Practical, experimental laboratory experiments are an integral and very important part of engineering education.	65 (88%)	9 (12%)	0 (0%)	0 (0%)	0 (0%)	74
c) Well maintained and calibrated equipment is essential for the pedagogic success of practical classes.	40 (54%)	27 (37%)	6 (8%)	1 (1%)	0 (0%)	74

Table 3: Executive support for coursework laboratories

the critical role that practical laboratory experiments play in engineering education, both in general and at their university.

5.2 Decision-making processes

The survey also looked at decision-making processes in order to implement these goals by supporting laboratory development and maintenance. In particular, we investigated the point of initiative for new developments and the level of authority required for funding approval, as seen from the *executive* perspective.

5.2.1 Design and development of new experiments

Firstly, it is important to evaluate who is believed to take initiative in designing and developing new experiments. (This was a multiple response question, hence the column for percent of cases equals more than 100%.)

Of the 70 respondents to this question, 68 (97.1%) indicated that academic staff usually provide the incentive for design and development of new practical coursework experiments and laboratories. Only in a few cases is the process complemented by input from

(EA.4) Who usually provides the incentive for design and development of new practical coursework experiments and laboratories?	RESPONSES		% OF CASES N = 70
	N	Percent	
Academic Staff	68	86.1%	97.1%
Laboratory managers, technical staff	11	13.9%	15.7%
TOTAL	79	100.0%	112.9%

Table 4: Executive opinion on laboratory development initiative

technical staff. This leads to the conclusion that, from an executive perspective, academics are seen as the main drivers in the development of experiments for coursework. In 3 cases (from 3 different universities), it was commented the school/faculty executive directly influences the development of experiments through policy measures, for example by mandating '...at least 3 practical sessions per engineering subject with no substitution by simulations permitted'.

Executives believe that the actual design and development of practical laboratory experiments and classes is often shared between academic staff

(EA.5) Who is typically responsible for the actual design and development of practical laboratory experiments and classes? [implementation]	RESPONSES		% OF CASES N = 70
	N	Percent	
Academic Staff	62	53.0%	88.6%
Laboratory managers, technical staff	55	47.0%	78.6%
TOTAL	117	100.0%	167.1%

Table 5: Executive opinion on laboratory development implementation

and laboratory managers/technical staff. Of the 70 respondents to this question, 62 (88.6%) indicated that academic staff members are typically responsible for this function, and 55 respondents (78.6%) indicated that laboratory managers and technical staff are typically responsible. (Cross-tabulation reveals that 47 respondents (67%) nominated both academic and technical staff.) Rarely, executives also commented that postgraduate students are involved in the implementation process.

5.2.2 Budget authority

Recalling that organisational structures vary significantly between universities, it was interesting to determine who allocates budgets or authorises the expenditure of funds for laboratories. (The question was phrased so that the organisational structure was appropriately reflected with respect to the interviewee's position.)

Interestingly, over 82% nominated the head of school to be the decision-maker. No significant difference could be found between larger and smaller universities, and the same statement applies to those (few) cases where the dean was nominated as being responsible for laboratory funding allocations. It was frequently commented that the responsibility depends on whether the head of school receives a one-line budget from the dean, or whether the budget is already

(EA.6) Who decides on the budget for coursework laboratories in your faculty/school?	RESPONSES		% OF CASES N = 70
	N	Percent	
Dean	13	17.6%	18.6%
Head of school/ department	61	82.4%	87.1%
TOTAL	74	100.0%	105.7%

Table 6: Executive opinion on laboratory budget authority

structured. Occasionally, it was indicated that the responsibility was shared in a committee or delegated to the faculty manager (rarely). In one case, laboratory funding was even reported as competitive between all schools and decided on PVC level.

The decision about how the budget is applied to coursework laboratories (i.e. what experiments are actually realised, or what equipment is being purchased) is also believed to lie mainly with the head of school, although obviously with noticeably more consultation with other parties, especially academic and technical staff. A frequently quoted

(EA.7) Who decides how the budget is applied?	RESPONSES N	Percent	% OF CASES N = 69
Dean	10	9.2%	14.5%
Head of school/ department	56	51.4%	81.2%
Academic Staff	24	22.0%	34.8%
Laboratory managers, technical staff	18	16.5%	26.1%
School manager	1	0.9%	1.4%
TOTAL	109	100.0%	158.0%

Table 7: Executive opinion on laboratory budget allocation

procedure for the involvement of individuals (other than the decision maker) is the invitation of proposals, mainly from academic staff, which are competitively assessed by a committee. The cases where the dean is immediately engaged in the application of the budget are strongly aligned with an involvement in the budget *allocation* (EA.7).

5.3 Funding and laboratory development

Having investigated the funding process, the survey endeavoured to collect data on actual dollar figures of expenditure for coursework laboratory support, excluding salaries:

> (EA.8) Would you be able to provide only a rough estimate for the current budget for coursework laboratory related expenses, excluding general computing facilities (i.e. purchase, maintenance, and upgrade of laboratory hardware and equipment, for teaching purposes only)?

Due to the complex and sensitive nature of the question, interviewees were given several options to respond with, or to opt out of this question altogether. Regularly, interviewees found it challenging to separate expenditure for teaching purposes from other activities, such as research. However, 44 respondents were able to provide a rough estimate, and these ranged from $10,000 to $4,000,000, with a mean of $373,978 but a much lower median of $200,000, indicating a distribution with outliers at the top end of the estimates. Six respondents expressed their budget estimate in terms of a percentage of the entire faculty/ school budget, and these percentages ranged from 1% to over 10% with a median of 5%.

All universities reporting expenditures over about $500,000 for the past reporting period were involved in major, one-off redevelopments of facilities or buildings, and it was often impossible to extract the actual coursework-related component. Many executives noted that the figure they provided was uncharacteristically higher than the usual budget due to 'momentary' funding (e.g. special projects, LEIF teaching grants, university-internal funding), and that the normal budget for laboratories would be significantly lower. In a number of cases, executives commented that laboratory-related expenses are usually not planned for at all and that allocations are made based on priorities. These comments often aligned with the expression of an overall lack of funding, not just for laboratories.

Interestingly, two senior executives from different universities (large and small) who had recently assumed their positions stated that the respective teaching laboratory facilities could be described as 'neglected', with virtually no investment for over a decade. Any budget allocated to laboratories would typically be used for urgent and essential repairs, but not for upgrades or new purchases.

Further comments were made in regard to either current or upcoming floor space charges at university level, which many executives saw as a major threat to engineering laboratories. While some admitted that the available space was not always efficiently used, there was general consensus that floor-space charges could potentially disadvantage engineering over other faculties or disciplines, if not fairly implemented by the university. Several interviewees commented that decision-makers at university-level may sometimes lack insight into the critical role of engineering laboratories, other than as a sole necessity for course accreditation. This opinion usually aligned with institutions where other disciplines attracted a higher awareness (and therefore higher investment) than engineering.

It must be clearly stated that the interpretations offered in this section are solely based on the comments made by executives and do not constitute observations or judgments by the survey administrator. Also, within the scope of this work, the analysis above aims to identify issues rather than to report on specific achievements.

5.4 Budget and floorspace trends

Along with staffing, the two other critical resources that have an immediate effect on engineering laboratories are budget and floorspace. The survey attempted to uncover any obvious trends by asking executives the following question:

(EA.9) In the last 3 years and the last 10 years, the budget (for equipment purchase, maintenance and upgrade) and the floorspace available to undergraduate coursework laboratories has:		Increased	Remained Unchanged	Decreased	Do not know/prefer not to say	N
Budget	last 3 years	28 39%	24 34%	13 18%	6 9%	71
	last 10 years	20 32%	15 24%	6 10%	22 35%	63
Floorspace	last 3 years	13 18%	35 49%	19 27%	4 6%	71
	last 10 years	15 23%	23 36%	13 20%	13 20%	64

Table 8: Executive opinion on laboratory budgets and floorspace. Budget trends can be considered inflation-adjusted

From these responses alone, one may conclude that both the budget and the floorspace situations are currently satisfactory, since both resources were either steady or have increased in the opinion of most executives. A closer look reveals that (usually small) budget increases have occurred more recently (3 years), and that floorspace was more likely to have decreased recently than over the last 10 years. It should also be noted that the number of executives able to comment on the decade-long period was somewhat smaller than for the shorter term.

This question attracted a considerable number of qualifying comments. In particular, executives reported increased funding for new building projects from federal and/or university level since 2008, which may be indirectly linked to the Government's response to the 'Global Financial Crisis'. As many as 15 of the surveyed 34 universities reported current or virtually complete building projects for engineering disciplines alone, often on a large scale. Alongside research, coursework laboratories are also expected to benefit from this development, including new or upgraded equipment. The latter factor is reflected in the budget trend, with equipment expenditure of several million dollars in one case. However, executives were quick to point out that these investments are rarely seen; "once in 30 years", as one participant said about his school.

Despite this, it must not be overlooked that laboratory budgets have recently decreased for more than 1 in 6 universities, and that 1 out of 4 respondents report a recent decrease in laboratory floorspace (for coursework purposes). This realisation must be connected with a more significant factor that is not reflected in Table 8: student enrolment trends. There is a report already available which has commented on rapidly increasing student numbers [5], and Table 2 extends those rises into the present time. Executives from major engineering universities report '...an increase of 100% in student numbers over 5 years', '...a 3-fold increase over 10 years, and 70% over the last 3 years', and that '...student numbers have doubled over the past 5 years, but none of our resources have kept up.'

Many participants commented that student numbers had virtually increased beyond capacity, while floorspace stayed the same, which has directly led to the reduction in laboratory sessions in some cases. With very few exceptions due to program and faculty restructures, engineering student numbers have increased at all universities. Consequently, the label 'floorspace unchanged' has actually been transformed into a per capita decrease of floorspace, especially over the past 3 years. With rising enrolments expected over the coming years by many universities, this will result in a further decrease of the real lab floorspace available 'per student'. While pedagogic and organisational remedies are currently under development in some cases, the seriousness of this outcome is further supported by the executive responses to question A.10 (next page).

Another factor, which will be revisited in Chapter 6, is the increased competition for space from laboratory-based research activities at a number of universities. Some cases have been reported where teaching laboratory facilities were converted into research space without compensation; however, whether this is possible depends on the priorities and policies of each individual university.

5.5 Overall resources

Flowing thematically from resourcing trends is the critical self-assessment of available laboratory budget, floorspace and technical staffing. Assuring strict confidentiality, executives were requested to give frank and unreserved answers which appropriately reflect the current situation, summarised in Table 9.

Almost half of all executives described the hardware and equipment budget as being at least somewhat underresourced, while 52% considered floorspace as under-resourced. Most critically, technical staffing levels were reported as under-resourced by 67% of executives.

A further analysis revealed that responses are not always consistent across larger universities and vary from one particular discipline to another. This indicated possible discrepancies in the internal allocation of resources. Besides, there is little correlation between the ratings in each category; as faculties or schools with 'fully sufficient' or 'adequate' funding and support staff numbers may still suffer from severe lack of space, which has usually been reported in metropolitan locations ('In some areas, there is sufficient money for new equipment, but no space for it.'). Conversely, a number of regional universities appear to be less space-restricted in relation to student numbers, but lack funding for equipment and sometimes also technical support staff.

Again, this question attracted a lot of qualifying comments. Most commonly, participants who had described resources as currently 'adequate' mentioned that rising student numbers would certainly lead to a classification as 'under-resourced' in the very near future. This particularly appears to affect final-year students, who have a higher demand on virtually all resources: on funding and floorspace for their final-year projects, and also on staff support, some of which is provided by technical staff.

It must also be mentioned that where funding was available, some universities have taken measures to remedy some of the shortfalls through innovative, but 'yet-to-be-proven' changes in the operational and pedagogic delivery of laboratories. As this topic is beyond the scope of this report, only some examples are provided here.

In one case, a dean commented self-critically that "floorspace is very scarce here, but it is not always efficiently used either". Subsequently, flexible laboratories were introduced to this large institution and forced major changes. A school executive at another large institution reported that "the running of [mechanical] labs has been rationalised" and that "no more big and expensive equipment" would be used in coursework. This is closely aligned with another faculty-wide, large-scale approach that saw most teaching laboratories converted "from maintenance-intensive to instruction-intensive" through very significant capital investment in engineering bench-top models and flexible learning spaces, resulting in a significant reduction of technical staff numbers. A head of school from a regional university commented that "academics and technical staff have been very creative in building good labs", despite shortages in equipment funding. Finally, several executives (especially from very large universities) voiced concern that student-to-demonstrator ratios had recently risen to unhealthy levels, and that the

(EA.10) How would you describe the following resources allocated to your coursework laboratory facilities, in relation to meeting your desired pedagogic objectives?	Fully Sufficient	Adequate	Somewhat under-resourced	Severely under-resourced	N
Hardware and equipment budget	5 7%	30 44%	27 39%	7 10%	69
Floorspace	4 6%	30 42%	30 42%	7 10%	71
Staffing	3 4%	20 28%	45 63%	3 4%	71

Table 9: Executive opinion on laboratory resourcing

overall quality of demonstrators had often severely declined due to lack of qualified staff – a topic further explored in Chapter 6.

With respect to technical laboratory support staff, respondents commented that it is increasingly difficult to find qualified and versatile technical staff who can contribute on both technical and pedagogic levels, and possibly also to research (e.g. professional staff in technical roles). Employees with such versatile skills were highly valued by executives, but it was also acknowledged that employing large numbers of full-time laboratory support staff was an expensive asset, hence postgraduate students were the usual choice as demonstrators (less so at smaller, regional universities). Consequently technical staff solely employed for maintenance and/or workshop tasks have been reduced across many, mostly larger universities

In summary, across all categories, between about half and two-thirds of executives believe that their laboratories are under-resourced, which is in stark contrast to the crucial role that they attributed to laboratories in questions A.1 and A.3. Rising student numbers aggravate the shortages, and reportedly some remedies still need to provide proof of their effectiveness.

A further question investigated whether faculties and schools take specific action to address any such issues, if applicable (Table 10).

In view of the circumstances described above, it seems surprising that only 38% of all interviewees replied with 'Yes'. However, it was frequently commented that executive committees were certainly striving for expedient cost saving measures everywhere, but that laboratories had not been 'explicitly singled out'. The most serious challenge posed the more efficient use of floorspace, which was often forced upon faculties

	Yes	No	N
(EA.13) Is it a declared goal of a faculty or school strategic plan to increase expenditure efficiency for running or maintaining practical laboratory classes?	27 38%	44 62%	71

Table 10: Executive opinion on laboratory expenditure efficiency

and schools by the university. One executive pointed out that 'better efficiency' should not be equalised with general 'cost cutting'.

5.6 Outsourcing and outlook

The final two general questions relate to a specific approach demonstrating how some of the issues could be addressed hypothetically. We also challenged executives to justify laboratory expenditure in relation to the desired outcome.

(EA.14) Have you ever considered, or would you consider, outsourcing some of your practical classes to a commercial, for-profit company?	Frequency	
We have done this in the past, or we are currently doing it	5	7%
We are currently considering it	5	7%
We have not considered it in the past, but we may in the near future	28	37%
We have never considered it and we do not plan to in the near future	36	49%
TOTAL	74	100.0%

Table 11: Executive opinion on laboratory outsourcing

Table 11 summarises the responses to the actual or hypothetical commercial outsourcing of practical classes. It was clarified to the interviewee that this question explicitly excludes cross-sector collaboration (e.g. the use of VET facilities) and the sharing of laboratories with other universities, only the 'outsourcing' of classes to commercial training companies, for example. Almost half of the respondents see laboratories (and their associated pedagogy) as a core coursework component that must absolutely be preserved within universities. Conversely, 44% believe that outsourcing could be considered (either currently or in the future), while 7% already have some experience with the outsourcing of laboratories.

Interestingly, of the 5 executives with past experience, 3 commented that outsourcing turned out more costly than before, and one commented that it was a poor experience overall. Besides, it was pointed out that this option may not even be available in most regional areas. The only area where respondents regularly reported a good experience was in the outsourcing of printed circuit board manufacturing to overseas companies.

Other comments included that outsourcing may be worth considering, but only with academic control over the delivery, only if the student experience is improved over what is currently available, and that it may actually be a sensible proposal, if it turns out to be 'more efficient' (without further specification). Of course there were also certain concerns with respect to the university's reputation, but collaboration with the VET sector was generally supported.

Finally, the respondents were asked to choose one statement that best reflects their personal opinion about resourcing teaching laboratories (Table 12).

More than three-quarters of respondents chose the third statement, reinforcing their belief that even under difficult circumstances, the importance of laboratories for engineering education must not be compromised. Still, for 15% of executives, the fulfilment of formal requirements (accreditation) was the main motivating factor. It is particularly interesting that this view was more pronounced at higher executive level, with 2 PVCs and 4 engineering deans (6 out of 11) choosing this option. There was no significant difference between large and small, metropolitan and regional universities with respect to the choice of any statement.

5.7 Summary

Part A of the executive survey has provided both quantitative and qualitative data to firmly establish a number of facts in regard to engineering coursework laboratories. Several challenges that engineering executives are confronted with have also been identified, with respect to the scope of this work. In particular, the survey has uncovered a significant discrepancy between long and short-term trends in laboratory resourcing and the subjective assessment of these resources, for the purpose of delivering practical classes. Aspects from Part B of the executive survey are included in Chapter 8 of this report.

