School of Civil and Mechanical Engineering

Identification, Characterisation and Prioritisation of Student Interactions in Face-to-Face and Remotely-operated Engineering Laboratories

Sulakshana Lal

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Doctor of Philosophy
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DECLARATION PAGE

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

Signature:

Date: 9-11-2020

DEDICATION

This thesis is dedicated to my family, who continuously believed in me and provided me with their support and motivation.

Abstract

This study aims to advance the understanding of learning in undergraduate engineering laboratories by recognising the factors that influence the actual design of the laboratory. Consequently, the research was guided by a theoretical framework, the Model of Educational Reconstruction, which emphasises the subject matter under investigation, students' and instructors' perspectives and the design and evaluation of the laboratory learning environments.

There are various modes of conducting laboratory activities in university-level engineering education. The present study focuses on laboratory modes which involve manipulation of real physical equipment as part of the conduct of laboratory activity, that is, face-to-face and remotely-operated laboratories as opposed to virtual laboratories and simulations. This study first identifies and characterises the interactions that underpin laboratory learning in both face-to-face and remotely-operated laboratories and then prioritises such student interactions to make recommendations for transfer from face-to-face laboratories to create effective remotely-operated laboratories.

Both qualitative and quantitative research methods are used. The quantitative method includes administration of pre- and post-laboratory surveys to students, seeking their expectations of interactions, actual occurrences of interactions, perceptions of the importance of interactions, and satisfaction with interactions. There are four main types of interaction in the conduct of laboratory activities, namely, student-student, student-instructor, student-equipment, and indirect interactions. In both pre- and post-laboratory responses, laboratory learning associated with interactions was divided into three areas: laboratory procedures, results analysis, and basic science concepts related to laboratory activities. Using qualitative methods, semi-structured interviews and video recording of laboratory sessions were conducted to understand students' views and opinions, and also to validate the results reported in the surveys of first-year students. Students from first- to fourth-year of an engineering degree participated in the study.

Irrespective of their stage in the engineering bachelor's degree, in the pre-laboratory surveys students indicated similar variations of the level of expectations across the four interaction categories. However, responses that were obtained in the post-

laboratory surveys from first-, second-, and third-year students for their actual occurrences of interactions during the conduct of laboratory activities were contradictory to their expectations. First- and third-year students' perceptions of the relative importance of different interactions for learning in the laboratory showed close alignment with the expectations reported for the interaction types. Students' performance, as indicated by marks awarded, in laboratory activities also influenced their perceptions of the relative importance of interactions. Studies of student satisfaction revealed that first-year students rated student-student interactions highly, while third-year students were most satisfied with student-student and student-equipment interactions. Students' satisfaction was also influenced by their level of achievement in the laboratory work.

First-year students' expectations for various interactions in the remote laboratory aligned with the expectations expressed for face-to-face laboratories. The actual occurrences of interactions and the perception of importance of interactions reported by first-year students for remote laboratories were similar to those expressed for face-to-face laboratories. Students in both laboratory modes also considered the laboratory-instruction sheet in the student-equipment interaction category to be a vital resource for effective conduct of laboratory activities.

For the attainment of laboratory-learning outcomes, fourth-year students reported that, over their course of study, their interaction with instructors had been the most important contributor. By contrast, instructors believed students' interactions with other students either directly or indirectly were the most important. The future design of both face-to-face and remote laboratories will provide an opportunity for instructors to address this gap and help students better attain expected laboratory learning outcomes.

The overall findings of the research on student interactions led to three main recommendations in the transfer and design of effective laboratory learning to the remotely-operated mode:

(i) Student-student interaction is frequent and most satisfying for students in the face-to-face laboratories so this interaction should be maintained in remote laboratories by creating ways for students to learn from each other while conducting the laboratory activities,

(ii) Student-instructor interaction is highly valued and should be retained in the design of remote laboratories by developing mechanisms that enable students to seek expert advice during the activity,

(iii) The laboratory instruction sheet is an important resource for face-to-face and remote laboratories. In remote laboratories, the laboratory instruction sheet provides students with the feeling of carrying out a physical experiment and therefore, warrants careful design.

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It is with immense gratitude that I acknowledge the support and guidance of my supervisor John Curtin Distinguished Professor Anthony D. Lucey. It was an honour to work and learn from him. This thesis would not have been possible without his guidance, encouragement, patience and understanding. I will be always grateful to him for he always heartily welcomed my ideas and allowed me to work on them. I always felt surrounded by his immense knowledge that motivated me to perform better in my tasks. He has provided me with his full support, encouragement and practical guidance. I could not have asked for a better supervision than that I have received throughout my PhD study.

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Publications arising from the research presented in this thesis

1. Lal, S., Lucey, A. D., Lindsay, E. D., Sarukkalige, P. R., Mocerino, M., Treagust, D. F., & Zadnik, M. G. (2017). An alternative approach to student assessment for engineering-laboratory learning. *Australasian Journal of Engineering Education*, *22*(2), 81–94. https://doi.org/10.1080/22054952.2018.1435202

2. Lal, S., Lucey, A. D., Lindsay, E., Treagust, D. F., Mocerino, M., Long, J. M., & Zadnik, M. G. (2018). The effects of remote laboratory implementation on freshman engineering students' experience. *Proceedings of the 2018 ASEE Annual Conference and Exposition*, 1–14. https://doi.org/10.18260/1-2--31094

3. Lal, Sulakshana; Lucey, Anthony D; Lindsay, Euan D; Treagust, David F; Mocerino, Mauro and Zadnik, Marjan G. A study of the relative importance of student interactions for the attainment of laboratory-learning outcomes. In: 30th Annual Conference for the Australasian Association for Engineering Education (AAEE 2019). Brisbane, Queensland: Engineers Australia, 2019: 372-380.

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4. Lal, S., Lucey, A. D., Lindsay, E. D., Treagust, D. F., Long, J. M., Mocerino, M., & Zadnik, M. G. (2020). Student perceptions of instruction sheets in face-to-face and remotely-operated engineering laboratory learning. *European Journal of Engineering Education*, *45*(4), 491–515. https://doi.org/10.1080/03043797.2019.1654433

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Glossary of Terms

Face-to-face laboratory:- A laboratory where students are physically present inside the premises of an institution to control and operate equipment under the guidance of an instructor.

Remotely-operated laboratory:- A laboratory where the real equipment and apparatus are controlled and operated remotely via the internet (Samuelsen & Graven, 2016). This term is alternatively called a remote laboratory in this thesis.

The remote laboratory studied in this thesis allowed students to perform an experiment independently. The web interface used for controlling and manipulating equipment did not allow collaboration with other students or seek guidance from instructors.

Synchronous remotely-operated laboratory:- A type of remote laboratory where students can collaborate and perform experiments together via the internet in real time. Some synchronous remote laboratories allow instructors to supervise and guide students during their conduct of the laboratory activity.

Asynchronous remotely-operated laboratory:- A type of remote laboratory where students do not collaborate with other students in real time and seek guidance from instructors during the conduct of the activity. Students, in this type of laboratory, independently perform laboratory tasks following a detailed instruction sheet provided to them.

Simulated laboratory:- A simulated laboratory is a computer-based activity where students perform experiments on virtual platform with similar interface and function like the real physical laboratory. This type of laboratory is also called virtual laboratory.

Student-student interaction:- Interaction between students during the conduct of the laboratory activities is defined as student-student interaction. This type of interaction can be either inter-group or intra-group during the conduct of laboratory activities by student groups.

Student-instructor interaction:- Interaction between student and instructor during the conduct of the laboratory activities is defined as student-instructor interaction. This interaction can be either student initiated student-instructor or instructor initiated student-instructor interactions.

Student-equipment interaction:- Interaction that occurs between a student and equipment in the laboratory is termed as student-equipment interaction.

Indirect-interaction:- Indirect learning of students in laboratory from interactions with other students or observed between another student and the instructor (e.g. eavesdropping) is termed as indirect interaction.

Laboratory design:- Laboratory design in this thesis refers to the way laboratory tasks have been designed for students to conduct the laboratory activities to achieve its desired learning outcomes.

Laboratory environment:- A laboratory environment is a collection of virtual and/or physical machines that can be used to develop and test applications. Laboratory environment in this thesis refers to whether the laboratory type is face-to-face or remotely-operated.

Unit:- A self-contained component of a degree program. It is sometimes called ‘course’, ‘module’ or ‘subject’. In this thesis, ‘course’ refers to the entire degree program.

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Chapter 1

Introduction

1.1 Introduction

Engineering education fundamentally comprises the study of applied science, designed with a focus on teaching students engineering knowledge and skills while also preparing them with the necessary professional skills for their future career. The extent and importance of the field of engineering is on the rise. To meet the emerging need of students' interest in the field of engineering, it is necessary that new modes of education be introduced into the education system, which not only will cater for the increasing demand, hence increased student numbers, but also will preserve the essence and purpose of engineering education.

Face-to-face engineering laboratories are the most widely used mode for the conduct of hands-on activities. With the purpose of extending access to laboratory education to larger cohorts of students, various other modes of laboratory, such as virtual, simulation, and remotely-operated, have been introduced into the engineering laboratory curriculum. Remotely-operated laboratories have gained popularity because they replicate hands-on manipulation of real physical equipment.

The focus of the present study is to consider an improved approach for laboratory education in the field of engineering. The aim is to identify the essential features of present physical face-to-face laboratory in terms of student interactions that can be transformed and integrated into remotely-operated laboratories. Identification of the essential features is based on the students' learning processes associated with the conduct of laboratory activities which incorporates mutual interactions between students, instructors, and equipment. The remote laboratory focused in this study is a first-year mechanical-type remote laboratory experiment where the interaction between students, instructors and equipment is asynchronous.

1.2 Problem statement/ Rationale for the research

Engineering students are provided with the opportunity to visualise and assess the cause and effects of theoretical concepts learned through lectures. Acquiring practical skills is important for engineering because of its inherent nature which requires the ability to apply and use various engineering tools and equipment. The Engineers

Australia accreditation guidelines (2019) express the requirement for institutions to provide experimental arrangements so as to meet the learning outcomes from laboratory education in the field of engineering. Ten distinct learning outcomes from laboratory work specified in the accreditation guidelines highlight the need for students to gain "*fluent application of engineering techniques, tools and resources"* (Engineers Australia, 2019). The guidelines also state that *"facilities need to support structured laboratory activities, experiments of an investigatory nature and more open ended project-based learning"*. This statement reinforces the need for engineering laboratories.

In the mid-1990s online experiments were conducted through technology mediation (Machotka et al., 2011). Since then the field has been much developed in terms of the technology use and its applicability. Constraints such as physical space and cost (as student numbers have increased) were partly solved by simulated laboratories (Ma & Nickerson, 2006). These laboratories helped students to relate theory and practice in engineering but were more useful for learning theoretical concepts. Simulation did not give the feeling of a real experiment and therefore could not meet the requirements of engineering laboratories (Nickerson et al., 2007).

Remotely-operated laboratories have features that are common to simulated as well as face-to-face laboratories. In these laboratories students can perform a real experiment without being co-located with the equipment (Machotka et al., 2011). When designing remote laboratories, the primary focus has been on providing a platform for learning and teaching of theoretical concepts practically, in the same way as would have been the case in face-to-face laboratories. Emphasis also has been placed on the need for students to become acquainted with the equipment.

Every laboratory activity involves three basic interaction categories that students experience, namely, student-student, student-instructor, and student-equipment interactions (Miyazoe & Anderson, 2010; Webb & Webb, 2005). A fourth category of interaction, called indirect interactions, occurs in the laboratory when a student has the opportunity to learn either by observation of other student-student interactions or by listening to and/or observing student-instructor interactions when students conduct the laboratory activities. The existence and balance of the four interaction categories described above, in any given laboratory setting, depends on the mode of laboratory for the conduct of the activities.

Traditional face-to-face laboratories have provision for all interaction categories to take place because of the synchronous physical presence of students, instructors and equipment when students are conducting the laboratory activity. On the other hand, in remotely-operated laboratories, students, instructors and equipment are all physically separated and interactions among them are mediated by internet-supported web interfaces. The only real-time interaction that occurs during a remote laboratory activity is when a student is manipulating the equipment, albeit through the internet.

The present study is primarily focused on identifying the essential interactions and their effects on the learning outcomes expected from engineering laboratories. These learning outcomes will further help to inform the design of both laboratory modes. The study of interactions, therefore, enables the improved design of laboratories, which along with right equipment and open-ended inquiry, enhances students' learning in laboratory irrespective of the mode. Engineering laboratories have been under continuous evolution for the past two decades, one of the reasons being an increase in remote operations in engineering industries. To meet the emerging challenges of engineering practice, requires present and future engineering students to be suitably trained in their university education. Due to developments in technology and the nature of professional work for engineers, there is a need for remote laboratories which can provide students and institutions with an instructional and learning environment that will also ensure their development and attainment of laboratory skills as put forth by the Engineers Australia accreditation board (Engineers Australia, 2019).

1.3 Theoretical framework

The research reported in the present study revolves around studying interactions and their effect on learning outcomes in undergraduate engineering laboratories. Further, this thesis makes recommendations for improved laboratory design in terms of interactions and hence improved laboratory learning experiences for future engineering students. In order to understand how the design of an undergraduate engineering laboratory learning environment should be understood, it is important to recognise factors that influence the actual design of a laboratory. For this purpose, the theoretical framework provided by Duit et al. (2012) called the Model of Educational Reconstruction (MER) emphasises the following essential aspects required for an effective teaching and learning process in any environment.

- Clarification of the subject matter and analysis of the educational significance of the chosen subject matter;
- Accounting for both instructors' and student's perspectives including students' prior knowledge of the subject, their attitudes, skills and interests in the subject matter; and
- Combining the above two aspects to design and evaluate a learning environment that is appropriate for teaching and learning to take place.

In the present study, the main focus is on studying students' learning process in an undergraduate laboratory learning environment in terms of students' interactions and then studying its significance for students' attainment of the learning outcomes in the engineering laboratory. These findings of this study will inform the design of laboratories of both modes. This thesis does not individually address the three elements of the Model of Educational Reconstruction discussed below.

Based on the Model of Educational Reconstruction, the design of undergraduate engineering laboratory learning can, in general, be depicted schematically as shown in Figure 1.1. There are three important components involved in the design of an undergraduate laboratory learning through the lens of interactions that are described as follows.