6 Academic Perspective

The questionnaire employed to survey the responses from academic staff was designed for participants with teaching responsibilities in subjects with a practical component. The comprehensive question set mainly focussed on pedagogic aspects and took approximately 90 minutes to complete, including related discussions. A total of 69 questionnaires were completed, and within the scope of this report, a specific subset of significant responses has been selected to support important findings. Due to the breadth and individuality of all engineering-related subjects taught in Australian universities, the data presented below can only be exemplary, but obviously not completely representative.

6.1 Academic activities by discipline and major

The first section of the academic questionnaire aimed to establish a snapshot of the respondent's activities, such as disciplinary affiliation (Table 13) and the subjects/majors involved in (Table 14). Subjects were only included in the survey if they incorporated practical laboratory work, but excluding entirely computer-based sessions.

Participants were able to nominate pre-defined disciplines or to add their own. It can be inferred from the results that on average, academics are involved in close to three disciplines. The most commonly nominated discipline was electronics engineering (15.9%), followed by electrical (12.3%) and mechanical engineering (11.8%). There was a very strong correlation between the nominations of electrical and electronics engineering, which explains the high combined percentage of cases (80%).

Since the spread of nominated disciplines is not very

(EA.15) If you had to comment on the faculty/school expenditure for coursework laboratories, which single one of the following three statements would you most agree with?	Frequency	
Providing practical laboratory classes is an essential requirement for receiving formal course accreditation by Engineers Australia.	11	15%
The cost of running numerous practical laboratory classes puts a significant burden on the budget, and viable alternatives should be explored	5	7%
The expenditure for running and maintaining numerous practical laboratories, even if costly, is a necessary and worthwhile investment in our pedagogic objectives.	58	78%

Table 12: Executive opinion on laboratory resourcing motivations

manageable for comparison purposes, especially with a significant number of single cases, a different approach was sought for the next question. Academics listed the formal titles of their subjects (with practical components), which were subsequently manually classified into 42 areas of study and further grouped into 15 majors, plus one 'general subjects' category (Table 14).

Some subjects were associated with multiple discipline areas and majors, resulting in a total of 723 allocations. The classification proved to be a very laborious and complex process, but it now allows the direct tracing of subsequent survey responses to specific majors in order to identify patterns. Therefore, the analysis by major adds value to the investigation, compared to the interviewee's affiliation by discipline alone. In particular, it reveals that academics are not just involved in their area(s) of expertise, but also general subjects in almost 18% of cases (e.g. first-year physics). The fact that 213 subjects resulted in 723 allocations to majors (factor of 3.4) also indicates

(AA.1)	Which engineering discipline(s) are you associated with, for teaching purposes?	RESPONSES		% OF CASES
		N	Percent	N=69
	Aerospace	1	0.5%	1.4%
	Agricultural	2	1.0%	2.9%
	Automotive	2	1.0%	2.9%
	Aviation/Avionics	3	1.5%	4.3%
	Biomedical	1	0.5%	1.4%
	Biomolecular	2	1.0%	2.9%
	Chemical	11	5.6%	15.9%
	Civil / Construction	17	8.7%	24.6%
	Computer Systems	15	7.7%	21.7%
	Educational Technology	1	0.5%	1.4%
	Electrical	24	12.3%	34.8%
	Electronics	31	15.9%	44.9%
	Energy / Renewable Energy	3	1.5%	4.3%
	Environmental	3	1.5%	4.3%
	Food Process	1	0.5%	1.4%
	Geotechnical	1	0.5%	1.4%
	Industrial Computing	1	0.5%	1.4%
	Manufacturing	4	2.1%	5.8%
	Materials	4	2.1%	5.8%
	Mechanical	23	11.8%	33.3%
	Mechatronic	14	7.2%	20.3%
	Mining	4	2.1%	5.8%
	Naval / Maritime	1	0.5%	1.4%
	Physics	1	0.5%	1.4%
	Product Design	1	0.5%	1.4%
	Software	9	4.6%	13.0%
	Systems	1	0.5%	1.4%
	Telecommunications	14	7.2%	20.3%
	TOTAL	195	100.0%	283.0%

Table 13: Affiliation of participating academics with engineering disciplines

(AA.2)	Which engineering coursework subjects with a practical laboratory component are you currently, or have you recently been, involved in?	RESPONSES		% OF CASES
		N	Percent	N=213
Major	Electrical Engineering	134	18.5%	62.9%
	Mechanical Engineering	102	14.1%	47.9%
	Mechatronic Engineering	86	11.9%	40.4%
	Computer Systems Engineering	96	13.3%	45.1%
	Software Engineering	71	9.8%	33.3%
	Aerospace Engineering	23	3.2%	10.8%
	Telecommunications Engineering	56	7.7%	26.3%
	Industrial Engineering	1	0.1%	0.5%
	Biomedical Engineering	2	0.3%	0.9%
	Chemical Engineering	31	4.3%	14.6%
	Civil Engineering	61	8.4%	28.6%
	Environmental Engineering	15	2.1%	7.0%
	Mining Engineering	5	0.7%	2.3%
	Irrigation Engineering	1	0.1%	0.5%
	Food Engineering	1	0.1%	0.5%
	General Subjects (common among most majors)	38	5.3%	17.8%
	TOTAL	**723**	**100.0%**	**339.4%**

Table 14: Surveyed engineering subjects classified by major

that there is a significant amount of content overlap between most engineering disciplines, which is not a surprising result.

94.7% were undergraduate subjects, and 11.2% postgraduate subjects, where indicated. This obviously includes some overlap. The distribution of the surveyed undergraduate subjects across the typical year (or stage) of the course is given in Table 15. (The single subject offered in year 5 is part of a combined degree with a nominal duration of 4.5 years.) The vast majority of these subjects (91.7%) were offered only once per year.

The year in which a particular subject is typically taught varied considerably between the majors defined above. Cross-tabulation shows that virtually no major-specific subjects are taught during first year, whereas 14 of the 38 general subjects ran in first year only (37%).

Furthermore, the number of students passing through those subjects per year ranged from a minimum of 5 to a maximum of 600, with a mean of 84 and a median of 50. Again, there was a considerable variation between stages, with most large subjects taught in the earlier years. Naturally, the distribution highly depended on the university size as well.

6.2 Implementation and development of laboratory sessions

6.2.1 Frequency and duration

The survey obtained extensive statistics in relation to the frequency and the duration of scheduled laboratory sessions, along with information about the inclusion of project-based laboratory sessions. Projects are typically run outside allocated time slots, where students have access to facilities and equipment and can work on assignments in their own time. The specific privileges of this access (e.g. after-hours, unsupervised etc.) vary greatly and are highly discipline-dependent, as further elaborated in Chapter 7.

	Year 1	Year 2	Year 3	Year 4	Year 5	N
Number of subjects	27 13%	58 27%	78 37%	46 22%	1 1%	213

Table 15: Subjects by year of the engineering program

Of the 199 subjects for which responses were given, 53 (27%) included projects or were entirely project-based with respect to laboratory work. For scheduled sessions, the most commonly quoted duration was 180 minutes (43%), followed by 120 minutes (42%). There were some outliers at the top end of the scale with some full-day sessions in specific disciplines, or as residential schools for distance education students.

In each subject, the number of sessions per typical 12-week semester ranged from 1 to 30 (Figure 5), with 2-6 sessions per semester being the most popular (up to fortnightly). There is another response cluster around 10-12 sessions per semester, which means sessions are run roughly weekly. The outliers at the top can be attributed to specially introduced 1st year subjects, which are designed to acquaint students with basic laboratory skills on a frequent basis.

6.2.2 Staff involvement and development

Further questions evaluated the type of staff running laboratory sessions, as seen by academics. Summarising the results, the following statements can be supported:

- Around 72% of the subjects had at least one academic involved in running scheduled laboratory sessions.
- Around 66% of subjects had at least one postgraduate or senior undergraduate student involved in running scheduled laboratory sessions.
- Around 40% of subjects had at least one technical staff member involved in running scheduled laboratory sessions.
- Only 12% of subjects had other staff (e.g. part-time, industry-based) involved in running scheduled laboratory sessions.
- Postgraduate students were virtually always involved when multiple identical (repeat) sessions were offered, usually in larger subjects.

72% of respondents stated that they had been actively involved in the design and development of new laboratory equipment in their subjects over the past 3 years. This can range from minor changes of the laboratory instructions to the re-design of laboratory experiments on a semester-basis, with evidence of very considerable efforts in some cases. Conversely, this also means that 28% of laboratory sessions have supposedly not seen any changes over the past 3 years, and several academics indicated that some fundamental experiments have been conducted in the same manner with unchanged lesson material for well over a decade.

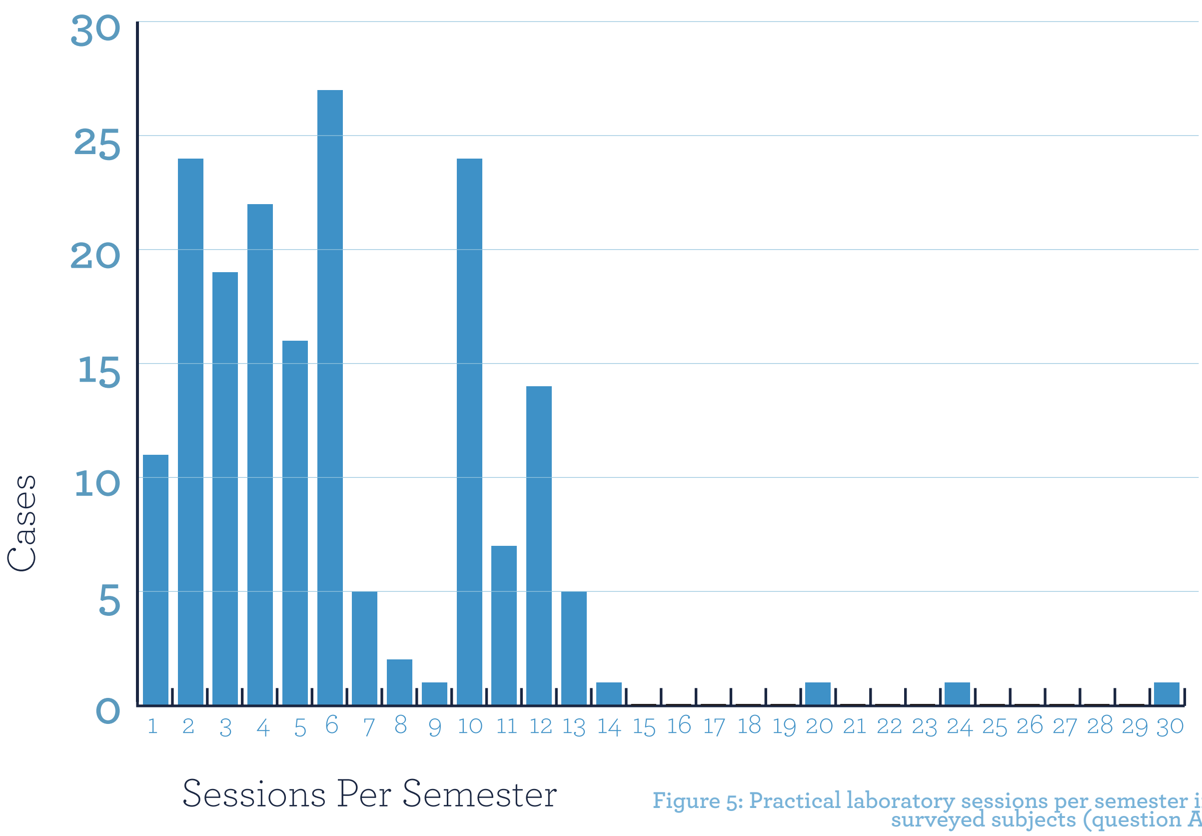


Figure 5: Practical laboratory sessions per semester in all surveyed subjects (question AB.2)

(AC.4a) Who usually provides the incentive for design and development of new practical coursework experiments and laboratories?	RESPONSES		% OF CASES N = 61
	N	Percent	
Academic Staff	58	76.3%	95.1%
Laboratory Managers	9	11.8%	14.8%
Technical Staff	5	6.6%	8.2%
Other	4	5.3%	6.6%
TOTAL	76	100.0%	124.6%

Table 16: Academic opinion on laboratory development initiative

More generally, academics were asked about their opinion on how changes to experiments or equipment are usually initiated. Table 16 clearly reflects that this initiative lies with the academic staff group (95.1% of cases), with some input from and collaboration mainly with laboratory managers. This is completely consistent with the response of executives to the same question.

When it came to the actual implementation, technical staff took considerably more responsibility (Table 17), with academics and technical officers equally represented. A high degree of collaboration is

(AC.4b) Who is usually responsible for the actual design and the development of practical laboratory experiments?	RESPONSES		% OF CASES N = 61
	N	Percent	
Academic Staff	47	37.9%	77.0%
Laboratory Managers	23	18.5%	37.7%
Technical Staff	47	37.9%	77.0%
Other	7	5.6%	11.5%
TOTAL	124	100.0%	203.3%

Table 17: Academic opinion on laboratory development implementation

indicated by the significant number of multiple responses – a fact that has also been acknowledged by executives. Comments indicate that typically, the academic is expected to contribute to the development process through pedagogic guidance and high-level design, while the technical staff member looks after the physical design, building and commissioning the equipment. This role changes with discipline, with academics in the electronics and telecommunication disciplines being far more likely to build laboratory equipment themselves, without technical staff involvement.

It was of great interest to learn who is directly involved in conducting practical sessions (i.e. interacting with the students), and who should ideally be involved. The academic perspective of the current situation is presented in Table 18.

The results reflect the academic opinion that most laboratory supervision is carried out by academics (69% of cases) and postgraduate students (68%), and to a lesser degree by technical officers (31%). The amount of responses, compared to cases, also suggest that multiple staff types are collaboratively supporting

(AD.5a) Who does currently mostly conduct or supervise laboratory sessions?	RESPONSES		% OF CASES N = 65
	N	Percent	
Academic Staff	45	34.4%	69.2%
Laboratory Managers	4	3.1%	6.2%
Other Technical Staff	20	15.3%	30.8%
Postgraduate Students	43	33.6%	67.7%
Senior Undergraduate Students	10	7.6%	15.4%
Externally Trained Demonstrators	2	1.5%	3.1%
Other	6	4.6%	9.2%
TOTAL	131	100.0%	201.5%

Table 18: Academic opinion on practical session supervision

practical sessions. From the data alone, one may conclude that work is mostly shared between academic staff and postgraduate students, however this is much more complicated. This may be true in many cases, but additional questions not included in this report and numerous comments also suggest that especially in larger subjects, postgraduate students often replace academic staff in laboratory sessions, sometimes assisted by technical staff. Smaller universities usually rely much less on postgraduate students to run laboratory sessions, and academics (and sometimes technical staff) are directly involved with the students.

Finally, academics were asked about their ideal circumstances for laboratory staff support, as shown in Table 19.

Most entries have seen little or no change of percentages, compared to the reported status quo. There is a slight increase in academic involvement, motivated by the realisation that direct student feedback from laboratory practice is important. It is

(AD.5b) Who should conduct or supervise laboratory sessions?	RESPONSES		% OF CASES N = 65
	N	Percent	
Academic Staff	50	34.2%	76.9%
Laboratory Managers	5	3.4%	7.7%
Other Technical Staff	18	12.3%	27.7%
Postgraduate Students	46	31.5%	70.8%
Senior Undergraduate Students	12	8.2%	18.5%
Externally Trained Demonstrators	9	6.2%	13.8%
Other	6	4.1%	9.2%
TOTAL	146	100.0%	224.6%

Table 19: Academic opinion on ideal practical session supervision

interesting that there is considerable demand for externally trained demonstrators (other than under/postgraduate students), typically former industry staff with extensive practical knowledge.

Although not reflected in this compilation, the strong involvement of postgraduate students as laboratory demonstrators has attracted an unexpectedly large amount of comments, which warrants the dedication of a separate section to this topic (Chapter 10).

6.3 Funding and resources

Similar to the executive survey, academics were asked for their understanding of how decisions about coursework laboratory funding are made. Summarised in Table 20, interviewees most frequently responded that the budget allocated to undergraduate coursework laboratory activities was determined by the heads of school/department (76% of cases), followed by deans (26%). All other cases are virtually negligible. When it came to deciding how the budget should be applied (Table 21), academics saw their own

(AC.2a) Who decides on the budget for coursework laboratories in your faculty/school?	RESPONSES		% OF CASES N = 62
	N	Percent	
Dean	16	23.5%	25.8%
Head of School / Department	47	69.1%	75.8%
Laboratory managers, technical staff	1	1.5%	1.6%
Other	4	5.9%	6.5%
TOTAL	68	100.0%	109.7%

Table 20: Academic opinion on laboratory budget authority

(AC.2b) Who decides how the budget is applied?	RESPONSES		% OF CASES N = 62
	N	Percent	
Dean	3	3.1%	4.8%
Head of School / Department	37	38.1%	59.7%
Academic staff	38	39.2%	61.3%
Laboratory managers, technical staff	13	13.4%	21.0%
Other	6	6.2%	9.7%
TOTAL	97	100.0%	158.0%

Table 21: Academic opinion on laboratory budget allocation

staff group almost equally represented by the executive group (around 60% each), followed by technical staff (21%). These questions attracted few qualifying comments by academics.

It is interesting to compare these results to the executive case presented in Section 5.2.2. Both staff groups are in close agreement that mostly the head of school and occasionally the dean allocates the budget, but the second question sees some significant differences. Academics consider themselves far more involved in the decision-making process regarding laboratory expenditure than executives believe they actually are (39% vs. 22% of responses).

Another question adapted from the executive survey asked academics to assess their university's resourcing for coursework laboratories, Table 22. On average, academics are relatively content with laboratory resourcing, but deficiencies are reported especially in the areas of technical staff support and equipment funding (each 37% under-resourced). Floorspace problems and lack of demonstrators are usually reported from metropolitan universities, which is less of an issue for regional universities with typically lower student numbers. Funding is a more serious problem for smaller universities and regional universities. Technical staff support was regarded insufficient mostly by very creative academics who were directly involved in the development of unique experiments in preference to over pre-built, standardised teaching models.

(AC.3) Overall, how would you describe the following resources allocated to your coursework laboratory facilities, in relation to meeting your desired pedagogic objectives?	Fully Sufficient	Adequate	Somewhat under-resourced	Severely under-resourced	N
Technical staff support	26 42%	13 21%	16 26%	7 11%	62
Support with tutors and demonstrators	19 33%	22 38%	14 24%	3 5%	58
Purchase of new equipment and hardware	11 18%	28 45%	13 21%	10 16%	62
Floorspace	17 28%	27 44%	12 20%	5 8%	61

Table 22: Academic opinion on laboratory resourcing

Other noteworthy comments in relation to resourcing were (paraphrased):

"We have great difficulties attracting good technical staff due to the severe competition from local industry." (regional university)

"The quality of technical staff support is highly variable, and would be sufficient, if properly utilised." (large metropolitan university)

"Lack of flexible, practical teaching spaces." (several)

"No funds for equipment available, purchases have to be cross-subsidised from consulting income by academics." (large metropolitan university)

"Cheap, simple experiments do not require a lot of resources." (large metropolitan university)

"We have difficulties finding suitable tutors." (several)

"Equipment is sufficient only due to donations from industry partners; otherwise it would be severely under-resourced." (small metropolitan university)

"The space is sufficient, but the quality of space is poor and not suitable." (large metropolitan university)

"Our new building will alleviate some of the current floor-space pressure." (three large metropolitan universities)

"The available space is adequate for teaching only, but not for students' self-study in labs." (metropolitan fringe university)

"Repair and maintenance of equipment relies entirely on academics." (regional university)

"We had to rent space off-campus to accommodate rising student numbers." (small metropolitan fringe university)

"Rising student numbers will soon lead to severe floor-space shortages" (several large and small metropolitan universities)

6.4 Group work

In order to establish the significance of group work in practical laboratory work, for each subject we first endeavoured to ascertain what share of experiments was performed in groups (Table 23). This was followed by surveying the typical number of students per experiment/apparatus during scheduled, practical

(AB.4a) To what extent are students required to perform the experiments individually or in groups during supervised coursework sessions?	RESPONSES N	RESPONSES Percent	% OF CASES N = 195
All experiments are performed in groups	148	74.4%	75.9%
Most experiments are done in groups, very few individually	14	7.0%	7.2%
About half of the experiments are done individually, half in groups	11	5.5%	5.6%
Most experiments are done individually, very few in groups	1	0.5%	0.5%
All experiments are performed individually	16	8.0%	8.2%
All experiments are demonstrated to the students	9	4.5%	4.6%
TOTAL	199	100.0%	102.1%

Table 23: Academic opinion on laboratory group work

coursework sessions, excluding projects (Table 23). In over three quarters of all cases (76%), group work was the sole form of delivery, without further specification of the composition of the group. Only a small number of subjects involved all but individual work (8%). Demonstrations of equipment by a tutor or technical officer with no direct student involvement were only used in disciplines with a high safety risk, for example in mining, civil and chemical engineering, however this is relatively rare.

Group sizes ranged from 2 to 40 students with a median of 4 and a mode of 2. 80% of the subjects had group sizes ranging from 2 to 5 students. Academics frequently commented that they were aiming for smaller group sizes than indicated, especially in those subjects with more than 4 students per group. Equipment availability and timetabling restrictions almost always resulted in larger groups.

Academics were subsequently asked a number of questions in relation to their coordination of laboratory sessions and group learning (Table 24, Likert scale).

Statement AD.7i attracted a very strong response. Over 70% of academics recognised that students often do not work effectively in groups of 3 or more. Comments included the observation that in groups of 3, 2 students work together while the third one is somewhat disengaged. In groups of 4, 2 groups of pairs would often form. Only 10% of respondents opposed this view, citing that while working in large groups may not be efficient, students have to learn how to deal with this work environment in preparation for their professional practice. Multiple academics commented that it was the tutor's job to engage all students. Cultural and language problems were cited as possible causes for the often difficult engagement of international students. Only in a very small number of cases, a lab session had been specifically designed to engage multiple students.

Statement AD.7j saw half of the respondents reject the opinion that individual work would be ideal, indicating that group work is a significant factor in the desired learning outcomes from a laboratory session, especially for first-year students. It was further suggested that if students are expected to work on assignments individually, they still share equipment and discuss results with peers. 33% of academics still support the idea of individual experiments, citing technical learning outcomes as priorities.

To investigate this topic further, statement AD.7p was phrased in a challenging way by changing the usual focus on technology in a laboratory environment to group interaction, with an implied priority of group work over other learning outcomes. Responses were often passionate, and the agreement of only 6% of academics confirms that this prioritisation is not supported. Technical learning outcomes are clearly considered most important, but group interaction is still highly desired. Frequent comments were that group interaction is practiced in other subjects that are not lab-based, and that laboratory time is too 'valuable' to give social interaction priority over technical learning.

Statement AD.7n gives an insight into some of the organisational challenges that academics face in delivering an appropriate amount of laboratory hours to their students. Over 60% of academics agreed or strongly agreed that their laboratory sessions are affected by throughput problems. They regularly have to compromise between group sizes, session numbers per semester and often also student-to-staff ratios in order to cope. Severe throughput issues were almost invariably associated with mainstream subjects at large universities and rarely reported at universities with small student numbers. Further mentioned factors aggravating this problem were the inflexibility of a particular university's timetabling software and the increased demand by students for additional or

(AD.7) Statement:	Strongly Agree	Mostly Agree	Neutral	Mostly Disagree	Strongly Disagree	N
i) With three or more students in a group, their individual engagement with the experiment is often imbalanced.	17 26%	29 45%	12 19%	5 8%	1 2%	64
j) If sufficient stations were available for all students, individual lab work would be more desirable than group work.	11 18%	9 15%	11 18%	25 40%	6 10%	62
p) The development of social skills in a group work lab-session should be regarded as more important than the development of professional, conceptual and design skills.	0	4 6%	22 35%	32 51%	5 8%	63
n) I often have to trade available laboratory time slots off against the number of sessions per semester and the number of students per session (throughput).	13 21%	25 40%	9 15%	15 24%	0	62

Table 24: Academic opinion on practical session coordination

after-hour access and the coordination with other courses (e.g. for double-degrees).

Finally, and all factors considered, we asked academics about the ideal group size (Table 25):

(AD.8): According to your experience, what would be the ideal number of students per station (group size) for successfully conducting a laboratory experiment and for meeting the pedagogic objectives?

Number of students per group	1	2	3	4	5	N
	5 8%	24 39%	19 31%	12 19%	2 3%	62 100%

Table 25: Academic opinion on the current number of students per laboratory group

In the context of previous questions, it is not surprising that having students work in pairs was the most desirable arrangement (39%), followed by 3 students per group. Responses declined rapidly after 4 students per group, and no academic nominated more than 5 students per group. The optimum group size in a teaching laboratory environment is a very active topic of discussion, and this report will make a contribution by presenting this feedback.

6.5 Desired laboratory and session conditions

There are several other factors that can affect the quality of a subject's practical component. While the majority of academics (59%) reported that the number of laboratory sessions had not changed over the past 5 years, 55% said that they would ideally like to include more sessions in their subjects – no respondents thought they should have fewer laboratory sessions than is currently offered.

The respondents thought the optimal number of laboratory sessions per subject, per semester ranged between 2 and 13 with the most popular being 6 (29%) and 12 sessions (18%) which roughly equates to fortnightly and weekly, respectively. Responses between 6 and 12 sessions per semester accounted for 65% of all responses. This result is well aligned with the outcome of the status quo analysis in section 6.2.1, which also saw a preference for either weekly or fortnightly practical sessions, although only 1 or 2 sessions per semester were more common.

The optimal length of each session ranged from 30 minutes to 180 minutes with the most popular session length being 120 minutes (44%) and 180 minutes (35%). No academic suggested session durations longer than 180 minutes.

(AD.9) Statement:	Not at all	Barely	To some extent	Significantly	Critically	N
a) Equipment in good condition and calibrated (if applicable)	0	2 3%	5 9%	25 42%	27 46%	59
b) Experienced and knowledgeable staff/demonstrators	0	0	0	25 42%	34 58%	59
c) Clarity of the experimental instructions (documented, oral, visual)	0	0	6 10%	32 54%	21 36%	59
d) Knowledge and motivation by other students	0	0	25 42%	29 49%	5 9%	59
e) Number of students in a group	0	0	17 29%	35 59%	7 12%	59
f) Disturbance and distraction by other students	0	6 10%	17 29%	23 40%	12 21%	58
g) Compulsory preparation for the session (e.g. pre-lab quiz)	1 2%	7 12%	21 36%	23 39%	7 12%	59
h) Location and layout of the facility	1 2%	13 22%	24 41%	16 27%	5 9%	59
i) Typical session duration	0	6 10%	22 37%	26 44%	5 9%	59
j) Time of the day (morning/afternoon/evening)	6 10%	10 17%	25 43%	15 26%	2 3%	58

Table 26: Academic opinion on factors affecting the quality of a session

Academics were also asked for their opinion on what influences the quality of a laboratory sessions for students, and to rate them on a scale from 'not at all' to 'critical'. The outcomes of this judgement are presented in Table 26:

(AD.9) In your opinion, how do the following factors affect the 'quality' of a laboratory session for the students?

The three factors considered most important in affecting the quality of laboratory sessions were 'experienced and knowledgeable staff/demonstrators' where 100% of respondents thought this affected the quality of a laboratory session either significantly or critically; 'clarity of the experimental instructions' (90%); and 'equipment in good condition and calibrated' (88%). Collaboration with group members is another relatively important factor, as it can influence productivity both positively and negatively (knowledge and motivation vs. disturbance). Opinion is most spread across all categories when it comes to compulsory preparation, but over 50% do recognise that it is an important factor.

Interestingly, a number of these factors are only marginally affected by resourcing issues. Rather, they can be seen as direct or indirect responsibilities of the academic, such as creating good experimental instructions, selecting experienced demonstrators, encouraging student preparation and motivation and maintaining a good working environment during the session. They only other key factor that is often beyond the academic's direct influence is the condition of the equipment.

6.6 Pedagogy and assessment

This section deals with a number of questions related to laboratory pedagogy, such as desired learning outcomes, assessment and the connection between those two.

Firstly, academics were asked to formulate learning outcomes that they would expect from their students after completing the practical sessions in their subject(s). 173 individual answers were received from 63 participants. The 10 most common responses are paraphrased below, and the reader is encouraged to compare this list with Section 5.1 for commonalities and differences with the executive perspective.

- Appreciation of the physical dimensions of real machinery and equipment
- Applying instrumentation and taking measurements
- Understanding the limitations of models and actual equipment
- Dealing with and interpreting unexpected outcomes and considering the possibility of failure
- Confidence with industrial equipment and laboratory jargon
- Experiment planning and methodology
- Note taking and laboratory report writing
- Critical thinking and problem-solving skills
- Teamwork
- Safety

Participants were asked to rank each of the four subject components (lectures, tutorial, homework assignments and practical laboratory work) in order of importance, with equal scores possible. The results are tabulated in Table 27.

Overall, practical laboratory sessions were ranked as the most important coursework component with a median rank of 1, awarded by 62% of respondents. 43% ranked lectures most important, followed by tutorials and homework assignments. This is an insightful result and warrants a separate discussion in Chapter 10.

(AD.2)	Rank of 1	Rank of 2	Rank of 3	Rank of 4	Median Rank	N
Practical laboratory session	39 62%	16 25%	6 10%	2 3%	1.00	63
Lectures	27 43%	21 33%	9 14%	6 10%	2.00	63
Tutorials	19 30%	28 44%	11 18%	5 8%	2.00	63
Homework	11 18%	19 30%	19 30%	14 22%	3.00	63
TOTAL OF CASES	96 153%	84 132%	45 72%	27 43%		252 400%

Table 27: Academic opinion on the importance of subject components

(AD.6) How do you assess a student's performance and learning outcomes during and after the laboratory session?	During the Session			After the Session		
	Responses		Percent of cases	Responses		Percent of cases
	N	%	N =53	N	%	N =62
By observation	31	37.8%	58.5%	n/a	n/a	n/a
By written quiz	11	13.4%	20.8%	6	6.5%	9.7%
By oral exam/demonstration	26	31.7%	49.1%	6	6.5%	9.7%
By written report	8	9.8%	15.1%	55	59.1%	88.7%
By inclusion in the final exam	n/a	n/a	n/a	22	23.7%	35.5%
Other	6	7.3%	11.3%	4	4.3%	6.5%
TOTAL	**82**	**100.0%**	**154.7%**	**87**	**100.0%**	**152.6%**

Table 28: Academic opinion on laboratory assessment

Assessment is one of the most commonly employed tools available to academics to drive students' learning outcomes. According to academics, laboratory components account for between 10% and 30% of the entire subject grade, with 20-25% being the most typical range. Common methods of student evaluation are presented in Table 28 and have been separated into assessment during and after the practical session. The most popular ways during the sessions were by direct observation of the student's activities in the laboratory (59%) followed by oral examinations or demonstrations (49%). However, it must be noted that observation was mostly qualitative and rarely involved awarding marks, whereas most demonstrations during a lab session were performed as a group and as a hurdle requirement only. More direct forms of assessment, like quizzes and reports, featured much lower in the list.

The preferred method of post-laboratory assessment is a laboratory report, with almost 9 out of 10 academics requiring this written submission, followed by the inclusion of laboratory-learned concepts in the subject's final exam (36%). The percent of cases column indicates that a large percentage of academics rely on the written report as the only post-session assessment. In combination with the in-session results (dominance of observation and demonstration), it may even be argued that the written report is essentially the only quantifiable assessment task for laboratory work in many cases.

Interesting comments included the following:

- good experience with bound, hand-written laboratory notebooks and reflective journals (frequently mentioned)
- dissatisfaction with the quality of teaching and report marking by postgraduate students (several cases)
- significant plagiarism in written reports, which renders them useless as an assessment tool (several cases)

Lastly, the responses to further, selected statements (Likert scale rating) regarding pedagogy in laboratories are summarised here:

- 95% of respondents strongly agreed with the statement that practical experimental laboratory sessions are an integral and very important part of engineering education.
- Only 13% of respondents agreed (none strongly) that the pedagogic objectives of many practical laboratory sessions could be equally well met by using computer-based simulation tools, while almost 70% disagreed mostly or strongly.
- 51% of respondents agreed or strongly agreed that students are often under time pressure to complete a learning exercise within the allotted laboratory session time, with a further 24% being neutral on this point.
- 96% of respondents agreed mostly or strongly that students require supervision and assistance by academics and/or demonstrators to successfully complete their experiments, in addition to written instructions.

- 57% agreed (mostly/strongly) that the actual learning process often takes place after the laboratory session when the students analyse and compile their results. Only 27% disagreed with this statement.
- 66% believe that pre-lab tests (e.g. quizzes) are a useful measure of encouraging student preparation for a laboratory session, but according to Table 28, only 21% actually practice this.
- Only 37% oppose the view that pre-lab tests should be a compulsory component of laboratory assessment.

6.7 ABET objectives

The previous section saw the identification of specific learning outcomes by academics, as well as an analysis of how assessment is conducted in relation to laboratory practice. Linking the two, academics were asked whether they can clearly assess a student's learning outcomes against the stated pedagogic objectives of the practical session, and if yes, how this was done.

54 academics responded to this question, and 85% expressed an assurance that they could meet this expectation. Conversely, about 1 in 7 academics stated that it was not possible to do so. When the former group was asked for their methodology in linking assessment and learning outcomes, by far the most common means was the report, followed by observation in class and the demonstration of a functional 'product' or procedure by the students. However, several respondents commented that many learning outcomes were too difficult to assess in a report and were therefore not formally assessed. Again, plagiarism issues in report writing and the 're-use' of other groups' data was raised as a factor compromising fair assessment. As always, there were notable cases where different forms of assessment were employed to test learning outcomes, usually requiring more contact time and resources than the average.

Many academics expressed difficulties in formulating meaningful learning outcomes for their sessions in the first place, making it difficult to verify the achievement of such objectives – or, "If you don't know where you want to go, you won't know which road to take and you won't know if you have arrived" [6]. Some interviewees also commented that objectives were rarely ever clearly defined, only 'implied' through the tradition that laboratory practice has always been part of engineering education.

These results hints that clear, easily applicable guidelines for learning outcomes from practical sessions would be very helpful for a large number of academics. To aid this, the survey endeavoured to expose Australian academics to an approach that has seen considerable success overseas [7].

Background: Similar to Engineers Australia, the 'Accreditation Board for Engineering and Technology' (ABET) is responsible for the accreditation of engineering programs in the United States. Following a major review, the year 2002 saw professional attributes and objectives defined not only for overall engineering programs, but specifically for practical laboratory sessions. It seems surprising that the so-called '13 ABET Objectives' were formulated less than 10 years ago [6].

We decided to include the original ABET objectives into the National Survey questionnaire and asked academics how important they would consider each objective as a practical learning outcome (Table 29).

"By completing the laboratory sessions in my subjects, a student will be able to..."