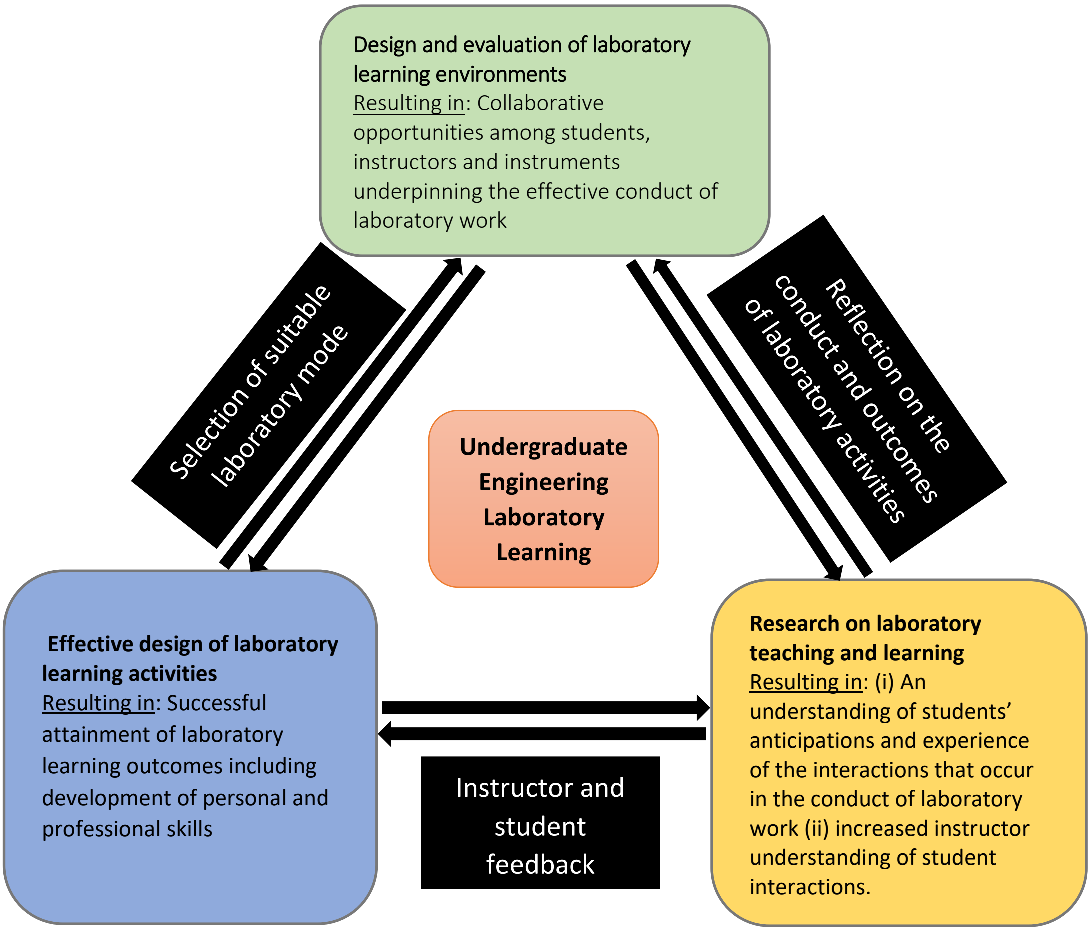


Figure 1.1: Theoretical Framework (based on the Model of Educational Reconstruction by Duit et al., 2012)

1.3.1 Effective design of laboratory learning activities

Laboratory work is an integral component of engineering studies. For students to graduate with an accredited engineering degree, it is important that they are provided with sufficient laboratory experience in their undergraduate studies. This experience can be enriching only when the activities are suitably designed for instructors to deliver and students to obtain a high quality laboratory education. Effective design of laboratory learning activities results in the students' successful attainment of laboratory learning outcomes including development of personal and professional skills.

1.3.2 Research on laboratory learning

To improve laboratory learning experiences for both students and instructors, it is vital that regular research is conducted on the ways in which laboratory instructional practices are carried out and to investigate students' learning experiences and the outcomes that result from those practices. Research can be carried out by

(i) Observing of students' conduct of laboratory activities,
(ii) Allowing students to self-report on their experiences of the laboratory, and,
(iii) Conducting semi-structured interviews to provide students with opportunities to express their needs and opinions on the effective design of laboratory activities.

Research on laboratory learning results in

(i) An understanding of students' anticipations and experiences of the interactions that occur in the conduct of laboratory activities, and
(ii) Increased instructor understanding of student interactions

1.3.3 Design and evaluation of laboratory learning environments

A well-planned design of laboratory activities firmly supported through research conducted for their cause and effect on students' learning can make the actual task of designing the laboratory environment much simpler. An ideal face-to-face laboratory environment provides opportunities for students and instructors to engage in productive interactions and also for students to learn through the hands-on manipulation of equipment and instruments. Design of the laboratory environment should be followed by evaluation of the design to assess its effectiveness in meeting the targeted objectives. The effective design and evaluation of laboratory learning environments provides collaborative opportunities among students, instructors and instruments underpinning the effective conduct of the laboratory activity.

1.4 Conceptual framework

For any laboratory design, the central focus is always placed around students who are linked with other students, instructors and equipment via a set of interactions. These relationships are illustrated in Figure 1.2. Thus, in the course of conducting a laboratory, a student may engage in four distinct types of interaction, namely, student-student (SS) interactions, student-instructor (SI) interactions, student-equipment (SE) interactions, and indirect interaction (IndInt). These interactions then support the student's conduct of the laboratory, namely, operation of equipment, data collection and results analysis that are defined or guided by the content of the laboratory instruction sheet.

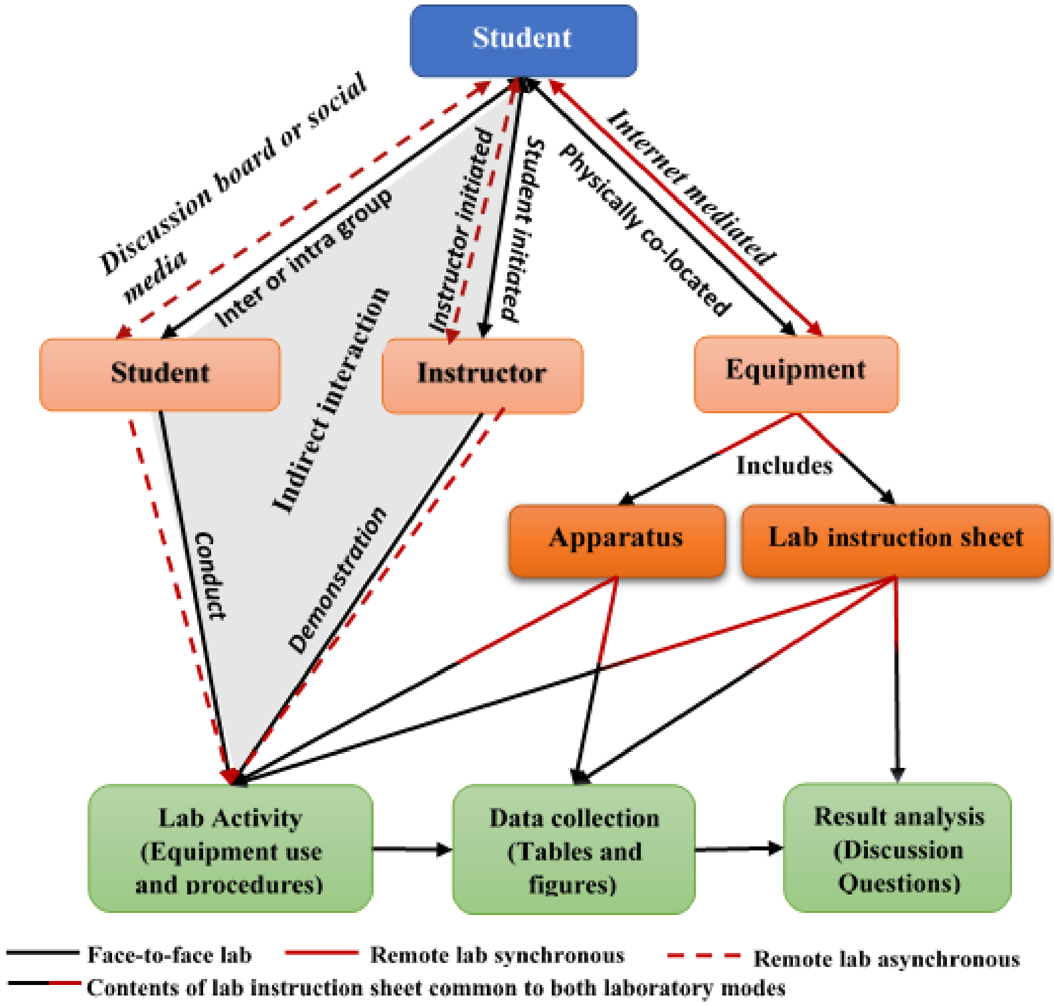


Figure 1.2: Relationship between the interaction types in face-to-face as well as remote laboratory modes

Each interaction category makes a distinct contribution to students' laboratory learning (Fila & Loui, 2014; Lowe et al., 2012; Park et al., 2017). In Figure 1.2, differences between face-to-face and remote-access laboratory modes occur as a result of whether the action link or interaction is synchronous or asynchronous (Heradio De La Torre et al., 2016; Jara et al., 2012). These interactions and their operation in the two modes are expanded upon in the following sub-sections.

1.4.1 Factors affecting the interactions

There are some important factors that influence the way that the elements - student, instructor, and equipment - interact with each other; these factors are: location, initiation and medium.

Location refers to the arrangements made in which the interactions occur in the laboratory. In the face-to-face laboratory, students, instructors and the equipment are all situated in the same physical facility and share synchronous interaction. By contrast, the only real-time interaction in the remote laboratory is between students and the equipment, this being guided by the laboratory instruction sheet (Ng, 2007; Sonnenwald et al., 2003) because students remotely access and control real equipment through a web interface.

Initiation relates to interactions between the student and the instructor which can be either instructor-initiated or student-initiated (Bright et al., 2008; Sher, 2009; Stang & Roll, 2014). Instructor-initiated interaction mainly takes place during a demonstration of the laboratory activity (most often at its start), whereas student-initiated interaction often takes place when students have difficulties with a laboratory task and therefore seek help from the instructor or have questions that may extend their understanding of the task. When the instructor is physically absent in a remotely-operated laboratory, initiation can only be due to the student. However, instructor and student initiated interactions can exist in the remote laboratory context when it is mediated by an internet supported platform.

Finally, the medium refers to the platform that permits student interaction with the equipment. Students are physically present with the equipment in the face-to-face laboratory, whereas in the remote laboratory student interaction with the equipment is mediated by an internet browser and a user-interface that allow students to establish a connection with and operate the equipment. In the remote laboratory (studied in this thesis), during the laboratory activities, students interact asynchronously (Corter et al., 2007) with other students and instructors generally on internet-mediated institutional platforms such as discussion boards or the social-media platforms like Facebook (Heradio De La Torre et al., 2016; Jara et al., 2012; Jeschke et al., 2008). However, some remote laboratories can be synchronous in terms of the interactions between students and their instructors during the conduct of laboratory activities (Garcia et al., 2021).

1.4.2 Important elements of traditional laboratory work

Student-equipment interaction includes interaction with the apparatus for its manipulation and also interaction with the laboratory instruction sheet. In engineering laboratories, the laboratory instruction sheet is the most comprehensive source of information for students, providing essential information on the operation of the equipment and its sequencing during the laboratory session. The laboratory activity also has two other important components, namely, data collection and results analysis that are related to the laboratory work. These components are also guided by the laboratory instruction sheet.

Equipment use and instructions for procedures contained in the laboratory instruction sheet initiates both student-student and student-instructor interactions for manipulating the apparatus and for all other laboratory related tasks. In a face-to-face laboratory, student-student interaction may occur between members of the same group or between different groups. The instructor interacts with the students during a demonstration of the laboratory procedures based on those described in the laboratory instruction sheet. Student-student and student-instructor interactions further give rise to indirect interactions. The data-collection and results-analysis instructions from the laboratory sheet initiate the student-equipment interaction. Thus, in the face-to-face laboratory, the contents of the laboratory instruction sheet influence all four interaction categories. By contrast, in the remote laboratory, the instruction sheet directly guides and influences the student-equipment interaction but it has limited and indirect influence over the other three categories of interactions, namely student-student, student-instructor, and indirect interactions. For both laboratory modes, the laboratory instruction sheet usually contains tables and figures and also discussion questions. These are designed to assist students with data collection and data analysis to arrive at findings that illustrate the concept that the laboratory is designed to reinforce or impart to students.

In the face-to-face laboratory all three interactions shown in Figure 1.2 are inter-related which then implies that the activities (in the row below) are also interlinked. On the other hand, the remote laboratory studied in this thesis provides opportunities for students to work independently and explore all aspects of the experiment but without the opportunity of directly collaborating with peers or seeking guidance from instructors.

1.5 Significance of the study

This study is significant in terms of the contribution that it aims to provide in designing remote laboratories for the future as well as to enhance the present and existent face-to-face undergraduate engineering laboratories. This study stands to

- Develop a better understanding of how students learn in laboratories.
- Help re-design physical laboratories for an effective teaching methodology in the face-to-face laboratories.
- Identify the gaps that have prevented the widespread adoption of remote laboratories. For this purpose this study will make an attempt to explain the actual learning process in engineering laboratories.
- Inform the design of efficient, effective and authentic remote laboratories for the future.
- Allow institutions to provide more flexible and high-quality laboratory education to larger cohorts at a relatively low cost and with similar learning outcomes to those of a face-to-face laboratory.
- Establish collaboration between institutions allowing them to share their laboratory resources and also help allocate their budgets efficiently.
- Help design an instructional platform for teaching practical and collaborative skills to engineering students which will prepare them for their professional careers where remote operation of tools and collaboration will be an integral component.

1.6 The intended outcomes of the study

This study will first identify the interaction types in a physical face-to-face laboratory through direct observation, surveying students and analyzing video recordings and then assessing their contribution to the learning processes involved in experimental work. A similar study will follow for remotely-operated laboratories. Interactions identified in both laboratories will be correlated with the expected laboratory learning outcomes. Finally, students' experiences from both laboratories will be compared in order to prioritise the most important interactions that must be incorporated in the design of remotely-operated laboratories for the future.

1.7 Research questions

The outcomes sought by the present study were obtained through the set of research questions presented below. These questions are deemed important to understand the way learning occurs and also the students' experience in the present design of the engineering laboratories in both modes so that recommendations for improved laboratories in both modes can be made. This thesis is not about designing laboratories but studying students' interactions and their effect on students' attainment of the learning outcomes. These learning outcomes will later help to inform the design of laboratories.

RQ1 How does the expectation from various interactions before the laboratory activity relate to the occurrence of interactions experienced during the conduct of laboratory activities in a face-to-face laboratory?

RQ2 How do student expectations relate to their perception of the importance and satisfaction for various interactions in face-to-face laboratories?

RQ3 How do student expectations relate to the frequency of interactions in a remotely-operated laboratory?

RQ4 How do student expectations relate to their perception of the importance and satisfaction for interactions in a remotely-operated laboratory?

RQ5 What are the effects of implementing remotely-operated laboratories on first-year undergraduate students' experience?

RQ6 What is the importance of the laboratory instruction sheet when students are conducting laboratory activities in face-to-face and remotely-operated laboratory modes?

RQ7 How do interactions in laboratory work contribute to students' attainment of the laboratory learning outcomes mandated by accrediting bodies?

RQ8 What interactions need to be prioritised for transferability from face-to-face to remotely-operated laboratories?

1.8 Organisation of the study

The research questions listed in Section 1.7 have been addressed in sequential order to arrive at a meaningful overall conclusion for the present study. Before addressing each of the research questions, Chapter 2 first sets up the background of the contexts used and described in this thesis. This chapter also provides a literature review for the area to justify the gap targeted for investigation in the present study. It sequentially summarises past and present research conducted for engineering laboratories in both face-to-face and remotely-operated laboratories, highlighting the benefits and drawbacks of each type. This is followed by a review of the interactions types. The literature on the significance of each type (student, instructor, and equipment) of interaction is also reviewed. Finally, a clear justification is provided for investigations required to answer the research questions presented in section 1.7. Each subsequent chapter explains the research methodology adopted for investigation and data analysis method for the research question being addressed.