OBJECTIVE	Critical	Important	Somewhat Important	Less Important	Insignificant	N
1 ...apply appropriate sensors, instrumentation and/or software tools to make measurements of physical quantities.	15 26%	30 52%	5 9%	8 14%	0	58
2 ...identify the strengths and limitations of theoretical models as predictors of real world behaviours. 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.	25 42%	32 54%	0	2 3%	0	59
3 ...devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterise an engineering material, component or system.	15 25%	32 54%	9 15%	3 5%	0	59
4 ...demonstrate the ability to collect, analyse and interpret data, and to form and support conclusions. Make order of magnitude judgements and use measurement unit systems and conversions.	28 48%	27 46%	4 7%	0	0	59
5 ...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.	19 32%	14 24%	14 24%	11 19%	1 2%	59
6 ...identify unsuccessful outcomes due to faulty equipment, parts, code, construction, process or design, and then re-engineer effective solutions.	17 29%	24 41%	14 24%	2 3%	1 2%	58
7 ...demonstrate appropriate levels of independent thought, creativity and capability in real-world problem solving.	21 36%	30 51%	4 7%	3 5%	1 2%	59
8 ...demonstrate competence in selection, modification and operation of appropriate engineering tools and resources.	10 17%	31 53%	15 25%	2 3%	1 2%	59
9 ...identify health, safety and environmental issues related to technological processes and activities, and deal with them responsibly.	16 27%	27 46%	12 20%	3 5%	1 2%	59
10 ...communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.	22 38%	24 41%	7 12%	5 9%	0	58
11 ...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.	20 35%	31 53%	4 7%	3 5%	0	58
12 ...behave with highest ethical standards, including reporting information objectively and interacting with integrity.	28 48%	23 40%	5 9%	2 3%	0	58
13 ...use the human senses to gather information and to make sound engineering judgements in formulating conclusions about real-world problems.	22 38%	24 41%	9 16%	2 3%	1 2%	58

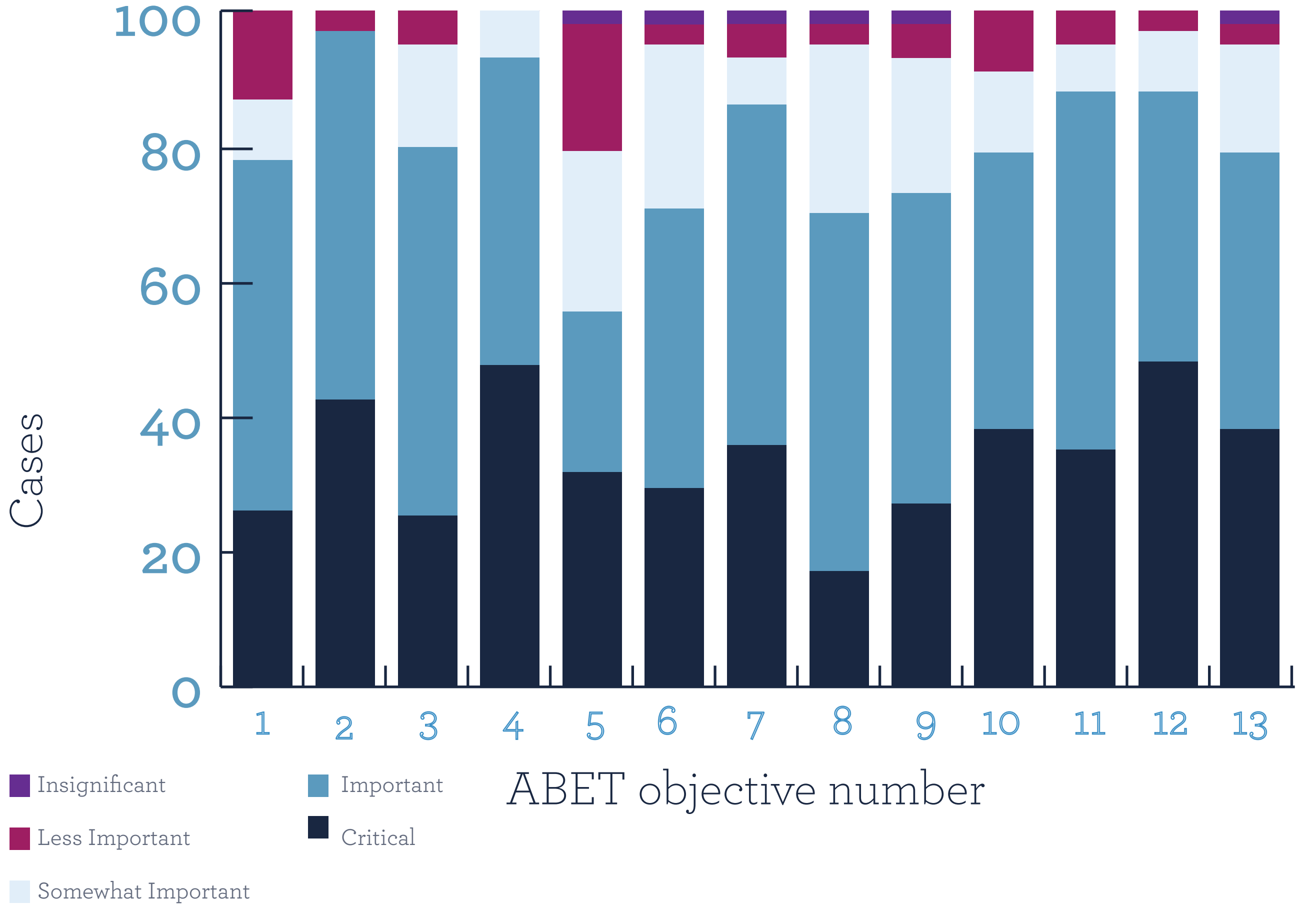
Table 29: Academic opinion on the 13 ABET objectives

Figure 6 illustrates that each and every objective was rated either 'critical' or 'important' by the majority of academics, with most exceeding 70%. Conversely, very few respondents (<10%) rated any objective 'less important' or 'insignificant' for their subject, with two exceptions: instrumentation (objective 1) and design (objective 5). Interestingly, there was a single cause for slightly less support for these objectives: all 11 academics in the disciplines of chemical and process engineering who participated in the survey commented that students are typically discouraged from assembling, modifying or instrumenting the pre-assembled laboratory equipment, so these could not be desirable learning outcomes. Other (rare) disagreements were usually very specific to a particular experiment.

Comments included that many of these objectives depend on the stage of the student, and that all of these outcomes are actually traits of competent engineers.

In summary, with the exception of a small number of discipline-specific limitations, virtually all ABET objectives have seen overwhelming support by academics. It is also interesting to note that only 1 out of the 59 respondents had heard of the existence of these objectives before. After revealing the source, interviewees were frequently interested in adopting the ABET objectives for the practical components of their subjects.

Figure 6: ABET objective importance as assessed by academic staff



7 Technical Staff Perspective

The responses by technical staff varied greatly according to the role of the interviewee, as explained in Section 2.2. Therefore, only sections of the questionnaire were completed that corresponded to the insight of the participant. As before, all references to laboratories exclude computer-only facilities (so-called computer labs).

(TA.1)	Which engineering discipline(s) are your laboratory facilities associated with, for coursework activities? [Multiple responses allowed]	RESPONSES		% OF CASES
		N	Percent	N=62
	Aerospace	1	0.4%	1.6%
	Automotive	6	2.2%	9.7%
	Aviation/Avionics	8	2.9%	12.9%
	Avionics	1	0.4%	1.6%
	Biomedical	7	0.7%	11.3%
	Chemical	9	3.3%	14.5%
	Civil/ Construction	27	9.9%	43.5%
	Computer Systems	17	6.2%	27.4%
	Control	2	0.7%	3.2%
	Electrical	23	8.4%	37.1%
	Electronics	28	10.3%	45.2%
	Energy / Renewable Energy	3	1.1%	4.8%
	Environmental	13	4.8%	21.0%
	Geotechnical	1	0.4%	1.6%
	Hydrodynamics	2	0.7%	3.2%
	Manufacturing	12	4.4%	19.4%
	Materials	3	1.1%	4.8%
	Mechanical	33	12.1%	53.2%
	Mechatronic	25	9.2%	40.3%
	Medical	1	0.4%	1.6%
	Metrology	1	0.4%	1.6%
	Microelectronics	2	0.7%	3.2%
	Mining	10	3.7%	16.1%
	Naval / Maritime	2	0.7%	3.2%
	Physics	6	2.2%	9.7%
	Product Design	2	0.7%	3.2%
	Robotics	1	0.4%	1.6%
	Software	10	3.7%	16.1%
	Surveying	1	0.4%	1.6%
	Systems	1	0.4%	1.6%
	Telecommunications	15	5.5%	24.2%
	TOTAL	**273**	**100.0%**	**440.3%**

Table 30: Laboratory facilities classified by discipline

Table 30 lists the association of the surveyed laboratory facilities with engineering disciplines, as nominated by the technical staff member. The large total in 'percent of cases' indicates that respondents either look after more than one facility, or that one facility is used for different disciplines. Both cases were frequently encountered.

The first part of the technical staff questionnaire asked for an exemplary listing of experimental equipment available for coursework activities. 232 entries were listed, and 229 of these were classified by 42 different areas of study as well as by 16 different majors, as clarified above. Experimental equipment could be associated with more than 1 area of study and more than 1 major. While the data collected is too specific to be presented in greater detail, it serves the purpose of a non-representative register of equipment availability, especially for rare and expensive equipment that could potentially be shared between institutions.

Equipment attributed to mechanical engineering was most frequently listed, followed by electrical and civil engineering, essentially covering all three major engineering areas. Besides, the relatively small difference between the response percentage total and the case percentage total indicates that only some of the equipment is useful or available to other disciplines.

7.1 Laboratory utilisation

Laboratory utilisation levels by undergraduate coursework depend on a variety of factors, some of which are looked at in greater detail below. Similar to the academic case in section 6.2.1, technical staff were questioned about the typical lengths of laboratory sessions, and the results are given in Table 32.

Technical staff members indicated that the most frequent average session durations are 180 and 120 minutes, which compares well to the academic case. Minimum times ranged from 30 to 180 minutes and maximum times ranged from 75 to 600 minutes.

Table 33 illustrates whether laboratory facilities were typically used with activities other than scheduled coursework sessions, for example project work, final-year projects or research.

44 respondents indicated that their facility was shared with activities other than scheduled coursework laboratory experiments, with only 8 respondents indicating their facility was not shared at all and only available for scheduled coursework sessions. Over 80% of the 44 respondents indicated that their facility was shared with undergraduate project work, however in 59% of all cases, research also took place in the same facilities. This was usually the case where large

(TA.2,3)	Laboratory equipment classification	RESPONSES N	RESPONSES Percent	% OF CASES N=229
Major	Electrical Engineering	67	21.1%	29.3%
	Mechanical Engineering	98	30.8%	42.8%
	Mechatronic Engineering	10	3.1%	4.4%
	Computer Systems Engineering	5	1.6%	2.2%
	Software Engineering	2	0.6%	0.9%
	Aerospace Engineering	3	0.9%	1.3%
	Telecommunications Engineering	15	4.7%	6.6%
	Industrial Engineering	8	2.5%	3.5%
	Biomedical Engineering	6	1.9%	2.6%
	Chemical Engineering	21	6.6%	9.2%
	Civil Engineering	44	13.8%	19.2%
	Environmental Engineering	11	3.5%	4.8%
	Mining Engineering	6	1.9%	2.6%
	Irrigation Engineering	5	1.6%	2.2%
	General Subjects (common among most majors)	17	5.3%	7.4%
	TOTAL	318	100.0%	138.9%

Table 31: Laboratory equipment classification

(TB.3) How much time would each student spend in the facility during a scheduled coursework laboratory session?		Frequency	Percent
Minutes	45	1	2.3%
(average)	60	4	9.1%
	90	1	2.3%
	120	21	47.7%
	180	14	31.8%
	240	1	2.3%
	270	1	2.3%
	300	1	2.3%
TOTAL		44	100.0%

Table 32: Technical staff opinion on practical session duration

(TB.4) Is the facility shared with activities other than scheduled coursework laboratory experiments?	RESPONSES N	RESPONSES Percent	% OF CASES N = 44
The facility is shared with project work (as part of a specific subject)	27	22.3%	61.4%
The facility is shared with undergraduate project work other than coursework	36	29.8%	81.8%
The facility is shared with postgraduate work other than coursework	15	12.4%	34.1%
The facility is shared with external consulting	17	14.0%	38.6%
The facility is shared with research	26	21.5%	59.1%
TOTAL	**121**	**100.0%**	**275.0%**

Table 33: Technical staff opinion on shared facilities

(TB.5) To what percentage do you consider your laboratory facility utilised by coursework sessions during an average semester week?	Frequency	Percent
Less than 10%	5	10.0%
10 – 24%	16	32.0%
25 – 49%	11	22.0%
50 – 74%	11	22.0%
75% or more	7	14.0%
TOTAL	50	100.0%

Table 34: Technical staff opinion on laboratory utilisation

and expensive equipment was shared, for example universal testing machines, dynamometers or network analysers.

Table 34 reflects the technical staff member's overall rating of laboratory usage for coursework during an average semester week. The results indicate that 64% of all facilities surveyed are utilised by coursework for less than 50% of the time, and that only 14% have a very high regular use. Interestingly, there is a significant correlation between high usage and project work: laboratories that allow project student access when no coursework session takes place have much better utilisation levels. This however depends on a lot of factors, such as health & safety regulations and supervision policies, and is highly discipline-dependent. Low overall utilisation levels can usually be found in facilities that are inflexible in their setup (e.g. due to large equipment) and which are unsuitable for research.

Comments by laboratory coordinators and technical managers show that many of these 'inefficient' spaces are earmarked for redevelopment into flexible laboratory spaces, provided funding is available.

7.2 Student access and supervision

Flexible student access to laboratory facilities can have a major impact on the pedagogy and the learning outcomes. Interviewees reported observations that scheduled sessions may restrict exposure to equipment, but can provide a more structured learning environment with assistance, if required. Project work and after-hour access can facilitate problem-based learning approaches, but require certain security measures to be implemented. The topic of student access to facilities is further investigated in this section, and the responses are summarised in Table 35. (Note: multiple responses were possible in this question, hence percentages sum up to more than 100%.)

For junior undergraduate students, access is generally only possible during scheduled, supervised lab classes (55.1% of respondents) or during supervised supplementary sessions (28.6%). Unsupervised access is much more common for senior undergraduate students (53% of respondents indicating largely unsupervised access during weekdays) and for postgraduate coursework students (61% of respondents indicating largely unsupervised access during weekdays).

(TB.7) Student access to the facilities may depend on the time of the day or the 'experience' of the student. Please attribute the following access restrictions to the type of coursework student:	Junior Undergraduate Students N=49		Senior Undergraduate Students N=49		Postgraduate Coursework Students N=23	
	Responses	% of cases	Responses	% of cases	Responses	% of cases
Access is only possible during scheduled, supervised lab classes	27	55.1%	11	22.4%	3	13.0%
In addition to scheduled lab classes, access is also possible at supervised supplementary sessions	14	28.6%	13	26.5%	4	17.4%
Largely unsupervised access is possible weekdays during usual work hours, provided no other session is running	4	8.2%	20	40.8%	8	34.8%
Largely unsupervised access is possible weekdays from early till after hours, provided no other session is running	3	6.1%	6	12.2%	6	26.1%
Students have full, unsupervised after hours and weekend access, provided no other session is running	2	4.1%	4	8.2%	5	21.7%
Students are treated individually for lab access according to their prior experience/qualification	1	2.0%	1	2.0%	0	0%
TOTAL	51	104.1%	55	112.2%	26	113.0%

Table 35: Technical staff opinion on student access to laboratory facilities

It must be noted that access policies vary significantly between universities, and especially with transport options available to students. Universities located in inner metropolitan areas reported a significantly higher percentage of 'after hours' access to laboratories than outer metropolitan and regional universities, where flexible access was mostly restricted to daytime only (apart from computer laboratories). In many cases where unsupervised access was not provided, health and safety issues were quoted. But even this issue does not seem to be treated uniformly across all surveyed universities, ranging from a 100% supervision policy to marginal supervision of experienced project students working in manufacturing workshops. Occasionally, logistic reasons prevent students from gaining access to low-risk laboratories, for example the issuing of keys. A number of cases were observed were student learning spaces were specifically designed to allow 24/7 access without supervision.

(TC.12a) Who usually provides the incentive for design and development of new practical coursework experiments and laboratories?	RESPONSES		% OF CASES N = 49
	N	Percent	
Academic Staff	42	51.9%	85.7%
Laboratory Managers	23	28.4%	46.9%
Technical Officers	16	19.8%	32.7%
TOTAL	81	100.0%	165.3%

Table 36: Technical staff opinion on laboratory development initiative

7.3 Technical staff involvement

In order to complete the view of all three target audiences, technical staff members were asked to give their opinion about the initiative in developing new laboratory experiments (similar to the executive and academic cases). The responses are shown in Table 36.

A considerable number of technical staff members (86%) acknowledged that the initiative for experiments is with academic staff, however there are many who co-nominated technical staff (managers and officers) for driving development. This is an interesting observation, since both academics and executive staff saw little initiative from technical staff in answering the same question.

Table 37 extends this perspective into the actual implementation (design and realisation) of experiments. Technical officers had the most responsibility here, nominated in 86% of all cases, followed by laboratory managers (with a high degree of collaboration between them). With 36%, academics appeared to be only marginally involved in the practical phase, according to technical staff. This result differs from the views of academic and executive staff above, who both saw almost equal roles of technical

(TC.12b) Who is usually responsible for the actual design and the development of practical laboratory experiments?	RESPONSES N	RESPONSES Percent	% OF CASES N = 50
Academic Staff	18	18.9%	36.0%
Laboratory Managers	34	35.8%	68.0%
Technical Officers	43	45.3%	86.0%
TOTAL	95	100.0%	190.0%

Table 37: Technical staff opinion on laboratory development implementation

and academic staff in the development of experiments. Technical staff believed that in reality, academics were far less involved in the implementation process.

Another question that allows a direct comparison with the academic staff group is the direct involvement in laboratory sessions and the interaction with students (Table 38). According to the survey, postgraduate students play a major role in the delivery of practical sessions, far more than any other individual group. Academics were reportedly involved in less than half of the cases, while technical managers and officers combined play another major role. That the delivery of laboratory sessions was considered a team effort is indicated through the high total percentage of cases.

This distribution is significantly different from the academic assessment of the status quo, who reported to be much more involved themselves, and the role of postgraduate students was less pronounced. At the same time, the participation of technical staff not just in preparing for the session by setting up equipment, but personally supporting the sessions was less than half what technical staff themselves estimate. Consequently, there seems to be a strong misunderstanding of the actual contributions that especially academics, postgraduate students and technical staff make to successfully delivering practical sessions.

When asked for their ideal view of staff involvement (Table 39), numbers shifted away from under and postgraduate students as demonstrators (81% compared to 112% status quo) and drastically towards academics (81% compared to 49% status quo). Technical staff numbers stayed virtually constant. This trend was also observed in the academic survey, but to a lesser extent. An interesting commonality is that both academic and technical staff saw value in external demonstrators with industry experience, whose numbers they liked to see increased.

(TD.5a) Who does currently mostly conduct or supervise laboratory sessions?	RESPONSES N	RESPONSES Percent	% OF CASES N = 43
Academic Staff	21	19.3%	48.8%
Laboratory Managers	12	11.0%	27.9%
Other Technical Staff	24	22.0%	55.8%
Postgraduate Students	35	32.1%	81.4%
Senior Undergraduate Students	13	11.9%	30.2%
Externally Trained Demonstrators	4	3.7%	9.3%
TOTAL	109	100.0%	253.5%

Table 38: Technical staff opinion on current staff involvement in practical sessions

(TD.5b) Who should conduct or supervise laboratory sessions?	RESPONSES N	RESPONSES Percent	% OF CASES N = 42
Academic Staff	34	30.1%	81.0%
Laboratory Managers	9	8%	21.4%
Other Technical Staff	28	24.8%	66.7%
Postgraduate Students	28	24.8%	66.7%
Senior Undergraduate Students	6	5.3%	14.3%
Externally Trained Demonstrators	8	7.1%	19.0%
TOTAL	113	100.0%	269.0%

Table 39: Technical staff opinion on desirable staff involvement in practical sessions

Comments included that academics are often too overworked to attend laboratory sessions, and that university expectations and promotion policies based mostly on research compromise the motivation of academics in direct involvement. Also, the quality of a practical session degrades rapidly with the lack of knowledge of the demonstrator. The topic of postgraduate student involvement again attracted a considerable number of comments, which are further analysed in Chapter 10.

7.4 Laboratory maintenance and development

Technical staff were asked about 3-year maintenance and equipment funding trends (Table 40). 39% of respondents said that their funding situation had actually increased, however this attracted a large number of comments, indicating that funding had to be regarded as 'transient' and a 'one-off' for many years, and that it would revert back to normal (little) in most laboratories. Many stagnant budgets were

(TC.6) In the last 3 years, the overall budget (for equipment maintenance and development) available to undergraduate coursework laboratory experiments in your facility has:	Increased	Remained Unchanged	Decreased	Don't Know/ Prefer Not To Say	N
	20 39.2%	19 37.3%	7 13.7%	5 9.8%	51 100%

Table 40: Technical staff opinion on laboratory budget trends

reportedly on very low levels. One experienced manager said that the availability of any capital investment funding for his laboratories in 2009 was the first in 20 years. In one case, the EA accreditation process had triggered expenditure by the university. A common pattern at a number of, but not all, smaller universities was the absence of annual laboratory budgets for regular coursework equipment maintenance and upgrades, which were reported to be funded on demand (quoted as "crisis management").

When asked to rank the most common reasons for the need of equipment maintenance or replacement, answers attracted a considerable variation (Figure 7). Overall, it is clear that normal wear and tear comes out as the leading cause (53% of first rank). The role of technical upgrades and obsolescence is less clear, featuring in all ranks to varying degrees. The change of academic objectives mostly ranked third in the list, while student mistreatment does not appear to be a major concern for technical staff, often ranking 4th or 5th. Other causes were nominated on 2 occasions only.

7.5 Resources

Apart from funding for maintenance and developments, technical staff also expressed their opinion in relation to other resources and funding. First, trends in floorspace were evaluated (Table 41).

The most common response in both cases was that floorspace had remained unchanged, but it was more likely to have decreased than increased over both the last 3 years and the last 10 years. Where new engineering buildings were under construction, interviewees expected a slight improvement, but were concerned that increasing student enrolments will neutralize this effect, as already established in Chapter 6. The same concern was voiced by

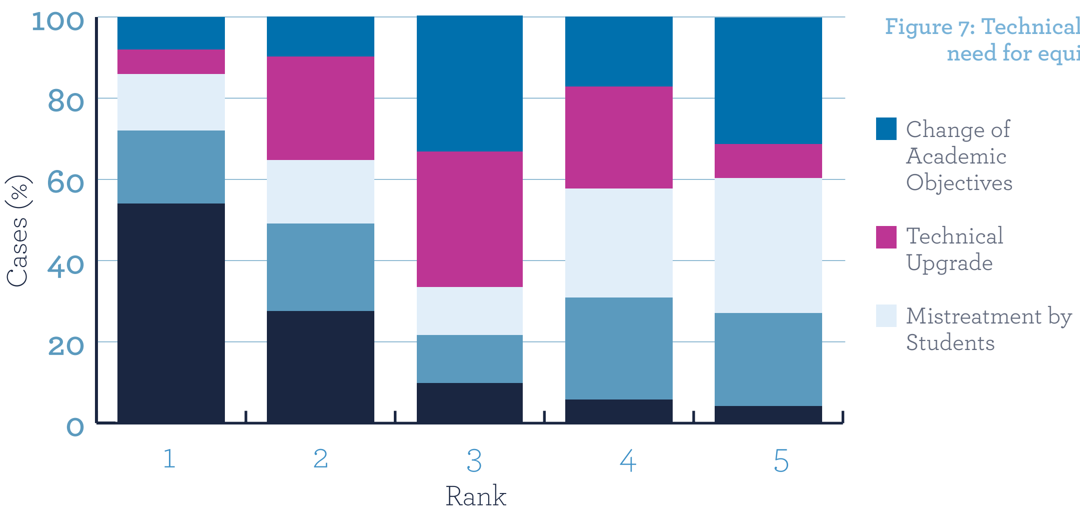


Figure 7: Technical staff opinion on the need for equipment maintenance and replacement

(TC.3) In the last 3 years and the last 10 years, the floorspace available to undergraduate coursework laboratories has:	Increased	Remained Unchanged	Decreased	N
last 3 years	9 17%	30 58%	13 25%	52
last 10 years	9 19%	24 50%	15 31%	48

Table 41: Technical staff opinion on laboratory floorspace trends

(TC.7) How would you describe the resources available to your facilities for coursework support?	Fully Sufficient	Adequate	Somewhat Under-resourced	Severely Under-resourced	N
Staffing (excluding involvement in coursework sessions)	12 23%	17 33%	16 31%	7 14%	52
Funds for equipment maintenance	12 24%	24 47%	11 22%	4 8%	51
Funds for equipment development/upgrade	11 22%	17 33%	16 31%	7 14%	51

Table 42: Technical staff opinion on resourcing

staff with unchanged or decreased floorspace resources. A technical coordinator from a large, metropolitan university commented that research is very demanding for both laboratory space and staff expertise, and it directly competes with coursework for those resources.

Analogous to the executive and the academic staff groups, technical staff gave their opinion on general resourcing, as summarised in Table 42.

Interestingly, opinions follow a fairly symmetrical distribution in all three cases around the adequate rating. Respondents were most satisfied with maintenance resources, as funds for consumables and repairs could often be secured in the short term. However, answers tended to cluster in the sense that several staff gave ratings of somewhat or severely under-resourced in all three categories, which indicated that this was an institutional issue. Interesting comments were that especially a lot of specialized equipment (purchased on grants) is wasted and totally under-utilised, and that manufacturing of equipment for laboratory support had been completely outsourced. One laboratory coordinator pointed out that the funding situation is aggravated through the university's annual budget cycle, which does not account for sudden failure of expensive equipment. The topic of floorspace was also interwoven with this question, and again, rising student numbers with stagnant floorspace was a major concern for timetabling and also health & safety.

7.6 Pedagogy

Technical staff involved in practical sessions were also asked to comment on a number of pedagogic topics, to complement the academic perspective. Their agreement and disagreement with selected statements is summarised in Table 43.

The importance of laboratory work in engineering education attracted a virtually unanimous response, with all but one respondent strongly agreeing (98%). Another noteworthy outcome is that over two-thirds of interviewees see students making mistakes as an important part of learning, despite the potential impact on the maintenance budget and hours spent on repairs. Although non-destructive mistakes are generally preferred, some managers and coordinators pointed out that as long as the mistakes are not careless or malicious, even accidents that lead to damage are tolerable, especially in the earlier years and with basic electronic components. Readers are encouraged to compare these outcomes to the academic perspective in Table 24, and also to the summarised outcomes at the end of Section 6.6.

Technical staff were asked the identical question to academic staff with respect to factors that affect the quality of a practical session for students (Table 44).

The overall similarity of the technical staff with the academic answers is striking, with little difference in most of the aspects. Again, the quality of equipment, staff/demonstrators and instructions were identified as the key elements for a high-quality session, closely followed by the student group size. However, technical staff had an even stronger desire for compulsory preparation by students.

7.7 Laboratory instrumentation

The existence of computer interfaces on laboratory apparatus was one of the few equipment-specific questions that could be statistically evaluated with reasonable effort. There was considerable variation in how this was implemented, ranging from retrofitting an almost 100 year-old universal testing machine to the latest industrial, fully automated equipment. 80 responses were received, but this figure does not allow a conclusion to be drawn regarding what ratio of equipment is computer-instrumented across all laboratories. The responses are shown in Table 45.

(TD.3) Statement:	Strongly Agree	Mostly Agree	Neutral	Mostly Disagree	Strongly Disagree	N
a) Experimental laboratory sessions are an integral and very important part of engineering education	39 98%	1 3%	0	0	0	40
b) Most students seem eager to apply their theoretical knowledge in laboratory sessions and to actively engage with the lab equipment	11 28%	24 62%	2 5%	2 5%	0	39
c) In addition to written instructions, most students require supervision and assistance by academics and/or demonstrators to successfully complete their experiments	15 38%	23 58%	2 5%	0	0	40
d) Towards the end of their degree, most students are relatively familiar with laboratory practices and procedures in order to achieve their experimental objectives, even without assistance	6 15%	23 58%	10 25%	1 3%	0	40
e) If sufficient stations were available for all students, individual lab work would be more desirable than group work	9 22%	4 10%	14 34%	12 29%	2 5%	41
f) It is generally desirable that students make mistakes when interacting with the lab equipment	8 20%	19 48%	7 18%	4 10%	2 5%	40
g) Students are often under pressure to complete the lab session on time	7 18%	15 38%	6 15%	12 30%	0	40
h) Accidental faults in the students' experimental setup often delay the timely completion of the lab session significantly	4 10%	19 48%	6 15%	10 25%	1 3%	40
i) The actual learning process often takes place after the laboratory session when the students analyse and compile their results	4 10%	21 54%	10 26%	3 8%	1 3%	39
j) The development of social skills in a group work lab-session should be regarded as more important than the development of professional, conceptual and design skills	0	8 20%	14 35%	18 45%	0	40
k) Most laboratory experiments tend to model somewhat outdated practice, while they should model contemporary practice	1 3%	13 33%	13 33%	11 28%	2 5%	40
l) With three or more students in a group, their individual engagement with the experiment is often imbalanced	12 29%	17 42%	8 20%	4 10%	0	41

Table 43: Technical staff opinion on pedagogic aspects

(TD.4) Statement:	Not At All	Barely	To Some Extent	Significantly	Critically	N
a) Equipment in good condition and calibrated (if applicable)	0	0	4 10%	16 41%	19 49%	39
b) Experienced and knowledgeable staff/demonstrators	0	0	0	19 49%	20 51%	39
c) Clarity of the experimental instructions (documented, oral, visual)	0	0	0	26 67%	13 33%	39
d) Knowledge and motivation by other students	1 3%	3 8%	19 49%	16 41%	0	39
e) Number of students in a group	0	0	8 21%	23 59%	8 21%	39
f) Disturbance and distraction by other students	1 3%	0	14 38%	18 49%	4 11%	37
g) Compulsory preparation for the session (e.g. pre-lab quiz)	0	3 8%	13 36%	17 47%	3 8%	36
h) Location and layout of the facility	0	4 10%	14 36%	18 46%	3 8%	39
i) Typical session duration	0	2 5%	15 40%	18 47%	3 8%	38
j) Time of the day (morning/afternoon/evening)	2 5%	10 26%	17 44%	7 18%	3 8%	39

Table 44: Technical staff opinion on factors affecting the quality of a laboratory session

(TD.2) Which experiments are equipped with a dedicated computer, and for what purpose? For example, does a computer control equipment, perform data acquisition or is used by students for data analysis and display?	RESPONSES		% OF CASES
	N	Percent	N = 80
Exclusive use	9	5.2%	11.3%
Equipment control	45	25.9%	56.3%
Data acquisition	68	39.1%	85.0%
Data analysis and/or display (separated)	37	21.3%	46.3%
Programming or peripheral devices	14	8.0%	17.5%
Other	1	0.6%	1.3%
TOTAL	**174**	**100.0%**	**217.7%**

Table 45: Purpose of computer use in engineering laboratories (other than computer-only facilities)

The category 'exclusive use' means a computer was not directly interfaced with the equipment or used with the experiment itself, but still required for the session, e.g. for simulations or web research as part of the practical session. In 85% of the responses, a computer was used for data acquisition and in 56% for equipment control. A further 46% used separate computers (i.e. non-interfaced) so that students could conduct data analysis and/or display for measurements that were obtained by means other than data acquisition, e.g. manual readings. The programming of peripheral devices was most common in the electrical, telecommunications, computer systems, software and mechatronic engineering disciplines (e.g. PLC, FPGA, embedded systems). The relevance of this topic is further discussed in Chapter 11.

PART 3

Remote Laboratories

8 Remote Laboratories: Familiarity and Potential

So far, none of the topics and questions related directly to remotely accessible laboratories. With an intentionally large degree of commonality between the three questionnaire types, the last part in each was dedicated to this subject in order to objectively gauge awareness, perception and the potential role of 'remote labs' in the Australian engineering education landscape.

8.1 Awareness and exposure

The first (and as it turned out crucial) question asked all participants about their general awareness of the remote labs concept (Table 46).

While the majority in each category seemed to have heard of remote labs in general, the awareness was the highest amongst executives and the lowest amongst technical staff. Following a positive response, all interviewees were then asked to verbally state their understanding of a remote lab.

There was significant misinterpretation of the term 'remotely accessible laboratories' amongst all groups, and also within each group (positions/ responsibilities). While about two thirds correctly understood that remote laboratories provide access to real, physical equipment over the internet by means of sensors, actuators and suitable software, some participants considered remote labs the same as virtual experiments and simulations available over the internet. This perception was a considerable concern for the validity of subsequent answers, therefore the survey administrator decided to briefly and objectively state the understanding of remote labs in the context of the National Survey, which was occasionally accompanied by a number of photos of exemplary setups. This also applied to participants who had not heard of remote labs before. Haptics in medical procedures were frequently quoted as examples outside the educational context.

Executive and academic participants who had answered 'yes' were subsequently asked where they had heard about remote labs (classified free-form answers, Table 47).

Both groups nominated literature and internet as their primary sources of information, followed by word-of-mouth by colleagues (for deans: ACED) and through conferences. AaeE and ALTC events were specifically mentioned by 4 executives and 4 academics.

All participants indicated their level of familiarity and involvement according to certain criteria (Table 48, multiple responses permitted). It is obvious that the number of nominations drops with the level of familiarity, and more than half of academics and technical staff consider themselves not even somewhat familiar with the concept. Only executives said they have a somewhat better insight, with more

(EB.1, AE.1, TE.1) Have you heard of remotely accessible laboratories before?	Executive staff N=71	Academic staff N=53	Technical staff N=43
Yes	60 86%	37 70%	28 65%
No	11 41%	16 30%	15 35%

Table 46: Awareness of the remote labs concept

(EB.2, AE.2) How or where have you heard about remote labs?	Executive Staff			Academic staff		
	Responses		Percent of cases N=46	Responses		Percent of cases N=31
	N	%		N	%	
On the internet or in the literature	46	69.7%	100.0%	31	77.5%	100.0%
Conferences, seminars	4	6.1%	8.7%	0	0%	0%
Colleagues	12	18.2%	26.1%	5	12.5%	16.1%
AaeE	2	3.0%	4.3%	4	10.0%	12.9%
ALTC	2	3.0%	4.3%	0	0%	0%
TOTAL	66	100.0%	143.5%	40	100.0%	129.0%

Table 47: Sources of information about remote labs for executive and academic staff

than one third indicating that they are quite familiar. Many executives (41%) and academics stated that they had actually used a remote labs experiment before, however there was likely still a factor of misunderstanding in these answers. Gauging the level of familiarity was an important exercise, as it has an impact on the reliability of subsequent responses. In general, technical staff were less familiar with remote laboratories than academics (e.g. 52% of the responding academics had used a remote laboratory on a few occasions c.f. 28% of laboratory managers). However it is clear that a smaller subgroup of technical staff has had considerable experience with developing remote laboratories (the last three categories).