Chapter 3 addresses the first research question: ***RQ1 how does the expectation from various interactions before the laboratory activity relate to the occurrence of interactions experienced during the conduct of laboratory activities in a face-to-face laboratory?*** In this chapter, analysis of the results obtained from the investigation conducted for students' expectation of the various interactions and their actual interactions in terms of frequencies are reported. Results reported are from first-, second-, and third-year undergraduate engineering students. As a validation of the frequencies of interactions reported, analysis from a video recording of the first-year undergraduate engineering students during their conduct of laboratory activities is also presented. Chapter 3 concludes with a quasi-longitudinal analysis of the results from three cohorts.

Answers to the research question: ***RQ2 how do student expectations relate to their perception of the importance and satisfaction for various interactions in face-to-face laboratories?*** is presented in Chapter 4. This chapter reports results obtained from first- and third-year undergraduate engineering students. Expectations of these cohorts for the interactions is compared against their actual perception of importance for each of the interaction types. In addition, satisfaction expressed for the interaction types by both cohorts is also reported. Perception of importance and satisfaction with interactions are also studied based on students' performance in the laboratory activities. Chapter 4 concludes with a quasi-longitudinal analysis of the responses received from first- and third-year students.

RQ3 and RQ4, which are respectively***, how do student expectations relate to the frequency of interactions in a remotely-operated laboratory?, and how do student expectations relate to their perception of the importance and satisfaction for interactions in a remotely-operated laboratory?*** are addressed in Chapter 5. While Chapters 3 and 4 have reported findings from the face-to-face laboratories, Chapter 5 reports results obtained from investigation conducted in a remotely-operated laboratory. The results are obtained from first-year undergraduate engineering students about their expectations of interactions, frequencies of interactions occurring during their conduct of laboratory activity, their perception of importance of interactions, and finally, their satisfaction with the interactions experienced. Chapter 5 concludes with a comparison between the results obtained from first-year students in both face-to-face and remotely-operated laboratories.

The next three chapters present further analysis conducted for the results reported in Chapters 3 to 5. Chapter 6 presents a further analysis of the results obtained from first-year students in the face-to-face and remotely-operated laboratories. Analysis is conducted to provide answers to the research question: ***RQ5 what are the effects of implementing remotely-operated laboratories on first-year undergraduate students' experience?*** Here a comparison is made between first-year students' perception of the importance of interactions and their satisfaction with the interactions in both face-to-face and remotely-operated laboratories. Students' opinions regarding the effects of implementing remotely-operated laboratories on first-year undergraduate students' experience are also presented from semi-structured interviews conducted for students in both laboratory modes.

Further analysis conducted for the importance of student-equipment interaction in Chapter 7 presents answers to the research question: ***RQ6 what is the importance of the laboratory instruction sheet when students are conducting laboratory activities in face-to-face and remotely-operated laboratory modes?*** Because the laboratory instruction sheet is a key part of the student-equipment interaction, again first-year students' perception of importance of laboratory instruction sheets in the conduct of laboratory is reported in this chapter. This chapter also presents students' views and opinions regarding the importance of laboratory instruction sheets and also recommendations for the improvement of laboratory instruction sheets for effective conduct of the laboratory activities in both laboratory modes.

Laboratory education is effective when it contributes to students' development of the expected personal and professional skills. With this in mind, Chapter 8 presents answers to the research question: ***RQ7 How do interactions in laboratory work contribute to students' attainment of the laboratory learning outcomes mandated by accrediting bodies?*** In this chapter, perceptions of final-year undergraduate students and instructors regarding the relative importance of interactions in their contribution to the attainment of the ten laboratory learning outcomes stipulated by Engineers Australia (Engineers Australia, 2019). This chapter concludes by identifying the most important interactions in face-to-face laboratories and also making recommendations for future design of remotely-operated laboratories.

Chapter 9 finally summarises the results reported in Chapters 3 to 8 to provide answers to the research question: ***RQ8 what interactions need to be prioritised for transferability from face-to-face to remotely-operated laboratories?*** This chapter presents a list of interactions that should be prioritised for transfer from face-to-face to remotely-operated laboratories.

1.9 Ethics Approval

The work reported in this thesis forms a part of an overarching project entitled "The online future of science and engineering education: The essential elements of laboratory-based learning for remote-access implementation" funded by the Australian Research Council for which ethics approval was granted on 19th October 2015 for a period of four years. The approval was further extended to 16th October 2020. The ethics approval granted for the project is shown in Appendix A.

1.10 Associated research conducted

Some of the results reported in this thesis have been published in a peer-reviewed journal or conference proceedings. The results of Chapter 6 have been presented in the annual conference of *American Society of Engineering Education* and published in the conference proceedings. Similarly, the findings of Chapter 7 have been published in the *European Journal of Engineering Education*. Also, the results of Chapter 8 have been presented at the annual conference of *Australasian Association of Engineering Education* and published in the conference proceedings. There are additional research studies conducted as part of the investigations reported in this thesis. This work is presented in the appendix section of this thesis. The first paper looked at an alternative approach to student assessment of laboratory work in engineering and was published in the *Australasian Journal of Engineering Education*.

1.11. Limitations of the study

This thesis focuses on the learning processes of students in the laboratory modes that involve manipulation of real physical equipment, that is, face-to-face and remotely-operated laboratories and does not consider other modes such as simulated and virtual laboratories. For face-to-face laboratories, students conducting traditional process-driven mechanical-type experiments are only reported in this thesis. In the case of remote-laboratories, students' responses only from one first-year mechanical-type remote-laboratory have been reported. The remote laboratory studied was remotely-operated and not a remotely-delivered experiment. Further, this study is largely about procedural (mechanical-type) face-to-face laboratories and does not report on open-ended laboratory types. However, students in their fourth-year attended open-ended laboratories and their experience of interactions in laboratories from all four years of engineering is reported. This study has been conducted using quasi-longitudinal method. Although an attempt has been made to present comparison of students' perceptions and opinions from first- to fourth-year of engineering degree, responses of students reported across all four years are from different cohorts.

Responses of students reported from their fourth-year of engineering and first-year students conducting remote laboratory experiments were from small cohorts of students and instructors. Students and instructors participating in the surveys were from Civil, Mechanical and Mechatronics engineering. The research presented in this thesis only examines accredited university engineering degrees. The findings reported in this thesis are based on teaching and learning processes in the undergraduate engineering laboratories in the context of Australian universities and does not explore international perspectives and scenarios.

1.12 Chapter Summary

An overview of the research reported in this thesis has been presented identifying the focus of individual chapters in terms of the formulated research questions. The theoretical and conceptual framework established has provided the foundation on which to clarify the main objectives and significance of the study. Chapter 2 presents a review of research literature to justify the purpose of the overall study.

Chapter 2

Literature review

2.1 Introduction

This chapter comprises a discussion of the literature, along with their evaluations, on the topics that have direct relevance to the theme of this research. The discussion is based upon the accumulation of findings in various fields such as engineering laboratories in general and in particular, face-to-face and remote laboratories, the learning process and learning outcomes for engineering laboratories, the role of social interactions in laboratory learning, comparison of the benefits and opportunities for collaboration in face-to-face and remote laboratory modes.

All of the areas listed above are reviewed in the sequence of their historical context with an overview of the key ideas and theories presented and relevance of the topic to the ideas at the core of this research. Finally, the central concepts are summarised to identify the gaps in the field of research.

This thesis reports findings from laboratories that involve manipulation of real physical equipment, that is, face-to-face and remotely-operated laboratories and does not cover simulated or virtual laboratories. Therefore, the literature review is focused on discussions of only face-to-face and remotely-operated laboratories.

The outline of this review is as follows:

- *Engineering laboratories (Section 2.2)*: The review commences by highlighting the importance of learning associated with the practical component of the engineering curriculum. A shift is then made towards describing the existing laboratory structure and its functioning in the engineering curriculum. A smooth transition is made towards the existing laboratory modes available for conducting experiments in engineering studies. Face-to-face and remote labs are highlighted as they are central to this research.
- *Different modes of laboratory in engineering (Section 2*.3): Different modes of engineering laboratories are discussed with a special focus on face-to-face and

remotely-operated laboratories as they include manipulation of real physical equipment.

- *Learning processes in the laboratory (Section 2.4)*: The purpose of laboratory education is described in detail identifying the learning processes involved in engineering laboratories. The discussion examines both face-to-face and remotely–operated engineering laboratories.
- *Interactions in the laboratory (Section 2.5)*: Following from the above, learning processes are explained in more depth based on established theories and also the interactions that are associated with the laboratory work. The three main categories of interactions highlighted in the discussion are those between student-student, student-instructor and student-equipment.
- *Association of interaction with learning outcomes (Section 2.6)*: The discussion notes the affordances of each laboratory mode in terms of interaction possibilities and finally presents a gap that has been presented as the area of focus in this research.

2.2 Engineering Laboratories

2.2.1 Defining a face-to-face laboratory in the engineering context

Laboratory work has been an integral part of engineering degrees. A laboratory provides students with an opportunity to experiment, observe and study phenomena. Engineering studies mandate students to acquire the essential practical skills necessary to work in the field as an engineer. The laboratory work not only empowers students with essential skills but also assists them in understanding the theoretical concepts learned through lectures in the classroom (Deacon & Hajek, 2011; Domínguez et al., 2018). Observing theoretical models in real practice through experimentation is believed to enhance students' work in their future careers (Hofstein & Lunetta, 2003; Trevelyan & Razali, 2012).

Laboratory experience is a requirement for students graduating with an engineering degree as stipulated by Engineers Australia (Engineers Australia, 2013). There are many reasons why laboratory learning is included as part of the engineering curriculum (Cooper, 2005). Laboratories are believed to foster many important and essential skills such as hands-on ability to manipulate engineering equipment, understanding safety and being able to apply a theoretical concept to develop models. Working in a laboratory is also associated with professional skills such as teamwork, communication, and collaboration (Rathod & Kalbande, 2016). All of the above skills are central to engineering work irrespective of the engineering discipline. Students should be able to extrapolate skills learned from laboratory work into a real-world situation. Also, Surgenor and Firth (2006) have shown that learning of practical concepts by activity helps in retaining about 75% of the concepts learned; this further justifies the importance of laboratories in the engineering curriculum.

2.2.2 History of laboratory in engineering studies

Laboratory work in engineering degrees has a history of more than a century in engineering educational practices. Feisel and Rosa (2005) have explained how engineering laboratory work became a mandatory part of engineering education. In their comprehensive review about the role of laboratory work, engineering education started its history with the apprentice in engineering, as the earlier engineering teaching practices were mainly founded on the concept of learning by doing. With time, the practical work was supplemented with theory and later balanced with it. So, engineering degrees started to include both theory and practical components in their curriculum. Feisel and Rosa (2005) further state that

"…institutions developed curricula that placed heavy emphasis on laboratory instruction and taught a new generation of young engineers how to design and build everything from turbines to railroads and canals to telegraph lines and chemical plants"(p. 122)

In their review, Feisel and Rosa have classified the engineering laboratory into three categories: development, research, and educational, a classification also discussed by Surgenor and Firth (2006). The present study will discuss the educational laboratories in particular in the engineering context. Educational laboratories are basically the platform where students are expected to learn skills and concepts related to the engineering practices that practising engineers are assumed to know. In reality this practice is carrying forward the legacy of engineering works and principles through to the next generation of engineers who obtain their engineering degrees that include laboratory studies as a major component.

The purpose of the engineering laboratory has been varied according to the discipline type. Nevertheless, a laboratory component is expected to provide skills and competencies depending on the field and discipline of engineering (ABET, 2017). The Accreditation Board for Engineering and Technology (ABET) briefly illustrates the importance of laboratory work for all disciplines related to the field of engineering. For instance, a laboratory for manufacturing engineers should equip them with the ability to measure variables and draw technical inferences from manufacturing processes. Similarly, for mining engineering the laboratory is essential for gaining expertise in geologic concepts, rock mechanics, and mine ventilation. Civil engineers strengthen their knowledge about the structure, properties, processing and performance of the materials systems suitable to a situation. Mechanical engineers should gain the ability to be professionally competent in working with thermal and mechanical systems which comes from the laboratory experience. Thus, it is evident that each discipline has its own purpose and set of technical expectations for students pursuing these studies.

According to Edward (2002), there are four objectives of laboratory work, namely, 'cognitive learning', 'inquiry methodology', 'vocational', and 'development of personal skills'. He further adds that among these objectives the most important one is 'inquiry methodology' because this indicates that the work starts with the formulation of a hypothesis and then progresses to obtain results with proper instrumentation and experimental work.

Some meaningful objectives were proposed by Ernst (1983) for the undergraduate engineering laboratory. He suggested that the role of laboratory work for engineering students should allow students to

a) Become a better experimenter,
b) Be innovative in their learning,
c) Gain a better understanding of the recent works in their field.

Ernst believed that the undergraduate engineering laboratory is not just for the students' development as an engineer but also for the Engineering academic to obtain improved professional development by gaining an opportunity to make revisions in the laboratory course in order to make it more contemporary for students' learning. In addition to face-to-face laboratories, many alternative modes have been introduced for performing laboratory activities in engineering. However, Magin and Kanapathipillai (2000) stood strongly against the replacement of the face-to-face laboratory in teaching a practical component of the course with any other forms or modes, as they discovered in their study that even not so well-designed experiments were sufficient to make students realise the importance of laboratory work in their field and thus enhance students' identity as engineers. Hofstein and Lunetta (1982) expressed concerns over the actual goals of laboratory teaching and learning being achieved in practice. But in general, it is an agreed fact that the laboratory is a useful medium for learning science and engineering concepts and is central to engineering studies in particular. The situations explained in their work are relevant to the modern teaching and learning context as well.

Engineering laboratories have seen numerous developments in techniques and tools used for experimentation. As technology has advanced, many forms of laboratory work have emerged, with a focus on providing better and improved laboratory experiences to a new generation of students and make them work-ready at the same time.

In the mid-1990s, the online teaching methodology shifted its focus towards laboratory education with experiments through technology mediation (Machotka et al., 2011). Since then there has been enormous developments in the field in terms of the technology used and its practical applicability, particularly through distance education initiated by simulated laboratories. Simulations succeeded in providing students with an improved medium to develop their understanding of the phenomena occurring in an experiment. Indeed, simulations have been widely used in the area of science and engineering (Feisel & Rosa, 2005). The three-dimensional view of equipment and ability to visualise the phenomena also in three dimensions assists in relating theory and practical work on any specific topic. Although this experience was a significant achievement, researchers realised that simulations could only be useful in exploring a theory conceptually with little scope for performing the actual experiment in the simulation mode (Feisel & Rosa, 2005; Nickerson et al., 2007). Simulations did not give the feeling of a real experiment as the possibility of variations in data and equipment was limited (Nickerson et al., 2007). Simulated laboratories could not meet the requirements of engineering laboratories.

Nevertheless, constraints such as physical space and cost were partly solved by simulated laboratories. However, their inability to replicate the features of a real face-to-face laboratory revealed the need to seek a medium which has the features of simulation as well as those of the face-to-face laboratory (Nickerson et al., 2007). The search for a new mode of laboratory, where students could perform a real experiment but without being co-located with the equipment, resulted in the advent of remotely-operated laboratories (Aktan et al., 1996). Remote laboratories addressed almost all technical, financial, and pedagogical issues related to carrying out the practical work (Lowe et al., 2009). When designing remote laboratories, the primary focus was on providing students and teachers with a platform where they could teach and learn theoretical concepts practically, irrespective of time and location (Lowe et al., 2013; Machotka et al., 2011) and most importantly preserving the learning outcomes available in the face-to-face laboratory (Corter et al., 2011). Emphasis was also placed on the need for students to become acquainted with the equipment.