As indicated in Table 48, a number of staff already had exposure to remote labs, or had even contributed to an experiment. In Australia, these included projects at UTS, UQ, UniSA, UWA, Curtin, USQ and Deakin (in order of frequency of nominations). International examples were given from MIT, Imperial College, the University of Texas, Oldenburg University and the University of British Columbia.

8.2 Public image and the potential role of remote labs

Since remote labs are still a relatively new concept at most universities, executive participants were asked to respond to a number of statements regarding how they would envisage their potential role, especially in relation to the traditionally established hands-on facilities (Table 49). It is very clear that executives recognise the advantages of remote labs both professionally for students and in perceptions of the public. There is considerable disagreement that either simulations or remote labs should (or can) replace hands-on labs in general, but as much as 80% of executives agree that remote labs should complement hands-on labs where possible. There was widespread consensus that hands-on labs will remain the core focus of practical engineering education for the foreseeable future.

However, statements c) and d) attracted some very interesting comments, from universities with and without current remote labs involvement alike:

- Remote and hands-on labs should coexist, valued in their own right
- The effectiveness of remote labs still needs to be proven
- Remote labs could be used to complement, replace and supplement hands-on labs due to their special properties and advantages
- Cumbersome and dangerous experiments should be replaced by remote labs, not just supplemented (several cases)
- Remote labs are ideal for smaller, regional universities with dispersed students, other alternatives are too expensive

(TE.2) Statement	Executive Staff			Academic Staff			Technical Staff		
	Responses		% of cases	Responses		% of cases	Responses		% of cases
	N	%	N=46	N	%	N=25	N	%	N=18
I am somewhat familiar with the technical concepts of remote laboratories	23	23.2%	52.3%	10	16.7%	40.0%	7	14.3	38.9%
I am somewhat familiar with the educational concepts of remote laboratories	26	26.3%	59.1%	12	20.0%	48.0%	5	10.2%	27.8%
I consider myself quite familiar with the technical concepts	16	16.2%	36.1%	10	16.7%	40.0%	7	14.3%	38.9%
I consider myself quite familiar with the educational concepts	16	16.2%	36.4%	7	11.7%	28.0%	6	12.2%	33.3%
I have used a remote laboratory experiment on a few occasions	18	18.2%	40.9%	13	21.7%	52.0%	5	10.2%	27.8%
I am a frequent and experienced user of remote laboratories	n/a	n/a	n/a	1	1.7%	4.0%	3	6.1%	16.7%
I am currently involved in the development of a remotely accessible experiment	n/a	n/a	n/a	4	6.7%	16.0%	9	18.4%	50.0%
I have contributed to the implementation of the following operational remote laboratory experiments	n/a	n/a	n/a	3	5.0%	12.0%	7	14.3%	38.9%
TOTAL	99	100.0%	225.0%	60	100.0%	240.0%	49	100.0%	272.3%

Table 48: Level of familiarity and engagement with remote labs

(EB.3) Statement:	Strongly Agree	Mostly Agree	Neutral	Mostly Disagree	Strongly Disagree	N
a) Remotely controlling physical equipment is a skill that will benefit our graduates in their professional career	17 26%	28 43%	16 25%	3 5%	1 2%	65
b) Most laboratory classes (whether hands-on or remote) can be replaced by computer simulations	0	5 8%	7 11%	33 51%	20 31%	65
c) Remotely accessible laboratories should progressively replace the majority of hands-on laboratories	0	7 11%	11 17%	35 53%	13 20%	66
d) The use of remote laboratories in coursework should only complement existing hands-on classes, but not replace them entirely	22 33%	38 57%	4 6%	3 5%	0	67
e) Including remote laboratories as part of our coursework will be perceived as a progressive and cutting-edge teaching technique by students and the public	18 27%	36 54%	6 9%	5 8%	2 3%	67
f) The use of remote laboratories may give rise to improved pedagogic outcomes and reduced cost at the same time	13 19%	27 40%	17 25%	10 15%	0	67
g) I would see it as a convincing advantage if laboratory equipment could be used alternatively on-location and remotely	16 24%	41 62%	6 9%	2 3%	1 2%	66

Table 49: Executive opinion on the possible role of remote labs in engineering education

- Remote labs should be an alternative, not just a supplement (several cases, metropolitan and regional)
- Remote labs should be integrated as a core part of some subjects. Essential skills should be taught hands-on, then most aspects can be automated
- Some labs may be entirely remote

Over 80% of executives agree with statement e) about the perception of students and the public, with only 11% disagreement. Many generic comments of support were made, such as:

- Remote labs will probably be perceived as 'normal' in due time
- Remote labs are an innovative concept
- Students will love the flexibility

A number of concerned remarks were:

- Only the need for remote labs would drive adoption
- Adoption is likely, if remote labs prove to be an improvement to pedagogy
- Students would prefer hands-on if they had the choice
- I would personally agree, but I'm not sure about our students
- Despite all the benefits, there is a risk that remote labs are seen as cost-cutting rather than pedagogy improvements, hence universities need to 'market' them correctly

- Most executives (59%) believe in the potential pedagogic advantages of remote labs at reduced cost, but comments indicate that more proof for these two points needs to be obtained (case studies, sharing trials, business cases)

Finally, statement g) evaluated the possibility of using existing equipment for both hands-on experiments in class, but enhancing it as a remote lab for off-campus access. This idea attracted wide-spread agreement, and one PVC commented that this combination could lead to 'big plans' for remote labs at his university. Others commented that some existing equipment should not really be used hands-on at all.

In summary, the survey indicates that executives widely recognise the supplementary role which remote labs should rightfully play in practical engineering education in the near future. Although there is demand for more evidence of pedagogic effectiveness and business plans, they are very positive about the public perception and how it would benefit their particular university.

9 Comparison Between Remote and Hands-on Laboratories

A recurrent topic in literature and in the National Survey is the comparison of remote with hands-on labs. While the (potentially) preferred method of adoption has already been established as chiefly supplementary in the previous chapter, the survey endeavoured to investigate particular aspects in greater detail. In particular, all three staff groups were asked to assess certain aspects from a student and then from the university's perspective. Due to the complexity of the data collected and for better comparison, charts have been provided in addition to the statistical tables.

(EB.4, AE.3, TE.3) In your opinion, where lie the potential strengths and weaknesses of remotely accessible laboratories in comparison to hands-on laboratories for undergraduate coursework?

Comparison from a student perspective (executive staff opinion)	Hands-on is far superior	Hands-on is better	Both are equally good	Remote lab is better	Remote lab is far superior	N
Sense of actual involvement in the experiment	19 29%	30 46%	13 20%	4 6%	0	66
Ease of equipment use	1 2%	16 24%	18 27%	28 42%	3 5%	66
Convenience of scheduling	0	4 6%	9 14%	26 39%	27 41%	66
Convenience of access	0	3 5%	4 6%	31 48%	27 42%	65
Overall satisfaction	5 8%	24 39%	24 39%	9 15%	0	62
Learning outcomes	6 9%	24 37%	37 42%	8 12%	0	65

Table 50: Executive staff opinion on the student's view of remote and hands-on labs

Comparison from a student perspective (academic staff opinion)	Hands-on is far superior	Hands-on is better	Both are equally good	Remote lab is better	Remote lab is far superior	N
Sense of actual involvement in the experiment	11 23%	31 65%	5 10%	1 2%	0	48
Ease of equipment use	2 4%	12 26%	14 30%	18 38%	1 2%	47
Obviousness of equipment use	4 9%	17 36%	19 40%	7 15%	0	47
Total time required for completion of a session	0	8 18%	13 30%	22 50%	1 2%	44
Convenience of scheduling	0	1 2%	4 9%	24 51%	18 38%	47
Convenience of access	1 2%	1 2%	5 10%	25 52%	16 33%	48
Clarity of instruction	1 2%	15 33%	26 57%	4 9%	0	46
Overall satisfaction	3 7%	16 36%	19 43%	6 14%	0	44
Learning outcomes	2 4%	19 40%	26 55%	0	0	47

Table 51: Academic staff opinion on the student's view of remote and hands-on labs

Comparison from a student perspective (technical staff opinion)	Hands-on is far superior	Hands-on is better	Both are equally good	Remote lab is better	Remote lab is far superior	N
Sense of actual involvement in the experiment	10 32%	17 55%	3 10%	1 3%	0	31
Ease of equipment use	5 17%	6 20%	7 23%	10 33%	2 7%	30
Obviousness of equipment use	4 13%	10 33%	8 27%	8 27%	0	30
Total time required for completion of a session	0	6 21%	8 28%	13 45%	2 7%	29
Convenience of scheduling	0	1 3%	1 3%	17 57%	11 37%	30
Convenience of access	0	1 4%	2 7%	14 50%	11 39%	28
Clarity of instruction	0	11 38%	16 55%	2 7%	0	29
Overall satisfaction	2 7%	14 50%	8 29%	4 14%	0	28
Learning outcomes	2 7%	15 52%	10 35%	2 7%	0	29

Table 52: Technical staff opinion on the student's view of remote and hands-on labs

9.1 Student perspective

The results from the tables above show the *opinion* of executives (Table 50), academic staff (Table 51) and technical staff (Table 52) how students would see different aspects of remote labs, compared to hands-on sessions. These tables provide an overall view of the universities surveyed and include all levels of insight or experience of the respondents with remote labs.

Figure 8 illustrates how the selected criteria compare. The results are fairly similar between the three staff groups, with only minor differences in the assessment of learning outcomes. While there is a strong belief that hands-on labs will achieve better engagement, from a student perspective the conveniences of scheduling and access that remote labs offer to students are clearly recognised (80-90% in favour of remote labs). Remote labs may also be somewhat easier to use (40-50%) than hands-on labs (25-35%). All respondents believe that students will think learning outcomes and overall satisfaction is better in a hands-on environment, however the large component that judged them both equally good must not be overlooked and is a clear indicator of the future potential in achieving these outcomes.

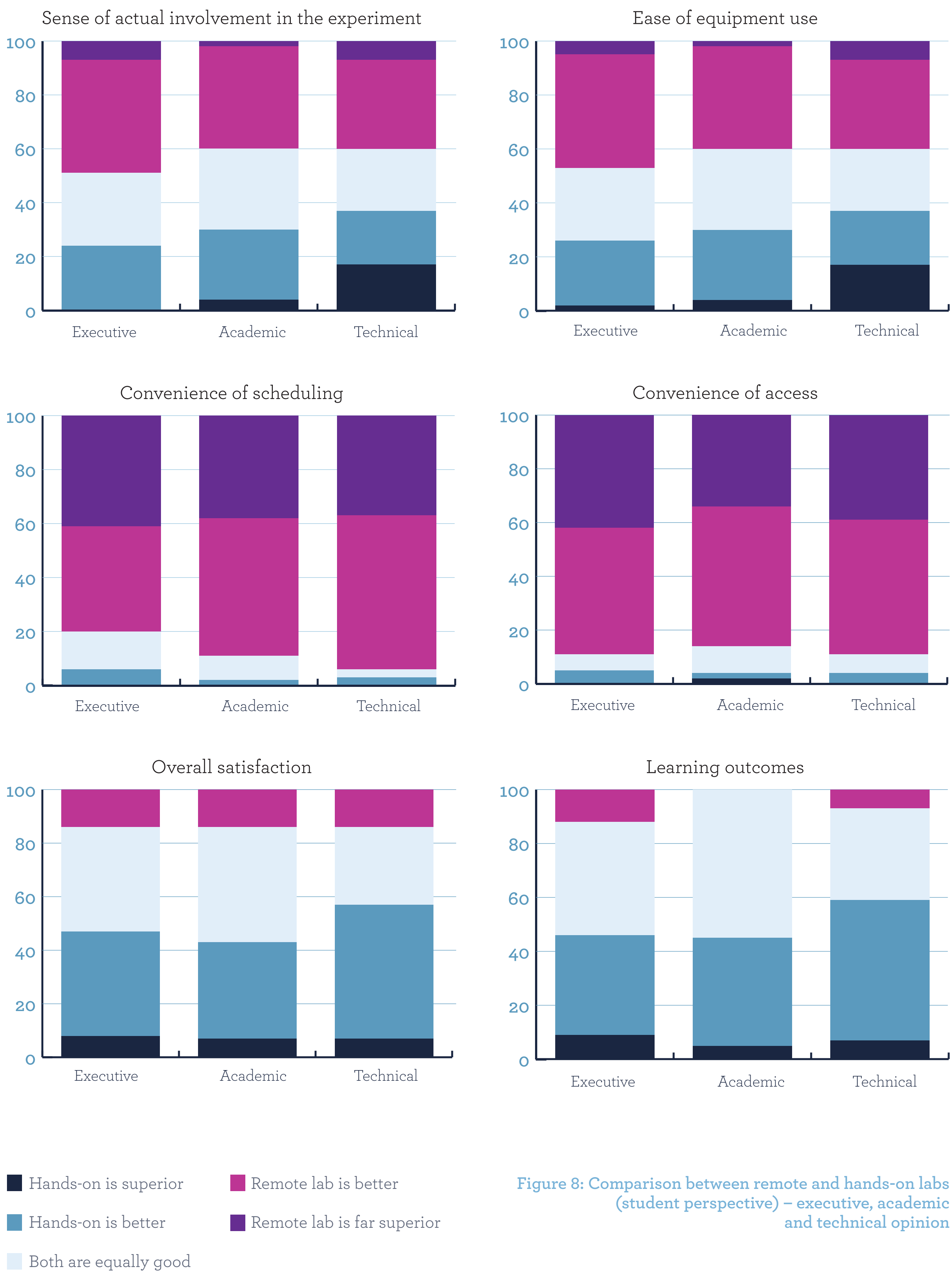


Figure 8: Comparison between remote and hands-on labs (student perspective) – executive, academic and technical opinion

9.2 University perspective

Apart from looking at the interests of the student alone, universities have to consider the efficient use of resources and the provision of good services. The second part of this question looks at the latter by asking all three staff groups the same question from the university's perspective. The results for each staff group are listed in Table 53, Table 54 and Table 55, respectively.

(EB.4, AE.3, TE.3) In your opinion, where lie the potential strengths and weaknesses of remotely accessible laboratories in comparison to hands-on laboratories for undergraduate coursework?

With the only exceptions being throughput and learning outcomes, opinions are once again reasonably unanimous across the three staff groups, as illustrated in Figure 9 and continued in Figure 10. Participants were unsure about the cost of initial equipment setup, resulting in a balanced response. The estimated higher cost for a remotely accessible apparatus with instrumentation was weighed against the cost of having to purchase multiple instances of equipment for a hands-on lab scenario. When it came to maintenance, it was mostly recognised that remote labs are potentially less maintenance-intensive than hands-on labs, which was also reflected in the reliability of experiments.

There was very clear consensus amongst virtually all participants that remote labs are better or even far superior in aspects of equipment utilisation, equipment security, use of laboratory floorspace and personal safety, with roughly between 75% and 95%

Comparison from the university perspective (executive staff opinion)	Hands-on is far superior	Hands-on is better	Both are equally good	Remote lab is better	Remote lab is far superior	N
Cost of initial equipment setup	3 5%	22 35%	18 29%	18 29%	2 3%	63
Cost of ongoing equipment maintenance	0	16 25%	20 32%	24 38%	3 5%	63
Reliability of experiments	0	8 12%	28 43%	27 42%	2 3%	65
Equipment utilisation (hours per unit per week)	0	0	5 8%	37 57%	23 35%	65
Equipment security	0	0	14 22%	31 49%	18 29%	63
Use of laboratory floor space	0	2 3%	8 12%	39 60%	16 25%	65
Personal safety (OHS)	1 2%	2 3%	5 8%	32 51%	23 37%	63
Throughput (number of students able to complete a specific, practical session per time unit)	0	1 2%	8 13%	35 58%	16 27%	60
Learning outcomes	5 9%	21 36%	24 41%	6 10%	2 3%	58

Table 53: Executive staff opinion on the university's view of remote and hands-on labs

Comparison from the university perspective (academic staff opinion)	Hands-on is far superior	Hands-on is better	Both are equally good	Remote lab is better	Remote lab is far superior	N
Cost of initial equipment setup	3 7%	16 36%	9 20%	15 33%	2 4%	45
Cost of ongoing equipment maintenance	2 4%	10 22%	10 22%	20 44%	3 7%	45
Reliability of experiments	5 11%	9 20%	17 37%	13 28%	2 4%	46
Equipment utilisation (hours per unit per week)	0	0	4 9%	27 60%	14 31%	45
Equipment security	1 2%	0	9 20%	21 47%	14 31%	45
Use of laboratory floor space	0	3 7%	7 15%	23 50%	13 28%	46
Personal safety (OHS)	0	2 4%	0	24 52%	20 44%	46
Throughput (number of students able to complete a specific, practical session per time unit)	0	2 4%	4 9%	23 52%	15 34%	44
Learning outcomes	5 11%	13 28%	25 54%	3 7%	0	46

Table 54: Academic staff opinion on the university's view of remote and hands-on labs

Comparison from the university perspective (technical staff opinion)	Hands-on is far superior	Hands-on is better	Both are equally good	Remote lab is better	Remote lab is far superior	N
Cost of initial equipment setup	1 3%	11 38%	8 28%	5 17%	4 14%	29
Cost of ongoing equipment maintenance	0	8 28%	9 31%	10 35%	2 7%	29
Reliability of experiments	0	8 28%	12 41%	9 31%	0	29
Equipment utilisation (hours per unit per week)	0	1 3%	0	19 66%	9 31%	29
Equipment security	0	1 3%	3 10%	14 48%	11 38%	29
Use of laboratory floor space	0	1 4%	6 21%	14 50%	7 25%	28
Personal safety (OHS)	1 3%	0	0	12 41%	16 55%	29
Throughput (number of students able to complete a specific, practical session per time unit)	0	6 21%	7 25%	10 36%	5 18%	28
Learning outcomes	1 4%	10 44%	7 30%	4 17%	1 4%	23

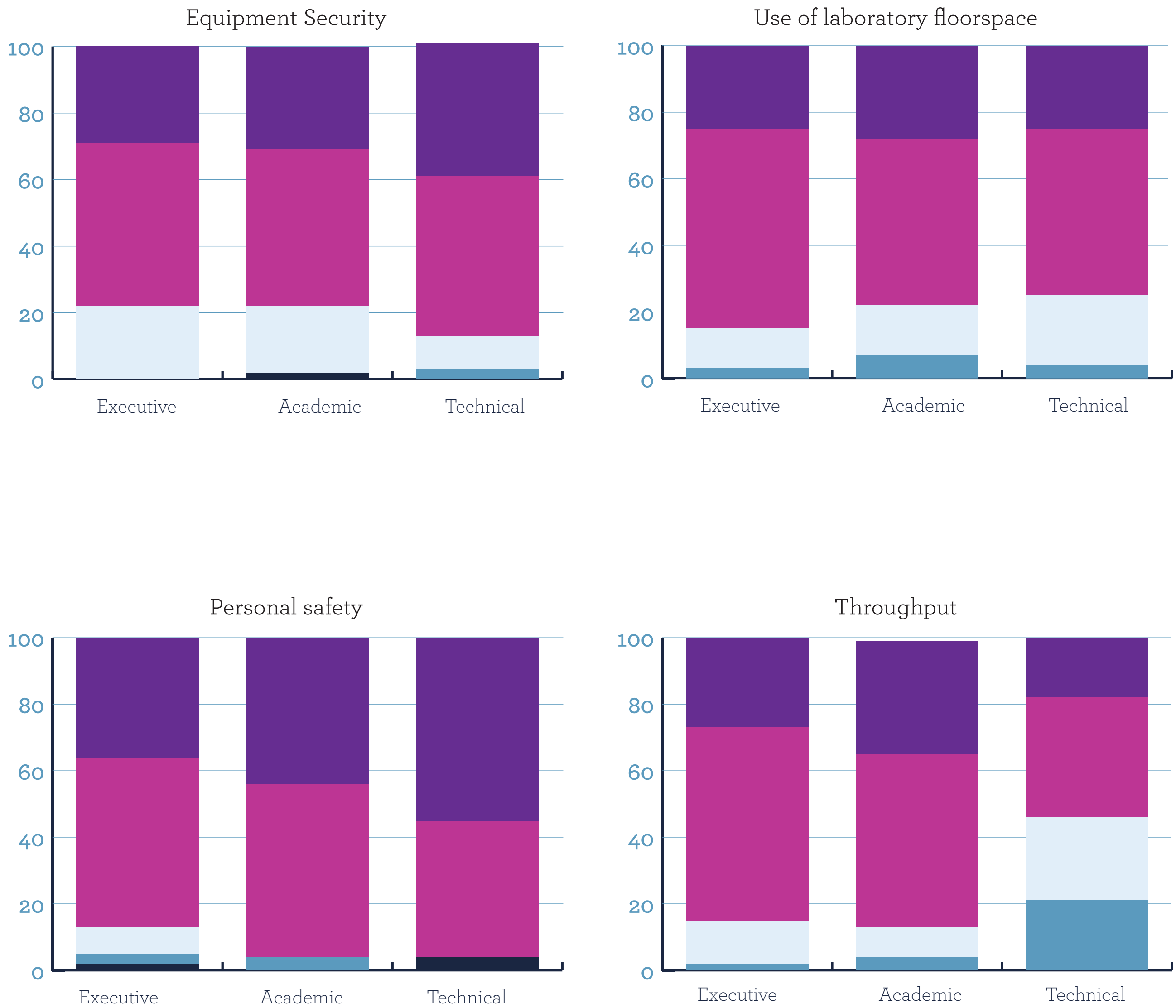
Table 55: Technical staff opinion on the university's view of remote and hands-on labs

of all counts. While executives and academics also agreed (with over 80%) that remote labs are better or far superior, technical staff were slightly more hesitant (54%).

Despite recognising potential advantages for the university in terms of cost and operation, both executives and academics think that better learning outcomes can still be achieved with hands-on labs, but the majority of participants actually think that both are (or potentially can be) equally good, which is an interesting analogy to the 'student perspective' case. Technical staff were much more divided on this issue and opted more frequently for hands-on labs for better learning outcomes.

In conclusion, this comprehensive comparison of opinions not only across all staff groups with impact on laboratories, but also with the involvement of key decision makers and technical managers has produced valuable results. Participants are fully aware of the aspects in which remote labs can provide tangible advantages, but they have also sent the message that they wish to be further convinced of the benefits in the areas of student immersion, learning outcomes and cost.

Figure 9: Comparison between remote and hands-on labs (university perspective) – executive, academic and technical opinion (a)



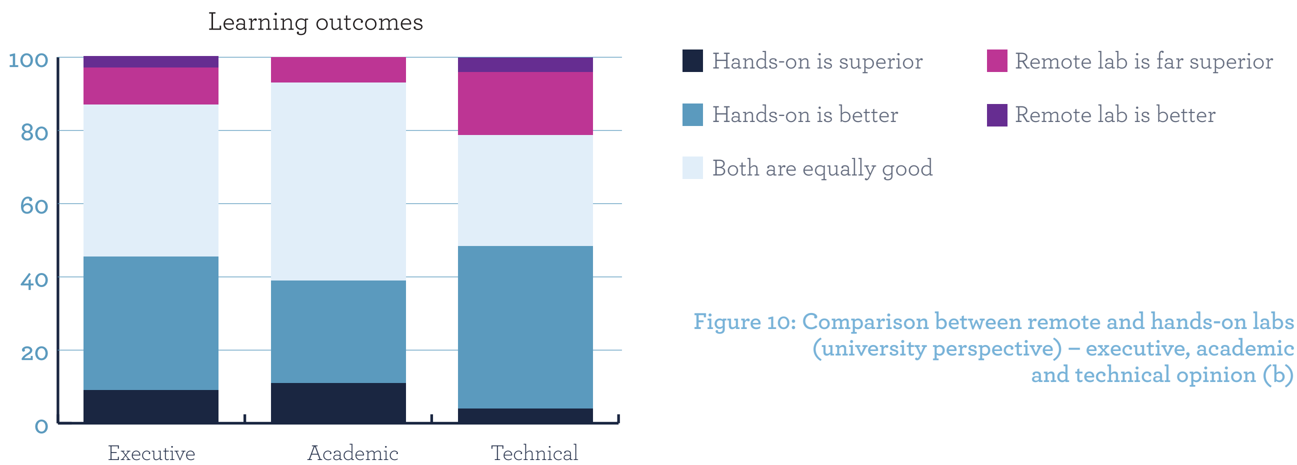


Figure 10: Comparison between remote and hands-on labs (university perspective) – executive, academic and technical opinion (b)

PART 4

Specific Observations and Future Work

10 Specific Observations

Throughout this survey, a number of topics were identified which deserve a more in-depth discussion. Most of these subjects featured frequently in discussions with participants during the completion of the survey and mostly relate to hands-on laboratories. It should be noted that the purpose of this section is to report on these topics only, without any intent to comment or to criticise.

10.1 Quality of practical session pedagogy

With engineering being a practical profession, experimentation and laboratory practice can be considered a long-standing tradition for engineering education. While hands-on laboratories are widely seen as the well-established and proven 'status quo', academics widely acknowledged that not all existing experiments conform to best pedagogic practice. What a 'best practice' laboratory session constitutes appears to be highly variable across all universities surveyed, and even within each faculty/school. Specific faculty or school policies about the frequency and duration of practical sessions may provide a basic framework, but in the end it usually depends on the responsible academic, whose resources are usually limited in many ways.

Especially in subjects that teach basic principles, such as materials testing and physics, it was frequently commented that the pedagogic material accompanying laboratory practice does not need to change, because the principles haven't changed. Consequently, there were reports that academics had 'inherited' material over generations (occasionally over 15 years), without seeing the need for modification. Conversely, there were several examples of academics who reviewed their laboratory sessions annually by incorporating modern teaching technology, accommodating different learning styles and going great distances to motivate students for a memorable and efficient time in the laboratory. Observations confirmed that this practice did not depend on quality of facilities or funding, but mostly on academics and the demonstrators.

Several academics (and also executives) commented that the time allocated to the pedagogic development of practical classes is severely impacted by promotion policies of universities. One associate dean (teaching and learning) of a large metropolitan university stated that regrettably, academic promotions are entirely based on research performance, therefore many academics direct their efforts to the generation of publications rather than involvement in laboratory practice.

10.2 Throughput

Previous chapters have established that rising student numbers, stagnant or diminishing floorspace and tight budgets have led to great challenges in coping with students attending hands-on laboratory sessions. Large universities with several thousand on-campus students are typically located in inner metropolitan areas, where floorspace is scarce. Virtually all large universities currently suffer from throughput challenges of some form, or have done so in the past and subsequently 'adjusted' the frequency of practical sessions. Academics often reported great difficulties in scheduling the number of sessions they considered necessary for good learning outcomes, along with a lack of opportunities for students to 'catch up' with missed sessions or to repeat measurements. At the same time, this large volume requires the involvement and coordination of additional staff. This often poses new problems, as detailed in the following section.

10.3 Quality of laboratory demonstrators

The single topic that attracted the most frequent comments from both the academic and the technical staff questionnaires was the quality of laboratory demonstrators, especially students as demonstrators. At small universities, academics or technical staff mostly conduct practical sessions themselves, hence this topic was mainly, but consistently raised at medium to large universities.

Questions AD.5 and TD.5 asked who currently conducts practical sessions, and who should ideally do so. Since the statistical outcome nominated postgraduate students in both cases, it is not immediately obvious that most respondents only nominated this option because they could see no practical alternative to it. Others requested that a big 'NO' be noted next to the option of postgraduate student involvement. Some strong views were expressed on this topic, for example:

Academic staff comments:

- The quality and performance of postgraduate students varies a lot
- High turnaround makes training cumbersome for academics
- Often no familiarity with the equipment or procedures (coming from different backgrounds)
- Insufficient communication and social skills (mostly applied to international postgraduate students)
- They are often not interested in student interaction, not keen to help
- Many just 'attend' the sessions and have other priorities. Some leave early
- Shortage of suitable demonstrators and large undergraduate student numbers lead to compromises in quality
- Little resource planning on higher levels, 'last minute' solutions for recruiting lab staff
- Postgraduates as demonstrators require close supervision by the academic and *only* then deliver good quality
- There is some suspicion that many work for the money only, without making any effort
- Students lack directions by postgraduates in what to do in the lab. This gets worse as class sizes grow
- Problems with marking consistency
- Local graduates (and often even senior undergraduate students) perform better in the laboratory

Technical staff comments:

- Frequent language barrier, complicating the interaction with students and technical staff
- Students are often not qualified, come from other fields and have communication problems
- Complaints about incompetent demonstrators are not acted upon
- Postgraduates are a necessity with varying quality.
- Often motivated by additional income
- Only 1 out of 20 demonstrators is of good quality
- Fluctuation of postgraduate students affects the quality of lab demonstrations
- Only good quality students should be involved - not just for the money
- Lab quality and student satisfaction have dropped since postgraduate students were increasingly used as lab tutors
- Deficiencies in directing students, lack of knowledge
- Should be closely monitored for performance, should not be 'over-used'

However, a number of academics also praised the quality of their postgraduate students involved in practical sessions. Interestingly, this was more common in disciplines with a health and safety risk than in other areas. In particular, no negative comments were received from academics and technical staff in the field of chemical/process engineering.

While the above comments show that many academics and technical staff alike see postgraduate student involvement as a very current and immediate issue for the delivery of good quality practical sessions, some academics and universities have reportedly recognised the problem and have already taken mitigating action, namely:

- 'Hand picking' of demonstrators (if available)
- Elimination of tradition and expectation that every postgraduate student is allowed to tutor
- Working initially under close supervision of academics, more independently after a few semesters
- Regular pedagogic training conducted by the faculty for all demonstrators (compulsory)
- Accountability for student complaints and feedback
- Record keeping about past involvement and performance as a basis for new contracts

Incorporating the data collected from question AD.2 (Section 6.6) in this consideration, a considerable majority of academics thinks that laboratory sessions are the most important component of their subject. In addition, demonstrators have consistently been rated as 'critical' for the quality of a lab session for students. Yet, it appears that the quality of this prime component can be (and has been) compromised by the selection of inappropriate resources, i.e. demonstrators who do not meet these expectations. The large scale and the intensity of the feedback received transform this topic into a major concern for the delivery of hands-on laboratory sessions, especially at institutions that rely on demonstrators other than academics.

10.4 Design lab sessions and projects

Many academics consider well-guided ('cook book') lab sessions with a high degree of hands-on tasks essential during the first two years, with a progressive move towards design labs (problem-based learning) in the later stages with less supervision. Those academics believe that design labs deliver superior learning outcomes, and there are some moves towards the inclusion of design labs even in the first year, with a high degree of team work and staff interaction. This approach is often part of the concept of technology-assisted learning in specially designed learning spaces, which have emerged at a number of Australian universities.

This report frequently refers to 'laboratory sessions', which still are the most commonly encountered mode of delivery across all disciplines. The increasing introduction of group projects and problem-based learning approaches has also introduced a breakdown in the clear separation of lectures, tutorials and practical sessions. Some universities are currently trialling subjects in which all components are merged into one session type. This, in turn, mandates that suitable facilities are available for this purpose. A number of these facilities have already been commissioned around Australia over the last 2 years, with more expected to emerge.

In this context, academics have voiced the hope that some remote laboratories will also support collaborative and problem-based learning approaches to some extent, e.g. by enabling group work between students. This concept has already been implemented in some existing remote labs, and further developments can be expected. Since a demonstrator will generally not be available, it has been suggested that an adaptive learning concept could be integrated in remote lessons that recognises systematic mistakes and provides either help or additional exercises for a successful completion of the session, very similar to what a demonstrator would generally do in a hands-on setting.

11 Adoption Potential of Remote Laboratories

Several academics at Australian universities have already been amongst the early pioneers of remote laboratories since the mid-1990s [8, 9], mostly in the form of individual projects and with single experiments. Given the rapid evolution of multimedia over the internet since then, these early implementations deserve respect for their technical achievements and for laying both technical and pedagogic foundations for today's work.

2000-2008 saw approaches to make remote equipment available to a larger number of students and to address throughput challenges, for example through replication of identical apparatus and access management systems of different forms [10, 11]. The topic of remote labs access for distance-mode education also received more attention [12]. However, until recently, many of those systems were available to students of the host university only. The latest development is the sharing of remotely accessible laboratories between universities, which has been the main objective of the Labshare project since 2009 in Australia. A similar approach is also under development on a global scale under the guidance of the Global Online Laboratory Consortium (GOLC).

Apart from capturing a snapshot of practical engineering education at Australian universities, the National Survey has also endeavoured to determine important factors for the possible nation-wide adoption of the remote laboratory concept. One particular study [13], contains a very thorough treatment of fundamental considerations, which will be complemented by outcomes from the survey in the following sections.

11.1 Teaching philosophy and pedagogy

It has already been established that over 80% of all executives agreed or strongly agreed that remote laboratories will be seen as an innovative coursework element by students and the public. Those who disagreed fear that it may be perceived as a cost-cutting measure, even if used as a supplement only. Interestingly, these concerns mainly originate from larger institutions with an international reputation – often the same where academics and technical staff reported throughput problems and a highly variable quality in the delivery of laboratory sessions by demonstrators. However, most academics and executives recognise that remote laboratories have the potential of delivering a highly consistent quality and learning experience – if well designed:

> "Not the mode of delivery is important, but the effective pedagogy of the delivery." (academic staff comment, regional university)

The development of suitable lessons specifically for remote laboratories is therefore paramount. Several academics noted that by being under intense scrutiny to deliver comparable learning outcomes to hands-on labs, remote lab lessons will eventually turn out to be pedagogically better than most existing hands-on lessons. Of course, a great deal of literature focussing on the pedagogy of remote laboratories exists [14-19].

Ongoing work shows that pedagogy and learning outcomes cannot simply be transferred from comparable hands-on experiments, but must be specifically adapted to take advantage of the recognised benefits of remote labs, such as a focus on conceptual understanding, the opportunity to experiment without time restrictions and to repeat experiments. This requires a re-think of pedagogic approaches, as immediate help and guidance may not be available, and numerous academics therefore commented that remote labs are more suitable for students in the second half of their degree who already posses hands-on laboratory experience.

Well-guided step-by-step ('cook book') lab sessions with a high degree of hands-on tasks are considered essential during the first two years, with a progressive move towards design labs (problem-based learning) in the later stages. Most academics believe that design labs deliver superior learning outcomes, and there are some moves towards the inclusion of design labs even in the first year, with a high degree of team work and staff interaction. This approach is often part of a recent, experimental concept of technology-assisted learning in specially designed learning spaces, which have emerged at a number of Australian universities. Given the flexibility that remote labs offer students in terms of 24/7 access from anywhere, specifically designed problem-based learning experiments may very well be part of this concept, although the collaborative aspect needs to be explored further.