Research in online laboratory learning has received wider attention in improving the learning experience. However, as stated above, the compromise that the new technology-supported laboratory brings in terms of collaboration and social interactions among the important elements of laboratory learning has remained a matter of concern for many educators today.

2.3 Different modes for laboratory work in engineering

2.3.1 An introduction to the face-to-face engineering laboratory

Modes of laboratory work refer to the different ways of performing an experiment or manipulating the equipment to obtain the desired data for analysis. The oldest and most common mode is the traditional face-to-face laboratory (Krivickas & Krivickas, 2007). In this mode, a student alone or in partnership with other peers manipulates a set of equipment based on the guidance received from an instructor in the laboratory or using the instructions provided in a laboratory instruction sheet (Jong et al., 2013). To date, this mode is more preferred and has received praise for providing a medium for effective delivery of practical concepts. This mode is well articulated in the literature on laboratory education. Before the introduction of online technology in educational practice hands-on work was the only mode of teaching the practical concepts to students (Domínguez et al., 2018).

2.3.1.1 Benefits of the face-to-face laboratory

Personally manipulating the equipment in the laboratory fosters sharing of conceptual knowledge among students (Jong et al., 2013). Jong et al. (2013) see the benefits of face-to-face experiments as providing opportunities for students to learn about complex engineering concepts through unanticipated events such as measurement errors that are much more likely to occur during the experiment in the face-to-face laboratory. The authors also state that the natural delays between the results obtained compel students to be more careful and reflective of their further investigations.

Ferri et al. (2016) have examined and reported the positive influence of hands-on activities on students' learning and also on the development of confidence in subject-related concepts. These authors also suggest that face-to-face experiments enhance and also help retain the concepts learned more effectively than any other medium of practical work. The authors also believe that face-to-face experiments trigger multiple senses such as vision, hearing, and touch which further instigates deeper mental processing thereby influencing students' learning and retention of the concepts for future implications.

In their literature review of educational objectives for laboratories in different modes, Elawady and Tolba (2009) have listed a several benefits of learning in the face-to-face laboratory. Some of the benefits mentioned are that the face-to-face laboratory:

- Provides real data
- Provides opportunity to interact with and manipulate the equipment
- Enables the design of open-ended experiments
- Provides opportunity to interact and work under the supervision of the instructor and also gives a sense of reality in experimental work
- Allows collaboration with other students for laboratory work
- Allows opportunity to work by trial and error

The benefits of working in a face-to-face laboratory have been investigated by Trevelyan and Razali (2012) who found that the traditional laboratories assist students greatly in developing practical intelligence which further helps in identifying faults in equipment. The authors relate these advantages to students' ability to efficiently continue their work after graduation. Elawady and Tolba (2009) also report that the proponents of face-to-face laboratories believe that the face-to-face experiments are vital from the perspectives of learning design skills and enhancing conceptual understanding of the subject. Corter et al. (2007) have reported that students found the face-to-face laboratory relatively more effective than any other form of laboratory in terms of educational outcomes. They also reports on the value of collaborative teamwork and physical presence in the face-to-face laboratory as perceived by students. Their study involved experiments which required students to substantially manipulate equipment.

2.3.1.2 Drawbacks of face-to-face laboratories

In their review of science and engineering laboratories, Jong et al. (2013) have highlighted some disadvantages of face-to-face experiments, such as being especially time consuming as they require more set-up time and space and there is time delay between the instruction and the result returned from the equipment. Ramos et al. (2016) expressed the concern that these laboratories always require a high budget allocation for buying sufficient numbers of equipment sets as well as for their maintenance. The authors suggests that these issues have primarily led to their reduced use in teaching of practical concepts today. Gomes and Bogosyan (2009) have also expressed similar concerns for traditional laboratories, stressing the high costs incurred due to the need for variety in forms and types of experiment in robotics, control, mechatronic engineering, automotive engineering, and micro/nanoscience.

Consequently, the drawbacks experienced while learning and teaching in the traditional face-to-face laboratories have led to the designing of many alternative modes for carrying out the experiment. Some of the modes which have gained popularity in the field of science and engineering are simulations, the virtual laboratory and the remote laboratory.

2.3.2 Origin of remote laboratories in engineering

Traditional engineering laboratories have existed for a century as an integral part of engineering courses across the globe. For approximately the last three decades, traditional laboratories have been complemented with internet-supported laboratories. There have been significant development in the remote laboratory and almost all disciplines have observed these developments to have either small or large effect (Chandra et al., 2014; Ellis et al., 2015; Fabregas et al., 2011; Yeung & Huang, 2003). Accessing the real equipment from a distance at any convenient time without the need to co-locate for performing the experiment is the foundational concept of remote laboratories (Fabregas et al., 2011; Lowe et al., 2009; Viegas et al., 2018). Remote laboratories can serve larger cohorts and require a fewer number of equipment sets (Teng et al., 2016). Lindsay and Stumpers (2011) have demonstrated that these laboratories, like traditional face-to-face laboratories, stand at the same level in terms of satisfying the accreditation requirement for engineering degrees. Lindsay and Good (2005) found that for some of the criteria, remote laboratories performed better than other modes of engineering laboratories.

Remote laboratories came into educational practice in the late 1990s (Aktan et al., 1996; Feisel & Rosa, 2005; Heradio de la Torre et al., 2016; Lameres & Plumb, 2014; Machotka et al., 2011). Computer-supported laboratory work has been in engineering education primarily to resolve issues of resource, space and financial constraints due to large student enrolments in the institutions (Gomes & Bogosyan, 2009; Lindsay et al., 2007; Magin & Kanapathipillai, 2000; Zubía & Alves, 2011, p. 12). In their article on the history of remote laboratories, Machotka et al. (2011) have presented an account of how remote laboratories were developed and how they have revolutionised engineering laboratory teaching and learning practices. Machotka et al. (2011) have pointed out some of the benefits that were envisioned for remote laboratories in the learning experience at university level. Remote laboratories:

- Allow effective management of time.
- Allow access to greater range of laboratory experiences and equipment.
- Are cost effective to set up and can serve large cohorts at one time.
- Remove the requirement of being physically co-located with the equipment for experimental purposes.
- Allow instructors to deliver and teach experiments online to domestic as well as offshore students.
- Allow students to conduct experiments at a convenient time and place.

The historical account of development and use of remote laboratory in Machotka et al. (2011) begins by mentioning the Mercury Project of 1994 where the tele-operation of robots was used on Mars to excavate artefacts in a terrarium. This account was preceded by facts about the first reliable remotely controlled laboratory developed by the Hewlett Packard Corporation at the end of 1960s where an individual could operate the equipment remotely through computers for data acquisition and also save those data for future reference. The graphical development environment of labview developed by National Instruments further enhanced the implementation of remote laboratories and also reduced the cost for future laboratory development and allowed multiple instruments to be controlled remotely through its integration with GPIB (General Purpose Interface Bus). The article by Machotka et al. (2011) further presents a history of how remote laboratories were developed and used effectively across multiple institutions between 1986 and 1999, before referring to remote laboratory development and implementation in Australia.

In Australia, remote laboratory work was first introduced by the University of Western Australia through the development of Internet Telerobot (Taylor & Trevelyan, 1995). The University of South Australia began its journey of remote laboratories through the development of Netlab which was first implemented in the Signals and Systems course (Machotka et al., 2011; Machotka & Nedic, 2006). In the Netlab, there is the possibility for up to three students to synchronise their laboratory work (Machotka & Nedic, 2006).

Corter et al. (2007) noted that for courses which focus more on the development of conceptual understanding for students, a traditional laboratory can be replaced with a remote laboratory. Remote laboratories were perceived as convenient in terms of time scheduling and ease of use by the students that were studied. Most of the remote laboratory studies revolve around enhancing the conceptual understanding of students (Elawady & Tolba, 2009). Some recent researchers have diverted their focus towards studying the role of human interactions in the laboratory learning process.

A comprehensive illustration of how remote laboratories were developed by Rutgers University and the University of Illinois at Urbana-Champaign for the Mechanical and Aerospace Engineering curriculum and the access then given to students has been given by Ogot et al., (2002). This partnered program was named the Integrated Remote

Learning Environment (IRLE).The main motivation behind the development appeared to be the requirement of catering for higher enrolments and the resultant budget and space constraints in the institutions. Although there were several benefits observed for this new approach, the separation of students from real physical equipment remained a concern. The authors also suggested some interesting approaches to outweigh the disadvantages that were associated with remote laboratories. Some of the suggestions given are listed below.

- Provide enhanced video quality of the experiment live feed.
- Make the experiment accessible from the web browser.
- Select experiments that mandate manipulation of equipment.
- Provide all components associated with a real laboratory with minimum instructor involvement.

Their study concludes by reporting that students' attainment of learning outcomes was not compromised and matched the corresponding achievements in the face-to-face laboratory. There have been numerous benefits observed in remote laboratory implementation. The following section will shed some light in this context.

2.3.2.1 The benefits of remote laboratories

Remote laboratories have emerged strongly as an important alternative to face-to-face laboratories for conducting laboratory experiments in the engineering field. Vuthaluru et al. (2013) have listed many useful aspects of remote laboratories, some of which are:

- Unrestricted access to the equipment for completing the laboratory assignment.
- Co-location with the equipment not mandatory for completing the assignment.
- Secured laboratories free from the risk of misuse or any damage by the students which significantly reduces the equipment maintenance cost.
- Academic performance of students learning distantly at the same standard as those traditionally taught in face-to-face laboratories.

Murray et al. (2008) have also reported similar findings as above. Students surveyed in their study for their conduct of remote laboratory work responded positively towards their interaction with the equipment. These authors have also demonstrated, through their work, the possibilities of scalability of remote laboratories in cases where expansion is needed. This aspect is attributed to the fact that remote laboratories can be designed and scaled to provide effective teaching and learning opportunities to larger student cohorts.

Remote laboratories have been found to be beneficial in teaching measurement techniques for digital courses in electrical engineering laboratories (Lameres & Plumb, 2014). The authors compared the effectiveness of remote laboratories with traditional face-to-face laboratories for digital circuit systems over a set of learning objectives such as cognitive, psychomotor and affective skills; they reported that there was no marked difference between the two modes studied.

Some benefits of remote laboratories are that they encourage students to think of the possible errors or any biases in the experimental data and provide students with a feeling of performing a real experiment (Jona et al., 2011). Moreover, data obtained from remote laboratories is perceived to be more reliable and trustworthy thereby providing students with a sense of ownership and full control over experiments. Francis et al. (2010) also highlight the potential benefits of learning online, as noted in their review article, which include: learner has the control over the environment in which s/he works, activity can be performed anywhere anytime and the communications made through email, chat systems, etc., can be stored for a long time for future reference.

Remotely-operated laboratories have been proven to be invaluable at the time when conducting in-person study has become challenging for universities, such as, during the recent COVID-19 pandemic (Achuthan et al., 2021). This pandemic has severely affected the education sector worldwide (Pokhrel & Chhetri, 2021). Remote teaching and learning of the practical component has been adopted by many engineering disciplines to avoid the gap in learning of students (Bangert et al., 2020). However, most of these have not been interactive. Most have used videos of an experiment being conducted with data provided to students for analysis.

Despite the benefits of remote laboratories, their implementation in educational practice is not wide. Instead some concerns have been reported which indicate the barriers to their wide adoption. Some of these concerns are discussed in the next section.

2.3.2.2 The constraints still overshadowing the benefits of remote laboratory work

The case studies presented by Watson (1993), which have reflected upon the positive and negative aspects of using Information Technology (IT) in education, have been further critically discussed by Kennewell (2001). Kennewell (2001) finds that students are more focused and motivated by the use of IT but on the other hand, insufficient knowledge of IT in instructors and students, and also the lack of a cooperative working environment for students, overshadow the benefits experienced. For remote laboratories to be as effective as face-to-face laboratories in engineering studies, it is essential that students and instructors are properly trained for conducting remote-laboratory experiments so as to achieve the same standards and essential learning outcomes provided by face-to-face laboratories in engineering (Lameres & Plumb, 2014).

The absence of physical touch of the equipment inclines students to prefer face-to-face laboratories over remote laboratories (Bright et al., 2008; Jona et al., 2011). There are factors listed in Bright et al. (2008) such as instructor assistance, group work and collaboration, interaction and presence, which have been stressed as important aspects in learning that can substantially affect the learning outcomes in remote laboratories. According to these authors, inadequate provision for students to connect and collaborate in real time for the experimental purpose can create a sense of isolation among students. To fill this gap they emphasise the need to create online social protocols which would enable students to collaborate, share and cooperate in their work in the remote laboratory. The authors also postulated that the opportunity for individuals to interact and operate equipment multiple times can be beneficial in enhancing the effectiveness of remote laboratories. Nevertheless, there is a lack of opportunity for students and instructors to interact face-to-face in the remote-laboratory setting (Cooper, 2005).

In the study conducted by Ives et al. (2014), students reported a positive attitude towards technology integration. They believed that a similar attitude from instructors is required for which they need to be rightly informed and trained. In contrast, Murray et al. (2008) write that similar face-to-face laboratory ‘consultative’ and ‘interrogative’ roles played by instructors when interacting with the students and also the intra- and inter-group interactions among students is difficult in the remote laboratory mode.

To improve the accessibility of remote laboratories and their wide adoption in education, Cooper (2005) argues that it is important that issues such as creating ways to guide students during the experiment, motivating them to critically think over the things that they do and observe during the experiment, and also ways to contact the remote instructor for resolving experimental issues and teaming up with peers remotely, are addressed. The author reminds his readers that designing a remote laboratory should not be just to provide access to the equipment remotely for convenience but also to provide a valuable learning experience. Further, a well-designed remote laboratory can enhance students’ participation in learning (Grout, 2017).

The findings reported by Francis et al. (2010) suggest that for online learning to be effective, first and foremost the learner should desire to study in this mode and this be complemented with the provision of adequate access and the right skills for using and working in the online environment. The other important aspect is the requirement of access to support at the time of their experience for any technical difficulties in operating the equipment.

For effective use of technology in teaching and the learning practice, Burkle and Kinshuk (2009) write that it is important to explore the possibilities for students to learn engagement in the classroom and also upgrade the technological skills and attitude of instructors to accept these changes in technology use. Technology integration should also allow instructors to encourage collaborative and independent learning among students (Geng et al., 2019; Le et al., 2018).

2.4 Need for studying the process of learning in engineering laboratories

The above sections put forth an argument which emphasises that in order to design and implement remote laboratories in engineering that are as effective as traditional face-to-face laboratories (Gustavsson et al., 2009), there is a need to design an internet supported laboratory learning environment with flexible opportunities to manipulate the equipment and, most importantly, an opportunity for students to synchronously team up with their peers and receive guidance and support from instructors. These requirements call for the further need to understand how students actually learn in remote laboratories and what learning outcomes are expected of them to graduate with an engineering degree. The following sections discuss these aspects of laboratory learning, that is, laboratory learning outcomes followed by the actual learning process, in detail.

2.4.1 Learning processes associated with laboratory work

Johri and Olds (2011) write that "*learning is a meaningful participation in a community of practice with an understanding of the 'constraints and affordances of social practices and of the material and technological systems of environments'"* (p.155). The authors also mention that "*it is through situated engagement in motivated action, using tools, and in interaction with others, that we learn some of our most essential skills"* (p.163).

Learning processes in the context of the present research refer to the mechanism of learning designed for students to acquire the intended learning outcomes highlighted above through experiments performed in the laboratory. A significant portion of this design is controlled by the University and the accrediting bodies such as Engineers Australia, Accreditation Board Engineering and Technology and Canadian Engineering Accreditation Board (Cicek et al., 2014; Surgenor & Firth, 2006), to name but a few. The learning associated with laboratory work is implemented using fixed set of variables such as the students, equipment, instructors, an allocated space, a laboratory instruction sheet and a period of time. Students continually engage with other variables during the laboratory work and demonstrate the expected learning in that setting. Theoretical concepts that have important practical application in the real world are only subjected for verification through the laboratory experiments. Almost all of the practical courses revolve around verification and testing of established theories.

Laboratory experiments are designed to allow students to learn many personal and professional skills (Prendergast, 2013). Laboratory work is broadly aimed at allowing students to develop laboratory skills under the instructor's guidance, how to interpret and implement information provided in a laboratory instruction sheet, how to collaborate and cooperate with peers in the laboratory and, most importantly, how to operate a set of equipment to obtain desired sets of results, and finally how to document and communicate the findings from an experiment. The purpose of coordinating students, instructors and equipment to achieve the engineering laboratory objectives is provided by the accrediting bodies for most institutions (ABET, 2017; Engineers Australia, 2013). All engineering disciplines have their own purpose and expectations from the laboratory work but the process of learning in all disciplines is the same.

Numerous research studies have been conducted to study the ways in which students, instructors and equipment behave in a particular laboratory setting. Many focus on the enhancement of collaborative opportunities between students (Bright et al., 2008; Ferreira & Mueller, 2004; Kolb & Kolb, 2013; Teng et al., 2016), while others have researched the effects of the collaboration between students and instructors (Gupta & Sharma, 2018; Lang et al., 2005; Nugent, 2009). Pedagogical aspects of laboratory teaching has also been a focus in some of the literature (Abdulwahed & Nagy, 2008; Round & Lom, 2015; Starks, 2017). The following paragraphs will illustrate each aspect in detail, as each has an important effect on the laboratory learning process.

Laboratory learning processes are alternatively understood as the activities and ideas which are mutually implemented or shared among students, instructors and the equipment. The other integral component in this process is the laboratory instruction sheet which governs and guides all activities during the laboratory experiment (Lal et al., 2020). The above-described learning process is also commonly termed as the interactions in the laboratory which define the way students learn and achieve from the laboratory work.

Abdulwahed and Nagy (2009) utilised Kolb's experiential learning cycle to describe their research on laboratory education which shows that knowledge can be obtained through either abstract conceptualisation or concrete experience of the field. Similarly, the gained knowledge can be transformed through either reflective observation or active experimentation. This fact is also applicable in the laboratory context, where learning is based on experience or personally operating equipment.

The review presented in Sher (2009) discusses several research studies on interactions between students and instructor in the context of web-supported distant education. His review has clearly indicated the important role that various interactions play in bringing better satisfaction and learning opportunities to students. Although the research reviewed was more inclined towards theoretical course content deliveries, the findings hold equal importance in all types of education, that is, both theoretical and practical subjects. The author himself investigated the impact of student-student and student-instructor interactions on students’ learning and their satisfaction for students who were enrolled in online learning programs in the area of Tourism Administration, Project Management and Health Sciences. His findings conclude that these interactions had significant influence over students’ learning and their satisfaction.

Students take on the information provided by instructors and then continually partner with their group members to exchange ideas and advice for better outcomes of the laboratory work. Students’ exchange of ideas continue beyond the laboratory premises as the laboratory experiment often then requires a well-written document with data adequately analysed. The learning process in the laboratory varies with the variation in the mode of conduct for a particular laboratory type. For instance, laboratory experiments are performed differently in remotely-operated engineering laboratories compared to the face-to-face laboratories (Elawady & Tolba, 2009; Ma & Nickerson, 2006; Machotka & Nedic, 2006). The former mode has asynchronous activities among the variables listed above while the latter involves all the variables interacting synchronously (Machotka & Nedic, 2006). These facts influence the students learning in the laboratory.

At the Colorado School of Mines, King et al. (1999) developed a multidisciplinary engineering laboratory in order to encourage students to be independent thinkers and become responsible for their own learning in the laboratory. Although instructors were present to guide them, students designed and carried out the laboratory procedures themselves. This approach was believed to have increased students’ excitement for laboratory work and prepared them better for industry.

2.5 Interactions in the laboratory

2.5.1 Introduction

Discussion on students' interactions with the essential elements of laboratory learning emerged from the time when technology entered educational practice. In the era of traditional face-to-face laboratory culture, studies show that more focus was placed on the enhancement of the skills for effective operation of machines or equipment and also how students can be better assisted in learning theoretical concepts. Hofstein and Lunetta (1982) stated that *"there is a need for obtaining more objective information about the interactions between teachers, curriculum resources and students, and about teacher and student behaviours during a laboratory based learning sequence."*(p.205).

Internet-supported laboratories in engineering have the potential to combat the physical and financial constraints of face-to-face laboratories. But soon remote laboratories gave rise to more concerns for educators and researchers. Primary concerns were related to students' learning of theoretical concepts along with acquiring better operational skills for handling equipment in laboratories to be operated over a web interface. Further concerns highlighted limited opportunities for students to physically interact with their peers, instructors and equipment synchronously with internet supported laboratory environment (Jara et al., 2012). The possibilities of establishing interactions between students, instructors and equipment in internet supported laboratories or remote laboratories has been a topic of discussion for almost two decades. There has been some attempts in resolving the above issues (Machotka & Nedic, 2006; Teng, Nedic, & Nafalski, 2016) but the complete resolution of the problem has not yet been achieved.

As noted by Dunlap, Sobel, and Sands (2007), teaching which does not involve interactions becomes a one way process of passing on the 'dogmatic truth and the cycle of knowledge acquisition' and where students are no more able to critically evaluate and validate knowledge. The authors also believe that interactions are vital for the students' learning experiences irrespective of the mode of learning, that is, online or on-campus. These views also resonate in Murray et al. (2008). Pea (1993) believed that "*knowledge is commonly socially constructed, through collaborative efforts toward shared objectives or by dialogues and challenges brought about by* *differences in persons' perspectives*" (p.50). The author also writes that the interference of computer technology in the educational practice has effectively replaced the instructional activity required for students but failed to create opportunities for students to use their potential in doing an activity or participating in an activity.

According to Pea (1993), design and accomplishment expectations for the tasks and activities at workplace mandate students' collaboration in their work for the purpose of effective learning. On the nature of work in the real world, the author adds that tasks are generally collaborative in nature and rely on resources which, for an individual, are impossible to memorise. The author further stresses the importance of interactions by saying that the ability to '*create and exploit social networks and the expertise of others*' assists greatly in learning and then, solving complex issues in the actual work scenario. In simple words, Pea's arguments are based on the context of the real world which is especially relevant for engineering work as well as engineering students. Most engineering work involves teamwork, a skill that is developed during student's interactions with instructors, peers and equipment.

Students learn through a socially shared activity which involves interactions with other students and experienced teachers in the classroom setting (Watson, 2001). Another interesting aspect highlighted in Watson (2001) is that students' sensory experience is triggered when they personally interact with physical material and also it helps them practice mental reasoning in the process. These interactions help students to enrich each other's learning. This fact is more relevant in a laboratory context where students are required to work in groups and perform a designated laboratory task.

Interaction in the learning process has received much attention for many reasons. Many psychologists and sociologists have expressed their views and opinions regarding the importance of learning through the interactions in any given educational setting. Rodrigo (2012) presents arguments based on famous psychologist Lev Vygotsky's theory. He writes that students while learning through the interactions with others, first personalise the knowledge and skills gained through these interactions and then utilise this knowledge and skills to define and direct their own actions and behaviour. Also, students' effective learning through interactions takes place in the zone of proximal development where the knowledge flow is generally from the more experienced to the less experienced. This understanding has been targeted towards the learning associated with the interactions resulting from the instructors and the students. In this zone of proximal development, Vygotsky believed that students and instructors are socially interdependent because there is mutual sharing of perspectives for the effective delivery of educational content. As reported by Hurst et al. (2013), students' perceptions of social interactions (not in the laboratory context) showed that interactions enhance learning experience by promoting their knowledge and helps in the development of critical thinking and problem-solving skills.

When students become dependent on the technology, they are unable to perform or understand the work in the absence of technology (Nwosu et al., 2015; Pea, 1993), an argument presented by Pea (1993). Also, computer-supported laboratory work is mainly designed to ease the work of students thereby saving their time. However, Pea (1993) warns that if students have minimum skills to contribute in the system performance then they are likely to lose their potential skills and also their interest in carrying out that task.

There is an important aspect discussed in Kennewell (2001) which states that the use of ICT in education is different depending upon the actor who uses it or are made to use it. For instance, teachers can make varying use of the same ICT and students' use depends upon the didactic information provided and the associated resources provided. Most importantly, the role of ICT varies significantly depending upon the subject area of use. This fact has great significance when advocating the creation of the opportunity for collaboration in the environment that is either controlled or supported by the ICT.

In the study reported by Allen and Conroy (1971), laboratory learning is described as a venue where individuals identify their own strengths and foster them further through collaboration with others in various situations. The authors further describe the learning environment in the laboratory as one which allows participants to explore their thoughts, ideas and feelings as well as one which enhances understanding, insights and skills of individuals, groups and the institution. The authors have also tabulated the learning objectives and outcome of laboratory training. These points indicate that in the laboratory, an individual feels motivated and is able to analyse the behaviours of others as well as its effect on oneself. Collaborating with other students also enables them to listen to and accept supportive criticism thereby preparing them to interact properly and in an effective manner with others. Similarly, laboratory learning also brings the benefits of establishing meaningful interpersonal relationships by allowing participants to understand dynamic complexities in group behaviour. Not only are the interpersonal relations well developed but also opportunities are provided to acquire skills that are useful in helping the group carry out of work smoothly and efficiently.

Allen and Conroy (1971) also suggest that laboratory work significantly increases cognitive openness, behavioural skills and understanding of social processes. Telhaj (2018) reviewed the research which studied the effects of students' interactions based on various parameters such as gender and ability level on the students' attainment of stipulated learning outcomes.

In their small sample survey on the perception of importance of discussion-based learning, Hajhosseini et al (2016) found that this approach to learning was beneficial in fostering critical thinking skills among students as well as improving social interactions among students and between students and their teacher. In their findings, discussion-based learning also enhanced students' *"truth-seeking, analyticity, cognitive maturity, critical thinking, self-confidence, self-evaluation and open-mindedness"*. The other benefits reported are:

- Better integration and synthesis of information.
- Arriving at a more fulfilling understanding of topic.
- Ability to explore a wide range of diverse perspectives.
- Improved tolerance for ambiguity.
- More insight about questioning of assumptions.
- Increased respect, along with more active listening.
- Collaborative learning that occurs more naturally.

The laboratory has long been believed to provide the essential personal and professional skills related to engineering work in industry. At work, individuals are expected to be a good team players and have excellent communication skills along with the required engineering skills. To obtain these skills, multiple factors come into play. Apart from learning skills to operate equipment, all engineering work involves group collaboration and strong team management. Group collaboration and teamwork are possible when students work in groups, guided by laboratory instructors.

Research has mostly focused on laboratory work to study the learning-outcomes requirements for engineers. However, some research addresses the way laboratory learning takes place. All the associated human as well as machine factors involved in laboratory learning have their special contribution towards the learning outcomes achieved by students which further play a significant role in their work as engineers in industry or related fields.

Hofstein and Lunetta (2003) pointed out the advantage of collaboration among students in the laboratory which they believe is most likely for the development of an understanding of how scientists work in a community to generate important findings for society. This important statement illustrates the need to enhance collaboration in laboratory work which should lead to cooperative learning. Thus in this study, which is a follow-up review of Hofstein and Lunetta (1982), they have stressed the need for studying the social interactions that occur in laboratory work.

Highlights from the Grinter Report (1994) have been presented in Froyd et al. (2012) which recommends the inclusion of coursework in social humanities into engineering curricula to help engineers develop social-interaction skills and also understand the consequences of technological developments in society. The authors also write that skills such as communication and teamwork are believed important by most professors and that they can be taught as well as assessed through properly designed marking rubrics.

Laboratory work is broadly categorised as being initiated by the laboratory instructor demonstrating the procedures related to experimentation, which is then followed by the group formation to carry out the laboratory work and collect related data (Watai et al., 2005). This approach initiates strong interaction between students and instructors which is mainly twinned around following the laboratory procedure and performing analysis to achieve the desired result (Kirkup et al., 2016).

2.5.2 Types of Interaction

Based on the above categorisation of work, interaction in the laboratory can be understood as the exchange of knowledge and experience among the students and instructors to obtain or test a data set by following a careful procedure to manipulate the equipment. Interaction has been defined as "*reciprocal events that require at least two objects and two actions*" (p.1) in Anderson (2003). When these objects and events mutually impact each other, interaction has taken place. Interactions have been observed and valued both in campus-based and distance-mode education (Anderson, 2003).

Students directly interact with each other, with laboratory instructors, and with equipment (Anderson, 2003; Moore, 1989; Sher, 2009b; Webb & Webb, 2005a). However, how each of these interactions contribute to the overall learning outcomes is not at all clear. Each interaction type makes a unique contribution towards students' learning outcomes from the laboratory work so these interactions cannot be ranked in any particular order of importance but generally the blend of the support received from all three interactions makes a laboratory experience useful to students. Laboratory work in all subject areas is so designed that all three elements are strongly inter-weaved together. The nature of their occurrences and effects in students' attainment of learning outcomes is heavily influenced by the mode of the laboratory selected for the conduct of the task (Lindsay & Good, 2005).

In a laboratory setup, interaction between student and the instructor is important. The presence of instructors in the laboratory provides assurance to the students (Tu & Mcisaac, 2010). This interaction is vital from the perspective that students not only gain practical skills but also receive more subtle influences like motivation and drive to learn subject matter (Stang & Roll, 2014). Similarly the interaction between students with their peers is important in developing team spirit and collaborative skills (Krauß et al., 2009). This interaction can make the laboratory activity engaging and encourages students' participation in the laboratory work. Finally, the third kind of interaction occurs between students and the laboratory equipment which ultimately contributes in reinforcing students' perceptions about the theory learned in lectures.

A laboratory must comprise one or more of the interactions mentioned above. Face-to-face laboratories have all three interactions working mutually while in the new era of remote laboratories, all the interactions between a student with the equipment and with the instructor are mediated by technology-supported platforms (Heradio et al., 2016). Some platforms operate on single interaction where students perform experiments independently, merely relying on an instruction sheets. Present proponents of remote laboratories envision a remote laboratory with the possibility of enabling all three interactions embedded in the system. Since there are distinct benefits from each interaction type, it is believed that an amalgamation of the three interaction types can produce a laboratory experience which is more beneficial and suitable to the modern demands from the social, political and international sectors.

Studies on interactions in laboratory learning rarely focus on the social composition of students that are defined by factors such as their status, gender or knowledge. The general presumption is that students collaborate and collectively build and share their knowledge when working in a group for laboratory work (Baumeister et al., 2016). Knowledge is socially constructed (Kittleson & Southerland, 2004; Pea, 1993; Young, 2010) and thus is significantly influenced by social factors that are involved in this process. Corter et al. (2007) state that '*the common experiences of a team, the way work is coupled, the incentives to collaborate, and the technology at hand are all factors that influence collaboration results (p.6)'.* Argyris (1967) writes that laboratory educators should create a challenge for students, which they either independently or collectively should investigate to find a solution. This point clearly indicates that the nature and the purpose of laboratory work intentionally promotes human interactions in the laboratory have a subtle but significant influence of the equipment associated with laboratory.