11.2 Operational considerations

The survey has shown that throughput is a major burden for almost all large universities. Most academics who have indicated that they struggle with throughput also admit that the quality of some laboratory sessions is not optimal. Qualitative feedback indicates that a number of those academics would be quite open to replacing at least one suitable hands-on experiment by a remote experiment in order to alleviate pressure on timetabling and to introduce more flexibility for the students. On the other side, this will create a significant 'guaranteed reliability and availability' challenge to the provider of that experiment, because a single, large cohort of students would depend on it entirely. It is therefore critical to evaluate the suitability and robustness of existing and future remote laboratories for large class sizes. One study is currently in progress as part of the national sharing trial, conducted by Labshare in the second half of 2010.

In one instance, academics from a large, metropolitan university reported that university-wide timetabling restrictions and a full curriculum prevented the inclusion of more practical sessions in the course, although sufficient hands-on laboratory resources existed. Remote laboratories could provide advantages here through a flexible access scheme.

The survey data clearly supports one particular mode of involvement as favourable for the initial adoption of remote laboratories at 'provider' institutions. 86% of executives saw it "as a convincing advantage if laboratory equipment could be used alternatively on-location and remotely", therefore preferring the modification of existing rigs (through additional instrumentation), so that their equipment can still be used hands-on for their own students when required. At other times, the equipment could be made available online for remote use ('mixed access mode'). Similar feedback was also received from academic and technical staff, who would prefer to maintain the option of hands-on use when required, but also see tangible advantages in sharing the equipment with other universities.

This approach, however, suggests that those rigs are operational 24/7. Especially at universities with severe space restrictions, this could pose a challenge. As reported above, a number of metropolitan universities visited are moving towards a flexible lab space design, i.e. experiments and rigs are only set up for a particular lab session, then packed up and stored elsewhere. While this issue could be easily addressed for equipment designated to remote-access only through off-site accommodation, mixed-mode access (especially to large equipment) may be more challenging in combination with flexible labs.

Further variations of this mode have been suggested, for example the time-restricted availability of expensive or delicate/hazardous equipment, which may only be accessible under direct, on-site supervision of qualified staff. This access mode appears suitable for the remote use of research equipment, which could then be made accessible to other researchers or a wider audience.

Engineering programs with large numbers of distance-mode students (in regional and remote areas of Australia or even offshore) often face the dilemma that all students are formally required to engage in practical experience during their engineering course. Typically, distance mode students exclusively attend hands-on lab sessions in a 2-week block per year ('residential school'), during which all experiments across several subjects are conducted. This has raised the pedagogic question amongst academics whether they have had the necessary time to reflect on their experiences before engaging in the next session, but of course these are organisational challenges. Some experiments mandate a time frame between sessions (e.g. for the curing of concrete samples), hence they ideally need to be performed several weeks apart. This has prompted universities with many distance mode students to potentially consider remote access in support of practical sessions, even for destructive testing. Another operational benefit has been suggested in that hazardous hands-on experiments can be conducted remotely, ensuring a controlled risk environment for students to experiment prior to experimentation in a physical laboratory. Examples of this can be found in chemical and process engineering.

11.3 Strategic considerations

It has already been recognised on several levels that collaboration between universities and also with other sectors should play a more significant role in sharing available resources. One example is the 'Engineering Collaboration Project' (information obtained through private communication), which in 2009 consisted of 7 Victorian universities and represented both single and dual sector institutions. Industry representatives, Engineers Australia and the Victorian Government were also involved. One project objective is the investigation of how resources can be shared between institutions, currently limited to a metropolitan scale, and a second how universities can gain sustainable access to industry-scale infrastructure. The project's rationale is stated as:

> "Access to industry scale infrastructure underpins world-class engineering education but is an increasing issue for engineering institutions. The current infrastructure is ageing, and replenishing it is made more difficult by the disconnection between increasing acquisition and maintenance costs and shrinking institutional budgets. Despite these challenges, institutions have by-and-large persisted with the practice of acquiring infrastructure on an institution-by-institution basis, even specialist equipment with low utilization levels. Complicating factors such as the location and accessibility of certain types of engineering infrastructure (e.g. teaching labs) and difficulties associated with managing sharing arrangements have perhaps reinforced this pattern. Where crossinstitution sharing does occur, it is generally negotiated on the back of personal relationships between staff in different institutions. [...]
>
> Institutions' efforts to access and expose students to industry scale infrastructure located in industry settings are also increasingly frustrated. Anecdotally, there has been a decline over the last decade in industry's readiness to make facilities and equipment available to institutions for practical student demonstrations, tours and the like. This difficulty is compounded by a range of factors, some more tangible – such as more stringent occupational health and safety regulation - than others. Engineering, as an applied science, needs to do more to capture and maintain industry's willingness to contribute to undergraduate skills development.
>
> Action in the area of improving access to industry scale infrastructure is therefore considered to have the potential of improving both the quality of the educational experience and the costs of educational delivery."

Commonalities with the rationale for remote laboratories are striking, therefore the survey administrator decided to discuss outcomes of this project with a number of deans and heads of engineering schools at Victorian universities during the visits. The dean of a large metropolitan university commented that in his opinion, the sharing of physical resources (in particular the shared use of hands-on laboratories) between universities/TAFE had not been successful due to logistic and timetabling issues. Remote laboratories can potentially address a number of these factors and support similar initiatives. Besides, the involvement of industry must be considered, as suggested manifold during the course of the survey.

11.4 Technical considerations

The National Survey has also uncovered that executives and technical staff frequently see destructive material testing in civil and mechanical engineering as a major burden, mainly due to the cost and maintenance of equipment, floorspace requirements, throughput problems and logistics (e.g. consumables). These experiments rank highly on the list of potentially interesting remote experiments, but many institutions still prefer the students to be involved hands-on and to appreciate the size of the machinery and the forces involved. A supportive role of remote laboratories appears sensible, however this would bear the challenges of dealing with consumables and destructive techniques. This would be an entirely new field for remote labs, but it must be looked at given the wide-spread demand.

There also is potential for rare, inaccessible or very costly rigs to be made available as remote labs by some institutions (even outside the field of engineering), but the demand side requires further investigation. Examples would be chemical and mining pilot plants, large wind tunnels and hydraulic structures, as well as equipment otherwise exclusive to research activities.

As previously mentioned, the survey has also collected a large amount of equipment-specific data through interviews with technical staff and visits to a large number of teaching laboratories across Australia. Unfortunately, the outcome of this attempt to establish a non-representative inventory of equipment suitable for remote access is too diverse to present in the context of this report, and further analysis is needed. Participants nominated specific apparatus that they think could be suitable for remote access, and also expressed interest in a number of experiments for which equipment was not available at their university. Besides, the evaluation of computer instrumentation in laboratories has revealed that many experiments are actually already conducted in the sense of 'remote' experiments, with students performing all tasks from the attached computer and rarely interacting hands-on with the equipment (e.g. PLC, FPGA, embedded systems). In one example, students were able to program and control a fully automated manufacturing cell, including consumables, with computers from the other side of a glass screen. By simply adding live feeds from cameras, this example can already be considered a remote laboratory. Consequently, some laboratory practice is already very close to a remote labs setup, both technically and pedagogically, but this fact was often not fully realised by participants.

11.5 Financial considerations

Naturally, executives were particularly interested in the potential cost vs. benefit aspect of remote labs, both from a 'consumer' and a 'provider' perspective. Probably the most commonly raised question was in regard to the approximate cost of a typical remote laboratory rig. The perception that a set of identical remote experiments is more expensive than a comparable hands-on rig (from a provider's point of view) was usually based on a simplistic one-to-one comparison, i.e. that a fully instrumented rig is obviously more expensive than a pure hands-on rig without data acquisition hardware and actuators. It was often overlooked that a typical hands-on setup would require significantly more stations than a small number 24-hour remote setup. Consequently, this point needs further clarification when discussing the cost of remote laboratories.

With few exceptions, executives generally stated that a potential involvement in remote laboratories, if any, would be primarily based on pedagogic merits. Only universities with new or very small engineering programs expressed interest in immediately incorporating remote laboratories into their business plan. Smaller and regional universities also appeared to be more inclined to initially participate as a 'consumer' rather than a 'provider' of experiments, with the main goal of allowing their students access to a wider range of experiments than locally available.

11.6 Future interest and collaboration

The topic of remotely accessible laboratories generated a lot of awareness and motivation during the survey, and therefore participants were given the opportunity to express interest in staying connected or getting involved on a variety of levels.

Academics were asked whether they could envisage having their students use remote labs as part of their subject. 38 out of 53 academics (72%) responded 'yes', and 36 were interested in actively participating in a national sharing trial of remote labs (68%).

Technical staff were also asked whether they thought their students should be exposed to remote labs. The somewhat greater hesitation of technical staff (coordinators/managers less so than officers) with remote labs was equally obvious here, with only 19 out of 52 (37%) responding with 'yes'. 10 (19%) were interested in participating in a national sharing trial, and most of those respondents were in a coordinator position.

(EB.5, AE.6, TE.7) Would you generally be interested in future collaboration regarding shared laboratory facilities? Please check all answers that apply.	Executive Staff			Academic staff		
	Responses		Percent of cases N=64	Responses		Percent of cases N=47
	N	%		N	%	
I would like to receive more information and future updates	61	29%	95.3%	46	31.9%	97.9%
I would like to learn more about using shared facilities for our students	56	26.7%	87.5%	43	29.9%	91.5%
I would like to learn more about participation in a national sharing trial, using existing remote experiments	51	24.3%	79.7%	36	25.0%	76.6%
I would be interested in becoming a partner in a national laboratory sharing consortium	42	20.0%	65.6%	19	13.2%	40.4%
TOTAL	210	100.0%	328.1%	144	100.0%	306.4%

Table 56: Interest in remote labs information and collaboration

Executives, academics and technical staff alike could indicate the level of collaboration with Labshare they would be interested in, as summarised in Table 56.

12 Summary and Future Work

The National Engineering Laboratory Survey represents one of the most comprehensive efforts ever conducted at Australian universities in capturing the situation of laboratory-based engineering education. With the participation of 100% of institutions and over 260 meetings with executive, academic and technical staff members, and with the collection of extensive survey data in both quantitative and qualitative form, this review possesses both the breadth and the depth to allow a deep insight into the processes, pedagogy and challenges that affect the practical components of undergraduate engineering degrees. In addition, the emerging concept of remote laboratories was evaluated as a supplementary factor to hands-on laboratories.

The survey has identified certain patterns in the funding and decision-making processes for coursework laboratories, in particular that schools are the typical level of budget responsibility, essentially regardless of the organisational structure of the university. Furthermore, the perception of decision-making differs between staff groups, as does the perception of who contributes to the development of experiments and to the delivery of practical sessions. As the core of the academic questionnaire, pedagogic aspects were evaluated in great depth, with one major outcome being the wide-spread support of the 13 ABET objectives for the assessment of laboratory learning outcomes.

The responses collected in relation to remote laboratories saw that not many participants were entirely familiar with the concepts, and that there was a common belief that this new mode of delivery aims to replace existing hands-on labs, and participants from all groups emphasised that hands-on labs will remain the main focus of practical engineering education. A comparison between hands-on and remote laboratories clearly identified that remote labs are considered superior in terms of flexibility (24/7 access from anywhere), utilisation, space savings and safety issues. Participants also accepted that remote labs have the potential of achieving learning outcomes equally as good as hands-on labs, but also that more studies and trials are required to prove this point.

The survey generated considerable interest, especially amongst executive and academic staff, in a trial of existing remote labs or contributions to future developments, which are currently being followed up on. Numerous comments were also received suggesting the extension of the concept of remote labs to research equipment, which is usually very costly and often immobile (e.g. electron microscopes, wind tunnels, microwave test equipment). While not directly within the scope of this project, these pathways will certainly be pursued in future.

The original questionnaires and a record of amalgamated, quantitative data obtained from the National Survey will be made available on the Labshare website, www.labshare.edu.au, in due course.

12.1 Sharing trials

Following the great interest expressed by numerous academics and institutions in gaining personal experience with remote laboratories, both from a technical and a pedagogic point of view, a number of sharing trails with existing equipment are currently being undertaken, involving around 1,000 students and 10 universities in Australia. Valuable lessons will be learnt from this experience, for example with respect to operations, student load on equipment and pedagogy, along with the collection of feedback from participating students and academics. More experiments are currently being built and will be trialled over the coming semesters.

12.2 Consortium

Although the concept of an Australian consortium for remote laboratories was still in its infant stages at the time of the National Survey, the idea was mostly well-received by executives and academic staff alike. There was a general consensus that specialised remote laboratory experiments should be developed and provided by those institutions with the best expertise in that field and shared with other participating parties. This would allow universities to coordinate any development and sharing between them, and also facilitate interaction between academics in lesson development, sharing of pedagogic improvements and a general establishment of a remote labs community. Therefore, the Labshare project has taken steps to evolve into a consortium, which will allow the sustainable growth and use of remote laboratories into the future.

Acknowledgements

The author wishes to acknowledge the assistance received by Dr Narelle Smith, Senior Lecturer in Mathematical Sciences at UTS and member of the Statistical Society of Australia. Narelle has been fundamental in providing guidance and advice on the design of the questionnaire, research methodology and survey ethics. Her intricate statistical data analysis following the survey and her preliminary reports were particularly helpful in composing this work.

The author would also like to thank Mr Jordan Nguyen and Ms Sepinoud Meisami, both doctoral candidates at UTS, for succeeding in interpreting the author's handwriting and for their tireless transcription of over 200 completed questionnaires, including transferring thousands of handwritten comments and annotations. In particular, the comprehensive overall analysis of both quantitative and qualitative responses was made possible only through Mr Jordan Nguyen's efficient design of data structures and an automated classification system.

The Australian Department of Education, Employment and Workplace Relations is gratefully acknowledged for providing funding for the Labshare project, along with all project staff members who have indirectly contributed to the success of the review through organisational support.

Finally, the author is indebted to the 34 universities, represented by hundreds of individual survey participants, who donated their time to this project. Each university extended a very warm welcome to the author, and it was a pleasure to experience the passion which so many individuals invest every day in educating the future generations of engineers around Australia. The good and sometimes personal relationships established with a number of participants will certainly be very beneficial for future activities.

Definitions and Acronyms

Definitions used throughout the report

faculty
a major division within a university comprising one broad subject area, with similar disciplines grouped together. At some Australian universities, this major division can also be termed college or school (not to be confused with the definition of school below). Faculties often comprise several schools.

school
organisational entity that is affiliated with one specific engineering discipline (at larger universities), or engineering in general (at smaller universities). Several schools are usually combined to form a faculty.

dean
university manager with significant authority over a specific academic unit, usually a faculty, and with responsibility for the overall delivery of educational programs and research. In the context of ACED, heads of school from universities with smaller engineering programs are also termed deans.

head of school
manager of a school. At some Australian universities, heads of school may also be termed school deans.

subject
the unit of study, usually delivered on a semester basis.

laboratory
in a coursework context: facility that allows students to engage with material and equipment and to conduct experiments. Excludes 'computer labs' (computer-only facilities).

experiment
a defined pedagogic lesson consisting of single or multiple activities and measurements carried out by a student while interacting with laboratory equipment or material.

Acronyms

AaeE	Australasian Association for Engineering Education
ABET	Accreditation Board for Engineering and Technology
ACED	Australian Council of Engineering Deans
ALTC	Australian Learning and Teaching Council
ATN	Australian Technology Network of Universities
Curtin	Curtin University of Technology
Deakin	Deakin University
DEEWR	Department of Education, Employment and Workplace Relations
EA	Engineers Australia
FPGA	Field-Programmable Gate Array
GOLC	Global Online Laboratory Consortium
MIT	Massachusetts Institute of Technology
PLC	Programmable Logic Controller
PVC	Pro Vice Chancellor
SPSS	Statistical Package for the Social Sciences
TAFE	NSW Technical and Further Education
UniSA	The University of South Australia
UQ	The University of Queensland
USQ	University of Southern Queensland
UTS	University of Technology, Sydney
UWA	The University of Western Australia
VET	Vocational Education and Training

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About the Authors

Thorsten Kostulski received his Dipl.-Ing. (FH) degree and the university medal from the University of Applied Sciences, Aachen (Germany) in 2002 and was awarded a PhD in telecommunications engineering from UTS in 2008. He joined UTS in 2001 and worked in experimental satellite communications by contributing to the design, construction and operation of a fast-tracking Ka band earth station prototype. His highly experimental research resulted in numerous publications in this field. Concurrently, he was involved in the coordination and delivery of several undergraduate coursework subjects, some with large student numbers, and he has since been actively involved in laboratory work with students. Combining his interest in engineering pedagogy with experimental practice, he later joined the UTS remote labs team as a senior researcher to help advance the pedagogic quality of remotely accessible laboratories. In addition, he currently coordinates the national sharing trials of remote laboratories across Australia and conducts associated feedback surveys of participating students and academics.

Steve Murray's professional background includes industrial computer systems development in Australia and the UK. He joined the UTS in 1992, having previously spent six years working on projects in industrial automation and flight simulation. After joining the Faculty of Engineering, he directed almost all of his efforts to the teaching and learning programs. As well as developing and delivering a great number of undergraduate and postgraduate coursework subjects, and completing a term as Program Head of the Computer Systems Engineering and Software Engineering programs, he has authored and co-authored several papers and a book chapter on topics related to remotely accessible laboratories. He was the team leader of a group which was honoured with a UTS Teaching Award in 2005 for work in this area, and received a 2006 Carrick Citation for work on remote laboratories.