The main factor that leads to either success or failure of online education is student interaction and teamwork plays a significant role in e-learning, the absence of which causes a dissatisfaction with distance education (Francis et al., 2010). The authors also report on a study conducted at Virginia Tech in the USA which indicated that online courses must incorporate multi-media instruction, chat rooms and other ways of communication between students and with instructors such as video conferencing.

Summarising the above discussion, it appears that there are three types of commonly observed interactions in the laboratory, irrespective of the discipline, area of study and mode of laboratory. These interactions are between students, students with their instructor and between students with the equipment (Anderson, 2003; Moore, 1989; Sher, 2009). In the following sections, some insights are given into individual interaction types.

2.5.2.1 Student-Instructor interaction

Student-instructor interaction is the one that occurs between a student and instructor during or for the conduct of laboratory work. Instructors in laboratory work bear the responsibility to explain and guide the laboratory work for students. During this process, there is significant delivery and exchange of information with students. These actions of students and instructors result in the student-instructor interaction category. Myers (2008) has discussed the nature of student-instructor interaction both in and out of the classroom context.

Students' interactions with the instructor have always been an implicit phenomenon for any laboratory work irrespective of discipline. Introduction of technology into the educational sector, specifically for the conduct of the practical work, has raised concerns over the effect of reduced or indirect interactions with instructors on students' learning (Burnett et al., 2016)

An important aspect of the interaction between student and instructor is mentioned in Moore (1997) which he termed 'transactional distance'. Moore believes that there are three interlinked factors associated with the transactional distance: dialogue, structure, and learner autonomy. Dialogue refers to the meaningful conversational exchange between students and instructors whose level is significantly influenced by the medium used. The level of dialogue is further impacted by the structure of the content to be delivered. A more structured content results in less dialogue between the student and instructor while the reverse is true for less structured content. Highly structured content also results in greater independence for students. This research implies that a student who is an independent learner will interact less with his or her instructor. If this interaction is not mandatory for learners of all ages, then it is meaningful to say here that the content should be well-structured in its design. However, if the interaction with the instructor is believed to have several benefits beyond student learning, the focus needs to be placed on designing contents that are less structured. These differences create opportunities for students to interact with their instructors, ultimately making them less autonomous learners.

The argument presented above is ambiguous in terms of implementation in any educational situation. Nevertheless, in order to increase student–instructor interaction, as it is perceived beneficial for students learning (Gray & Diloreto, 2016; Sher, 2009), content should be designed in a manner that will allow students to remain dependent upon instructors for all major purposes. The default structure of the remotely-operated laboratory expects students to become independent. Synchronous collaboration between students and the instructor is difficult to achieve in some remote laboratories. Moore's theory about student-instructor interaction has been critically analysed by many other researchers for its validity in designing collaborative opportunities between students and instructors in the remote laboratory (Falloon, 2011; Gorsky & Caspi, 2005; Lindsay, Naidu, & Good, 2007). There is still a challenge for designers and implementers of this mode to create ample opportunities for collaboration between students and the instructor as well as for learners' independent learning.

Following the argument of Moore's theory of transactional distance is the theory of transactional presence described in Shin (2003). Transactional presence is concerned with the level of students' perception regarding the '*availability of, and connectedness with instructors, peers and institutions*' (Lindsay et al., 2007). In students' perception each of the three factors affect their learning outcomes. The argument holds great importance especially in the online learning context (Kehrwald, 2010).

Some important instances of interactions between students and instructors have been captured by West et al. (2013). They noted that instructors, during their interaction with the students, are either instructing them about the procedures or clarifying any doubts related to the instructions given in the laboratory sheet. At other times, instructors are engaged in dialogue with students where they either listen to their questions or formatively assess them by asking closed or open ended questions for assuring the correctness of the procedures followed as well as ensuring that the intended learning is occurring. These interactions are a common feature in practical courses as well. Like theory courses, the authors also noted evidence of some indirect or passive interactions between students and instructors where the instructors are not directly involved with students in any sort of dialogue but are continuously keeping an eye on them and their activities during the assigned activity. West et al., (2013) also write that different instructional styles significantly affect the way students interact with their instructors.

The role of interaction between the students with their instructors on the students' learning in a Physics laboratory has been researched by Stang and Roll (2014). For the purpose of their study, the authors investigated the student-instructor interaction for its frequency, initiation and duration of interactions, as they believed that instructors make a substantial contribution to students' learning in the face-to-face laboratory. They reported that frequent instructor-initiated interactions with the students in the laboratory play a significant role in the students' engagement in the laboratory activity. However, their findings indicate that the actual duration of interactions has no important effect on students' laboratory learning.

Three main issues that students generally ask their instructors about have been highlighted in Högström et al. (2010); these are related to safety and risks, procedures and equipment, and the concept behind the experimental work. All these issues are vital components for any laboratory work and any opportunity for students to interact with the instructor in the laboratory to resolve these appears to be a useful learning experience for students (Kirkup et al., 2016). In the study conducted by Högström et al. (2010), instructors were found to be of great help for students in learning data interpretation skills and also the appropriate way to think and behave in order to achieve the desired laboratory skills. Also, the authors pointed out that students take queries to instructors that they develop during the interaction with the other students during their laboratory work. It would therefore be meaningful at this point to explore the importance and context of students' interaction with other students in the laboratory learning process.

2.5.2.2. Student-student interaction

Student-student interactions in the laboratory occur when students work together by sharing their skills and prior knowledge to achieve a common goal set for the laboratory task (Fila & Loui, 2014). Although the initial design of the laboratory was based on the availability of resources, later research revealed several benefits for students working collaboratively in carrying out laboratory tasks (Högström et al., 2010; Sher, 2009). Interaction between students results in some significant skills acquisition which are highlighted as vital professional and personal skills in the accreditation guidelines for engineering degrees. For instance, teamwork and communication skills are considered to be important professional skills required in the workplace (ABET, 2017; Engineers Australia, 2013). The attainment of these skills are a direct consequence of the interaction between the students in the laboratory setting or any such condition where a task requires group work.

In their qualitative analysis, Stein and Wanstreet (2003) state that having the ability to choose group members as well as a collaborative format as part of the course structure were factors in course satisfaction and contributed to a greater comfort level with group members, increased learner-learner interaction and lessened the effects of transactional distance. Stein and Wanstreet (2003) cite the work of Moore, who recommends that the three types of interactions mentioned above are dependent on the design of the course; among them student-student interactions help build communities of learners where new ideas related to the course are shared and created. Laboratory courses, irrespective of the mode considered, are intentionally designed for students to learn and realise concepts in practice and through mutual collaboration.

Cooperative learning helps engineering students better perform academically by enhancing their attitudes and interest towards learning, regardless of educational setting and the nature of the task to be performed (Hsiung, 2012). Cooperative learning also enhances social skills for students such as teamwork and collaboration skills. Johnson and Johnson (2009) present the argument that in student-student collaboration, the group size plays an important role in learning. Specifically, the authors argue that students collaborating with fewer members in the team tend to distribute the tasks and responsibility among each member which increases individual accountability. On the other hand, larger groups tend to struggle through an unequal distribution of responsibilities.

While investigating the group-size effect for student collaboration in an Electrical and Computer Engineering laboratory, Fila and Loui (2014) present an argument that in collaborative learning amongst students, the interactions and the conversations in the laboratory provide students with the opportunity to argue and expand their knowledge and understanding. These interactions are believed to have a strong link with students developing skills for better reflection and reorganisation of their gained knowledge in the process.

The face-to-face laboratory mode provides students with opportunities to interact with other students synchronously and work in groups, while in the remote laboratory it is difficult to replicate the same opportunities for students (Ma, 2006). Stein and Wanstreet (2003) presented an argument supporting the above statement that students tend to interact more with each other if they can realise the partner's physical presence; thus, the reverse can reduce the interaction. Markman (2010) reports the findings of Johnson's (2006) literature review that compared synchronous and asynchronous computer-based discussions in educational settings. Johnson (2006) reports that synchronous conversation among students is most effective in education resulting in greater volumes of communication which can further contribute to students' motivation and skill development. Also, synchronous conversation can also lead to social relationship development which includes effective interactions among students and between students and their instructors, and also greater involvement in learning processes. The above article suggests that in the synchronous interactions, there is equal opportunity for students and the instructors to raise queries but in the asynchronous interaction, it is the students only who tend to ask questions of their instructors. Synchronous and asynchronous interactions can be organised in the remote laboratory contexts but the affordances and drawbacks mentioned above remain the same.

In the study of Sonnenwald et al. (2003), it is reported that students working in the remotely-operated laboratory did not feel a negative influence of the lack of synchronous interaction with other students. In fact, they performed as effectively as in the face-to-face mode. Students in this study also reported that they were more productive as well because the asynchronous interaction with other students only existed for meaningful conversations and discussions. However, the qualitative findings show that despite the benefits experienced, the opportunity to interact face-to-face with other student still remained a preference for students (Corter et al., 2007).

The literature on student-student interactions is divided when the mode of laboratory is considered. Many research studies present arguments in support of students working collaboratively because it helps them to develop teamwork, communication, and collaboration skills. These are the proponents of face-to-face laboratories. On the other hand proponents of remote laboratories believe that the opportunity to work alone or in collaboration (if required) helps students to develop independence and accountability for the data obtained through experimentation. From the perspectives of students, the depth of cues provided in handling the equipment in any laboratory setting determines the need for interaction (Sonnenwald et al., 2003). Lowe et al. (2012) also present some division of opinion among students regarding face-to-face and remotely operated laboratories.

Most of the remote access laboratories developed have been unable to provide students with a web-based environment that precisely recreates the collaborative group working and instructor driven experiences of traditional on-campus based laboratories (Callaghan et al., 2007). This article refers to the DIESEL (Distance Internet-Based Embedded System Experimental Laboratory) project which allows students to undertake real practical experiments either individually or collaboratively or alternatively under the direct guidance and supervision of the instructor. The authors believe that this mode of laboratory instruction can recreate a similar level of instructor-student and student-student interaction remotely as is the case in face-to-face laboratory. Their article presents a detailed architecture for remotely operated Embedded System experiment for establishing collaboration among students, and supervision for instructors to guide and interact with students.

One of the reason for student-student and student-instructor interactions to occur is for equipment manipulation and its handling. Similar to the effects of laboratory type in students' laboratory learning experience discussed above, the effects of students' interaction with equipment in student's learning experience have also been reported in literature. In the following section we discuss in detail the nature of student-equipment interaction in both face-to-face and remotely operated laboratory modes and the resultant effect on the student's learning experience.

2.5.2.3 Student–equipment interaction

Controlling and manipulating machines and equipment are an integral part of the engineering curriculum as well as engineering field work. A purpose of carrying out practical work is for students to become familiar with equipment and its operation. Students' interaction with the equipment, either face-to-face or remotely, has been perceived to be the most important in almost all research on laboratory education. This is so because most of the technical skills expected of engineering graduates is deemed possible through the interaction of student with the equipment for its operation. Feisel and Peterson (2002) have defined instructional laboratory experience as the *"personal interaction with equipment/tools leading to the accumulation of knowledge and skills required in a practice-oriented profession (p.6)"*

The importance of student interaction with the equipment was realised when alternative modes of laboratory work came into existence. Several researchers have investigated the learning effectiveness of different laboratory modes (Corter et al., 2007; Lowe et al., 2012; Ma & Nickerson, 2006; Nickerson et al., 2007). In all of these studies, the major concern is the lack of proximity with the real equipment during the experiment. Although the learning effectiveness in terms of the knowledge gained about the laboratory activity remained the same across all modes, students' preference to work in proximity with the equipment remained high. Direct interaction with the equipment resulted in the attainment of all skills stipulated by the accrediting authorities, whereas in the remote and simulated modes, there was some comprise. In the remote laboratory, students were reflective in their observation, worried less about equipment hazards and the associated safety concerns, and were pleased by the time saved by not having to setup the equipment (Vuthaluru et al., 2013). On the contrary, the lack of physical proximity did not allow students to detect faults in the equipment. From the real-world perspective, fault-finding and correcting errors are one of the common activities in the engineering workplace. Other research such as that by Machado et al., (2007) attempted to provide the experience of real equipment operation remotely using haptic devices. This approach further stresses the importance of hands-on operation of equipment in laboratory work.

2.6 Association between laboratory interactions and learning outcomes

Engineering students are expected to demonstrate various technical and professional skills for working as an Engineer, alongside subject knowledge and its conceptual understanding. For instance, it is critical for Engineers that they understand Occupational Health and Safety related issues. Although these concepts can be learned through lectures, first-hand demonstration and experience in the laboratory can be of great value. This reflects the importance of instructor presence in and during laboratory work.

Some important objectives for laboratory learning have been described by Hofstein and Lunetta (1982) such as planning and designing investigations, carrying out an experiment, observation of particular phenomena and analysing, applying and explaining results obtained through experimentation. These objectives have been well defined and documented formally for institutions to implement in their programs.

ABET and the Sloan P. Foundation came together in 2001 to establish 13 laboratory learning objectives for engineering undergraduate degree programs (Feisel & Peterson, 2002; Gustavsson et al., 2009). The objectives established for the engineering instructional laboratories were *Instrumentation, Models, Experiment, Data analysis, Design, Learn from failure, Creativity, Psychomotor, Safety, Communication, Teamwork, Ethics in the laboratory and Sensory awareness.* These objectives, also discussed in Krivickas and Krivickas (2007) and Froyd et al. (2012), clearly define students' achievement as an engineering graduate. Engineers Australia has very similar laboratory objectives for Australian engineering instructional laboratories (Engineers Australia, 2019). Male and Chapman (2005) have defined competency as *"the ability to perform activities in an occupational category or function to the standard expected in employment"* . Engineers Australia varies slightly from ABET in that the teamwork and communication skills are defined as professional competencies rather than as a laboratory objective for engineering students. These objectives set a benchmark for students' work in the laboratory as well as define the laboratory instructional design to be followed by the laboratory instructors.

A study of students' perception on the learning outcomes of laboratory work reported that students believe laboratories enhance their knowledge and conceptual understanding of a course which subsequently increases their interest in the course Salim et al. (2013). Students also realised the importance of laboratory work which is essential for developing practical skills and some professional skills such as team working and communication skills. In their investigation on learning outcomes, Lindsay and Good (2005) identified some task-specific and generic skills associated with the engineering laboratory, namely appreciation of the hardware, reasons for calibration, the complexity of signals, identification of assumptions, exception handling, processing of data, limitations of accuracy and comparison of data. The learning outcomes expected of engineering graduates, irrespective of the mode of laboratory used, are generally the same for all because there is no other formal documentation suggesting a difference in the learning outcomes. However, it is accepted that with the variation in the mode of laboratory work, there is variation in the learning outcomes achieved by students (Lindsay & Good, 2005).

Taking ABET (2005) as a reference, Corter et al. (2007) write that face-to-face laboratories equip students with psychomotor skills and sensory awareness, which they believe is not possible in remotely-accessed laboratories. Interestingly, teamwork is observed to be an achievement common to both face-to-face and remotely accessed laboratories. Corter et al. (2007) also concluded that students developed conceptual understanding of the course related to laboratory topic in the remotely accessed laboratory at a similar level to the face-to-face laboratories. Many other studies have reported on insignificant differences in the learning achieved through different mode of laboratories (Achuthan et al., 2021; Nickerson et al., 2007; Ogot et al., 2003).

It is seen above that an engineering student upon graduation is required to attain important laboratory leaning outcomes. Only a few studies have specifically investigated the effects of interactions on the attainment of those expected laboratory learning outcomes (Francis et al., 2010; Okebukola, 1984; Webb & Webb, 2005). Instead, investigations have been more focused on studying the effectiveness of the laboratory modes in attaining the essential learning outcomes (Bright et al., 2008; Lindsay & Good, 2005; Lindsay & Stumpers, 2011; Lowe et al., 2012). Most research on interactions are targeted towards online non-laboratory studies (Kim et al., 2009; Sher, 2009; Telhaj, 2018). These have indicated that interactions in learning is vital for the overall development of students. The following section outlines the need to study the transferability of interactions between face-to-face and remote laboratory modes.

2.7 Summary

It is accepted that laboratories are vital for engineering studies and that engineering laboratories today are conducted in different modes, the two of which have received the most attention are face-to-face and remotely-operated laboratories. Each laboratory mode has distinct advantages and disadvantages.

This chapter reviews important literature in the area of face-to-face and remotely-operated laboratories to show the need and importance of studying student interactions in laboratory as it has direct impact on students' attainment of learning outcomes expected for laboratory. Arguments supporting the need stated above are presented below.

1. Modern industry demands students be trained in a laboratory environment that prepares them for work that are carried out either in-person or remotely.
2. Face-to-face laboratories are widely used in engineering but have limited scope when students' enrolment are high and physical space and budget are a constraint. Remotely-operated laboratories are beneficial in such circumstances and are capable of providing similar level of learning as face-to-face laboratories.
3. Various interactions that occur during the conduct of a laboratory work supports in the development of some important personal as well as professional skills in students.
4. Interactions are mainly of four types: student-student, student-instructor and student-equipment and indirect-interactions.
5. Student-student and student-instructor interactions are easily observable in the face-to-face laboratory mode but in remotely-operated laboratories (especially mechanical-type engineering laboratories) students are generally deprived of the opportunity to interact synchronously with their peers and instructors during the conduct of the laboratory.
6. Manipulation of equipment remotely over the internet provides possibilities for effective interaction with the equipment during experimentation.
7. Research on laboratory education focuses more on instructors and less on students' learning processes. There is no proper method developed to catalogue student interactions and their impact on learning in laboratories.
8. The affordances of the face-to-face laboratory in terms of social interactions and their associated benefits, and also the gap that has been found in remotely-operated engineering laboratories, establishes a strong foundation for the research reported in this thesis.

Having noted the importance of student-student, student-instructor and student-equipment interactions, it is logical to investigate student perceptions and preferences for laboratory work through the lens of these interactions. Some interactions are vital from the perspective of acquiring the technical skills while others make a significant contribution to the attainment of personal skills such as teamwork and communication. The research so far has not clearly identified the essential interactions that every mode of laboratory must incorporate. Face-to-face laboratories provide opportunity for all interaction types while remotely operated laboratories provide only limited interactions which may have hindered their wide adoption by the engineering educators' community.

2.8 Direction for future implementation

The present study sheds light on the gap areas highlighted above. The main motivation for this research is to find techniques that can enhance learning and teaching in remote laboratories so as to increase their adoption in engineering-education practice. This outcome will be achieved through a detailed investigation of the interactions in face-to-face and remote laboratories. Thus this study aims to provide answers to the research questions presented in Chapter 1 (Section 1.7) which will ultimately assist in recommendations for the improved design of remotely-operated laboratories.

The sequence of the findings presented in the thesis have been arranged so as to ascertain the actual interaction types and their nature in both the face-to-face and remotely-operated laboratories. An understanding of students' perspectives on the importance of interactions types observed in both the laboratory modes is next investigated. Also investigated is the association between the important interactions and the laboratory learning outcomes. This aspect is followed by exploring students' perceptions on the relative importance of interaction types that contribute to attaining important laboratory learning outcomes. Based on the findings from those investigations, a prioritisation is made of the most important interactions that should be incorporated in the design of remotely operated laboratories.

Chapter 3

Students' expectations of the importance of interactions and frequency of occurrence of interactions in face-to-face undergraduate engineering laboratories

In Chapter 2, a justification for the need to investigate interactions in face-to-face laboratories was presented. Investigations conducted in Chapter 3 will identify interactions that occur frequently in face-to-face laboratories of first-, second-, and third-years of undergraduate engineering studies. Identification of interactions in the face-to-face laboratory were conducted on the basis of (i) student expectations from interactions expressed in the survey before the conduct of laboratory activities, and (ii) occurrence of interactions experienced by students during the conduct of laboratory activity, reported by a post-laboratory survey. The post-laboratory analysis for first-year students' response is validated with observation of student interactions in a video recording conducted for one of the selected laboratory sessions of a first-year undergraduate engineering laboratory.

3.1 Background and aims

Practical work is mandated for all students pursuing an engineering degree. A general characterisation of practical work in engineering is that it comprises a set of equipment that is developed to illustrate scientific theory and principles. This equipment is used by students in a laboratory to generate data measurements for the verification of theoretical models and concepts. All laboratory tasks, irrespective of the mode, are designed for students to develop better understanding and visualisation of the concepts learned through the curriculum.

Face-to-face laboratories incorporate four types of interaction that involve students, instructors, and equipment. These interactions that occur during a laboratory activity are believed to contribute to the attainment of learning outcomes expected for students learning in an engineering laboratory. The focus of this chapter is to understand the students' expectations of the importance of interactions and investigate how frequently those interactions occur in the laboratory, which involves coordinated activities among students, their instructors, and equipment assigned for experimental purposes.

Before presenting the investigation of this study, it is worth recalling some basic understanding of the meaning of the types of interaction focused upon in this chapter. As reviewed in Chapter 2, there are basically three main categories of interactions that occur in any given laboratory setting (Anderson, 2003):

1. ***Student-student interaction*****:** This interaction takes place between students during the conduct of laboratory tasks in the laboratory. Student-student interactions can occur between members of the same group or from different groups. The context for their interaction can vary from matters specific to the laboratory activity or to matters that are totally unrelated to the laboratory activity. Face-to-face laboratories provide opportunities for students to synchronously collaborate in their conduct of laboratory activity.

2. ***Student-instructor interaction*****:** During a laboratory activity, instructors may interact with a single student or a group of students. The first example of this interaction occurs when a student asks questions to an instructor regarding any matter related to laboratory, such as laboratory procedures, results-analysis, and clarifying theoretical concepts being illustrated by the laboratory activities. A second type occurs when an instructor instructs the whole class about the processes involved in performing the laboratory activity. Student-instructor interaction can be of two forms: student-initiated and/or instructor-initiated. This category of interaction is easy to identify in a face-to-face laboratory as both students and instructors remain present in the laboratory for the conduct of laboratory activity.

3. ***Student-equipment interaction*****:** Students interact with equipment in the conduct of a laboratory activity. This interaction involves students' manipulation of equipment to obtain the required data from the laboratory activity. This interaction is facilitated by instructors and peers present in the laboratory. Instructors provide initial guidance and demonstration of the operation of equipment, while peers collaborate with one another to manipulate it and collect data, following the guidance or instruction received. A student's interaction with equipment is also supported by a carefully designed laboratory instruction sheet. Students and instructors continually refer to this sheet throughout the laboratory activity. In face-to-face laboratories, students and instructors are physically co-located with equipment for conducting the designed laboratory activity.

These are the basic and visible interactions in the laboratory. However, there are some further interactions which require careful consideration such as a student learning by observing other students' actions and behaviours. These types of interactions are termed ***indirect interactions***. The interactions discussed above allow engineering graduates to develop appropriate technical skills and, more than that, professional outcomes that are characterised by social skills such as collaboration, teamwork, and communication skills.

The following sections introduce the research question and research method adopted for the investigation, followed by a description of the survey instrument used for the purpose of data collection. Finally, a discussion of the findings obtained through this study will be presented along with implications for further investigation.

3.2 Research Question

Chapter 3 provides answers to the first research question presented as a gap in Chapter 2, that is,

RQ 1: How does the expectation from various interactions before the laboratory activity relate to the occurrence of interactions experienced during the conduct of laboratory activities in a face-to-face laboratory?

3.3 Research methodology

In order to identify the interactions that govern the laboratory activity, a quantitative study (Creswell, 2014) was conducted in first, second and third years of an undergraduate engineering degree. A quasi-longitudinal study is considered important as the objective is to study the behaviour of students as they progress and develop from first-year to third-year of their engineering studies along with their conduct of the laboratory activities in the face-to-face engineering laboratories. Also, it was believed that the findings obtained through this study could be generalised to some other engineering disciplines and not limited to one specific engineering discipline. The first-year student cohort included students from all disciplines of undergraduate engineering studies. Second-year students were limited to Civil, Mechanical, Chemical, and Petroleum Engineering disciplines. The third-year students were all pursuing a major in the Bachelor in Mechanical Engineering degree.

Video recording was conducted for first-year students with permission from students, unit coordinators, and the associated laboratory instructors. This recording was done to validate the responses captured through the survey of students.

3.3.1 Design of laboratory activity

In the first-year undergraduate engineering program, students in a face-to-face laboratory were observed during their conduct of laboratory activities in the Engineering Mechanics unit. Details of the activities conducted in first-year face-to-face laboratory mode are provided in Appendix B and also in Lal et al. (2018).

Similarly, second-year students performed face-to-face laboratory activities for their Fluid Mechanics unit and third-year students were observed for their conduct of an activity in their Applied Fluid Mechanics unit. The details of the experimental arrangement for the second-year and third-year laboratory studied is also given in Appendix B.

3.3.2 Development of instruments

For the purpose of this study, pre- and post-laboratory survey questionnaires were designed. Pre-laboratory survey questionnaire has student-student, student-instructor and student-equipment interaction categories, while post-laboratory survey questionnaire has all four categories of interactions. Each category further has activities that are associated with that particular interaction type. The survey instruments were designed through multiple iterations to arrive at an optimal design of the instrument so that the actual laboratory procedures along with the factors associated could be identified.

3.3.2.1 Pilot study

Prior to the commencement of this study, a pilot study was conducted with first-year undergraduate engineering students to identify the essential factors and procedures of undergraduate engineering laboratory teaching. Once a firm understanding was developed, the activities and elements were grouped under relevant themes represented by the three categories of interactions discussed above. The pilot study was conducted to develop and test both pre- and post-laboratory survey instruments.

Pre-laboratory survey instrument

The pilot study concluded with the identification of 13 common laboratory activities associated with interactions between students, their instructors and the equipment they used during a laboratory activity. The survey designed for capturing pre-laboratory expectations of importance of interactions, had activities related to student-student and student-instructor interactions, student's activities during the pre-laboratory activity, and use of the laboratory instruction sheet. Each category had a further three activities that were the same for all categories. In other words, all of the categories mentioned above comprised laboratory procedures, basic science concepts, and results-analysis. Considering the direction of the overall study towards technology supported engineering laboratories, a question was included to understand students' perception of internet use for learning the basic theoretical concepts related to the laboratory activity.

Post-laboratory survey instrument

The questionnaire that was designed for studying perceptions of students after conducting a laboratory activity was called the post-laboratory survey. In this survey, responses to the interaction categories and their associated activities given in the questionnaire were sought in terms of the occurrence that students experienced during their laboratory activity. Occurrence of an interaction was categorized as either 'Never', 'Few times' or 'Many times'. The survey questionnaire is shown in Appendix D.1

Like the pre-laboratory survey, the main categories of interactions in the survey were student-student, student-instructor, and student-equipment interactions. Each of these interactions contained activities related to the learning of laboratory procedures, basic science concepts, and results-analysis. A further two activities were identified under each of the interaction categories which were students' discussion of general topics or topics that were related to engineering learning but not directly related to the laboratory activity.

A fourth category of interaction was identified during the pilot study as indirect interaction. This interaction was associated with a student learning either by listening to or observing other students' activity and/or other students' conversations with the instructors of the laboratory.

3.3.2.2 Revised instrument

Pre-laboratory survey instrument

For the first part of the study conducted in the first- and second-year undergraduate face-to-face engineering laboratory in 2017, the pilot version of the instrument was utilized. There were no pre-laboratory activity but interactions with the equipment and use of the laboratory instruction sheet were a major component of the engineering laboratory activity, therefore, the next version of the survey questionnaire contained activities related to the following interaction types: student-student, student-instructor, student-equipment, and student-laboratory-instruction sheet. This revised instrument was used in the investigation of the third-year face-to-face laboratory.

In all versions of the pre-laboratory survey instrument, students were asked to choose five interactions out of thirteen choices that they thought to be important and rank them in the order of importance ranking from 1 to 5, where 1 represented most important and 5 the least important. The final version of the instrument used in the study is shown in Appendix C.

Post-laboratory survey instrument

The post-laboratory instrument (shown in Appendix D.1) developed during the pilot study was administered to first- and second-year undergraduate engineering students working in a face-to-face laboratory at the initial phase of this study. In the revised post-laboratory survey instrument, a question on satisfaction for each interaction category was also included, as it was deemed important based on several studies that reported on students' satisfaction for laboratory activities and also various interactions (Nikolic et al., 2015; Sher, 2009).

With a view to providing students with more refined options for classifying their frequency of interactions, the survey questionnaire designed for the third-year students was revised with options as either 'Never', 'Rarely', 'Occasionally', 'Frequently' or 'Very frequently' to denote occurrences of interactions during the conduct of laboratory activity. Questionnaire used for third-year students in the post-laboratory survey is shown in Appendix D.2.

3.3.3 Data collection

Data for this part of the study were obtained over the first semester of 2017 and second semester of 2018. Prior permission was sought from the unit coordinator of each of the laboratories studied. Permission was also sought from students before they were requested to fill in the survey forms. Students were also provided with an option to withdraw their response and so participation in the study was voluntary. In semester 1 of 2017 for the undergraduate engineering degree, 112 first-year students and 205 second-year students provided their responses. Similarly, in semester 2 of 2018, 109 responses (approximately 50%) from students in the third-year of their undergraduate degree were received using the pre-laboratory and post-laboratory survey forms.

The pre-laboratory survey questionnaire was administered to students before they commenced their laboratory activity and also before the instructors began their demonstration of the laboratory activity. The estimated time to complete a survey was approximately three minutes of the total laboratory time.

The post-laboratory survey questionnaire was given to students after their completion of the laboratory activity and all its related laboratory tasks. During this process of seeking responses, an effort was made not to interfere with the regular operation of the laboratory and the teaching and learning processes.

Some of the laboratory classes were randomly chosen for video recording. The main purpose of the video recording was to assess the validity of the responses captured by the survey. The most recurring interactions as well as the reason for student interactions in the video were analysed. The recordings were observed using the GORP (Generalised Observation and Reflection Protocol) which is a video analysis tool developed by The University of California, Davis (Velasco et al., 2016). The original tool is based on the COPUS protocol, which was further customised to capture interactions observable in the laboratory selected for the study. The complete list of protocols used for observation in GORP is presented in Appendix E.

3.4 Results

This section presents an analysis of the data collected and discusses the findings to understand their implications. The results are presented in two subsections, where, the first discusses the results obtained through the analysis of the pre-laboratory responses and the second is the analysis of post-laboratory responses. It is to be noted that in the case of surveys all results under the student-instructor interaction are student-initiated student-instructor interaction. Similarly, for the video analysis conducted, student-instructor interaction refers to instructor-initiated student-instructor interaction.

3.4.1 First-year students in Engineering Mechanics

3.4.1.1 Students' expectations of various interactions

The type of interaction categories selected by students in the pre-laboratory survey reveals their level of awareness of those interaction categories. These responses also indicate their expectations of the interactions they were to experience during the laboratory activity. Figure 3.1 shows the proportion of students (in %) who selected an interaction category along with the associated laboratory activity out of the thirteen choices.

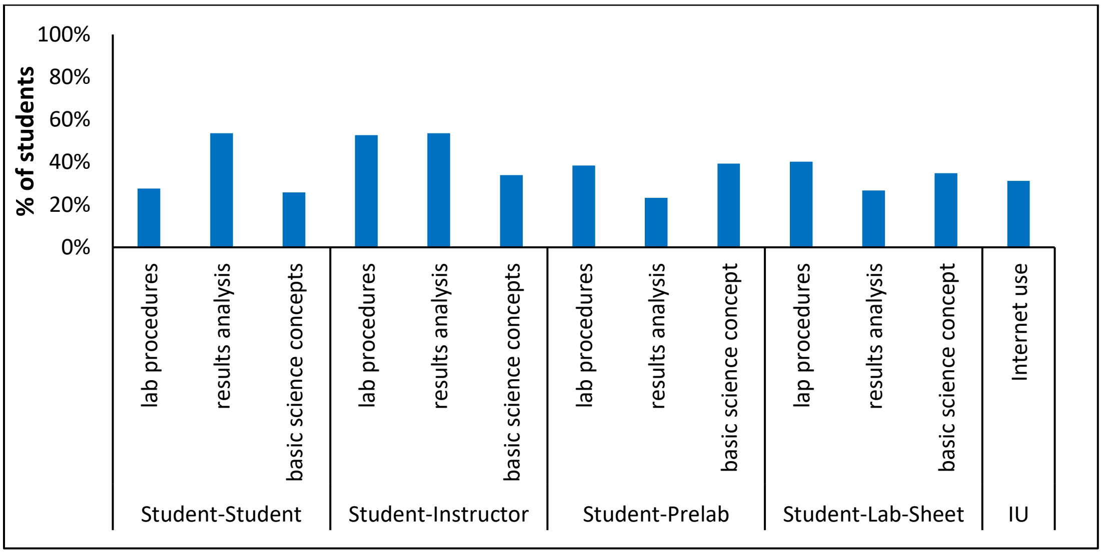


Figure 3.1: Pre-laboratory responses from first-year students (N= 112). Note: Vertical axis represents the proportion of the cohort who chose a particular laboratory activity under each interaction category, as one out of the thirteen choices. Note: IU=Internet Usage

The bars showing higher response represent more students perceiving that interaction category important for a particular laboratory task. For instance, students clearly expected student-student and student-instructor interactions to be more important than the other categories. Student-student interaction was thought to be important for learning skills relating to results-analysis and student-instructor interaction was expected as important for both learning laboratory procedures as well as results-analysis.

Similarly, results-analysis was expected to be enabled by interaction with peers and also with instructors. Also, this cohort expected to learn laboratory procedures from their interaction with the instructor.

As a preparation for the laboratory activity, prelab materials were made available on the Learning Management System (LMS) to students. Pre-laboratory responses reveal that they expected that reading prelab materials before the actual conduct of laboratory activity to be useful in learning laboratory-related procedures and also, underlying basic science concepts. Similar expectations were captured for laboratory instruction sheets.

In Figure 3.1, students' expectations for learning results-analysis (54%) under student-student interaction, and laboratory procedures (53%) and results-analysis (54%) under student-instructor interaction received most expectation from students than other categories. Figures 3.2 and 3.3, respectively, show the proportion of students under each rank level for results-analysis in the student-student and student-instructor interaction categories.

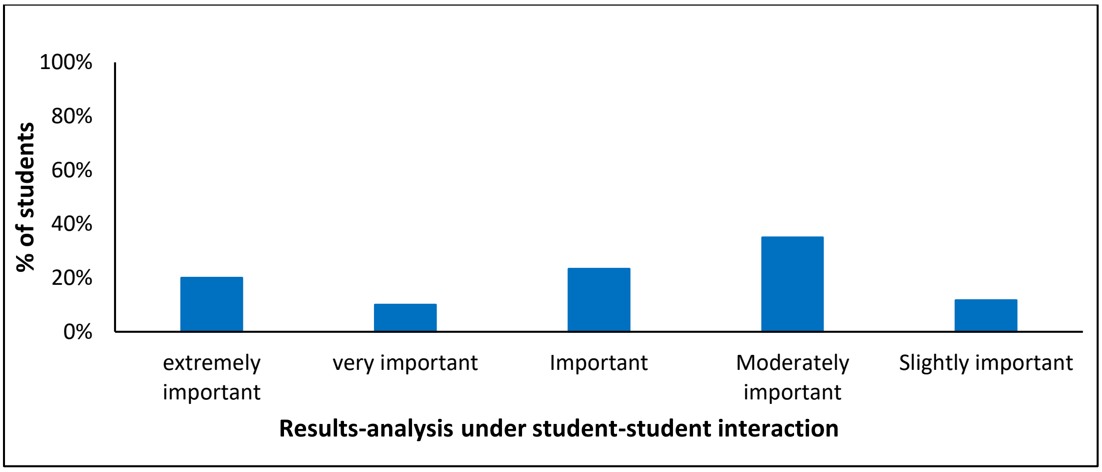
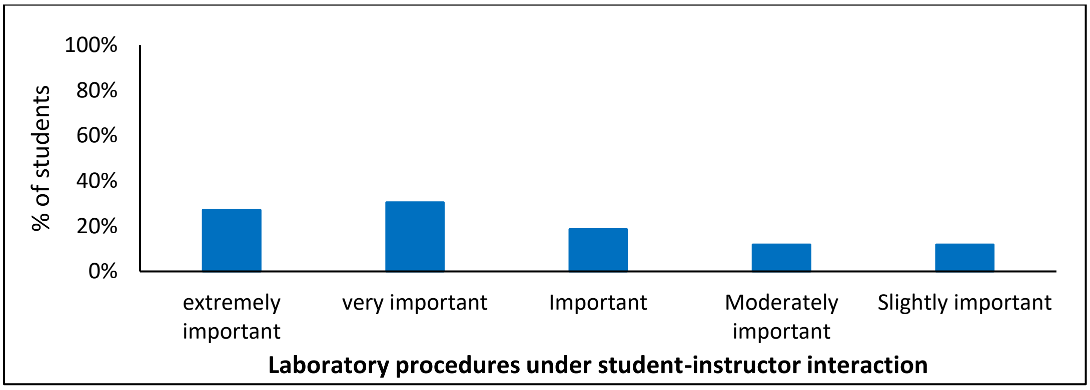
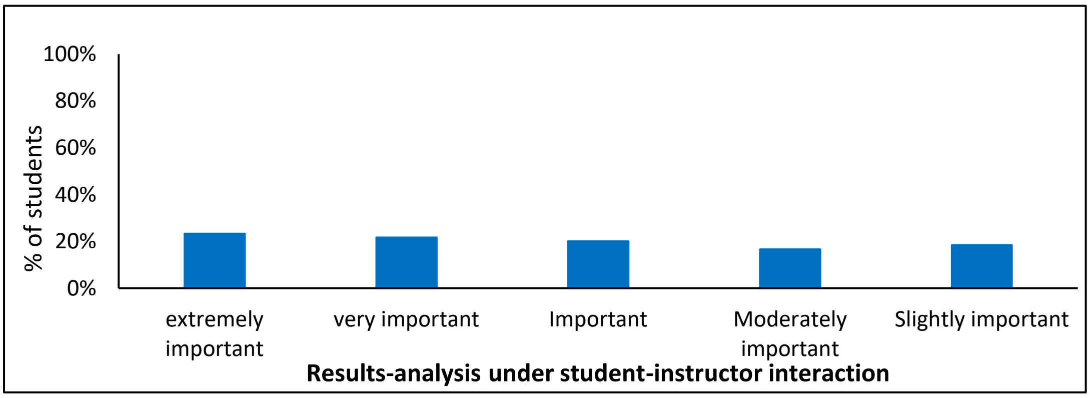


Figure 3.2: Analysis of the rank given by students for learning results-analysis through student-student interaction. Note: Vertical axis denotes distribution of students within each response who provided a rank out of the five rank choices provided. For calculating the proportion for each rank, total response under each rank was calculated and then divided by the total number of students who chose this activity. This figure is a further analysis of Figure 3.1.

Rank analysis in Figure 3.2 indicated that 20% of the total students who choose results-analysis under student-student interaction category considered it extremely important while 35% regarded it as moderately important.



(a)



(b)

Figure 3.3: Analysis of rank given for (a) laboratory procedures and (b) results-analysis in the Student-Instructor interaction category. Note: Calculations involved in the figure are the same as for Figure 3.2. This figure is a further analysis of Figure 3.1.

Similarly, Figure 3.3 (a) and (b) shows the proportion of students for each rank level for the laboratory procedures and results-analysis respectively under the student-instructor interaction category. These results show that the majority of students had high expectations of interaction with instructors for the purpose of learning laboratory procedures as well as for learning results-analysis of the data obtained through experimentation.

3.4.1.2 Frequency of occurrence of interactions

Figure 3.4 shows all levels of frequency of occurrences of interactions, that is, 'many times', 'few times', or 'never', experienced by first-year students.

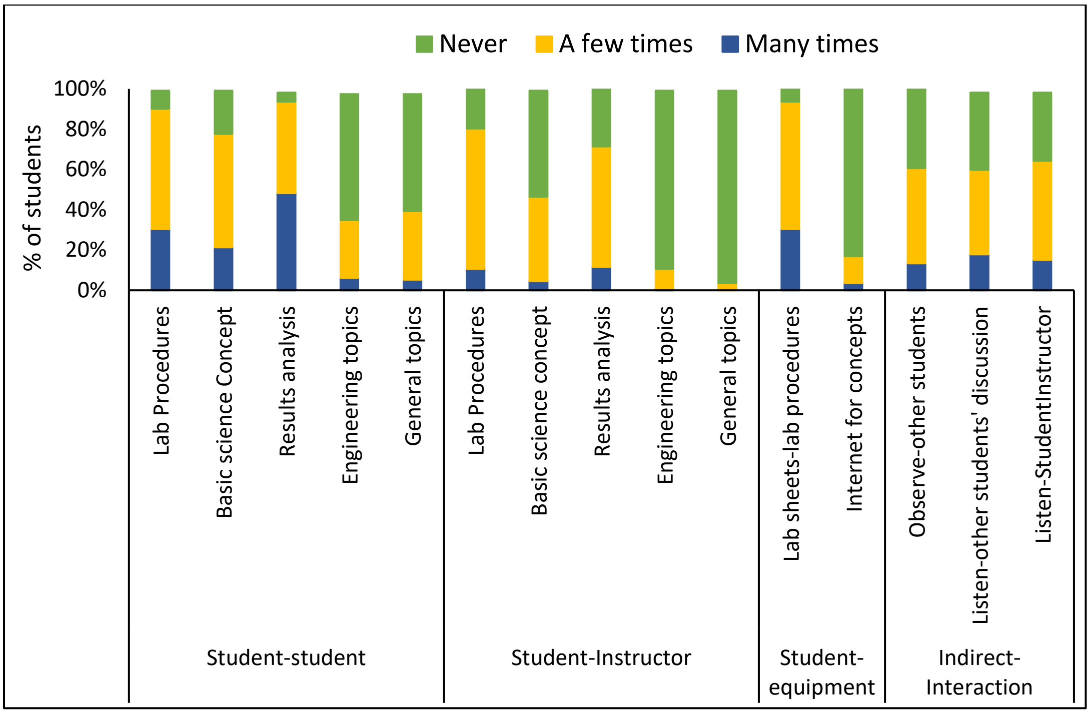


Figure 3.4: Occurrence of interactions experienced by first-year students (N=112). Note: Vertical axis shows the % of students reporting at each occurrence level. Some of the bars do not add up to 100% as not all students responded for those activities.

In Figure 3.4, first-year students' responses captured in the post-laboratory slightly varied when compared to their expectations reported in the pre-laboratory survey. Students' indicated that they interacted with their peers relatively more than with instructors for all aspects of laboratory learning. Laboratory instruction sheets were frequently referred to for learning laboratory procedures. Discussion of topics that were not directly related to laboratory activity was much less frequent than other activities.

Figure 3.5 depicts the activities that were most frequently experienced by students during their conduct of the laboratory activity and is extracted from Figure 3.4. About 48% of students said they interacted many times with their peers for learning results-analysis. For learning laboratory procedures and understanding basic science concepts, students again interacted most frequently with other students (30% for laboratory procedures and 2% for basic concepts respectively). Student-instructor interaction was the least frequent interaction exhibited in the response shown in Figure 3.5. Apart from peers, students also referred to laboratory instruction sheets (30%) for learning laboratory procedures.

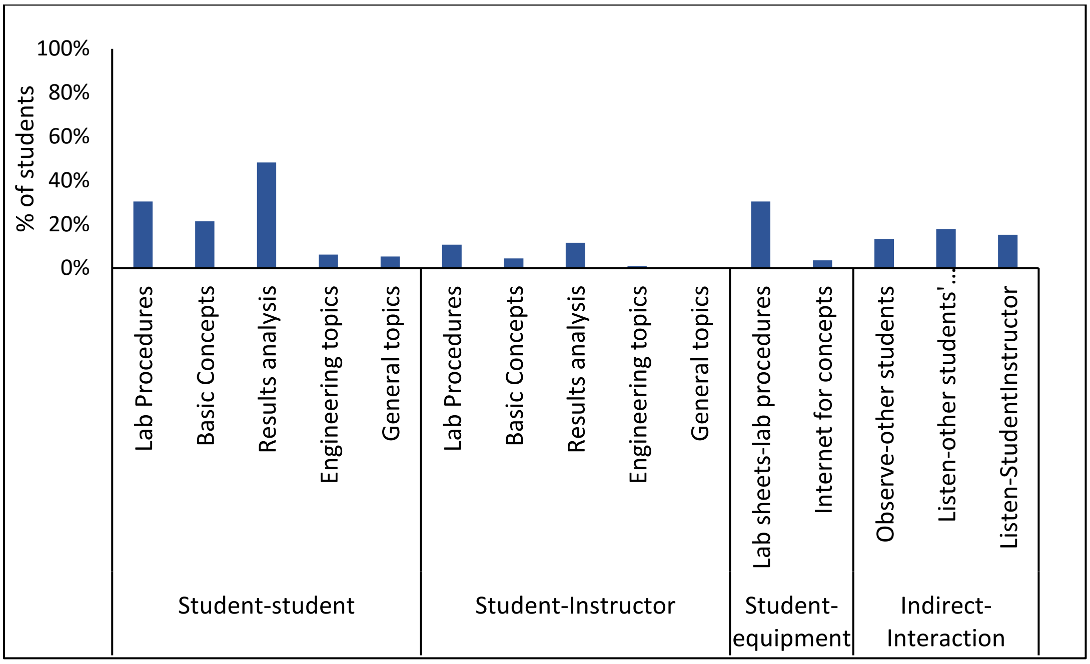


Figure 3.5: Occurrence of interactions ("many times") experienced by first-year students. Note: Vertical axis represents % of students reporting their occurrence of interaction for each laboratory activity as 'many times'. This figure is a further analysis of Figure 3.4.

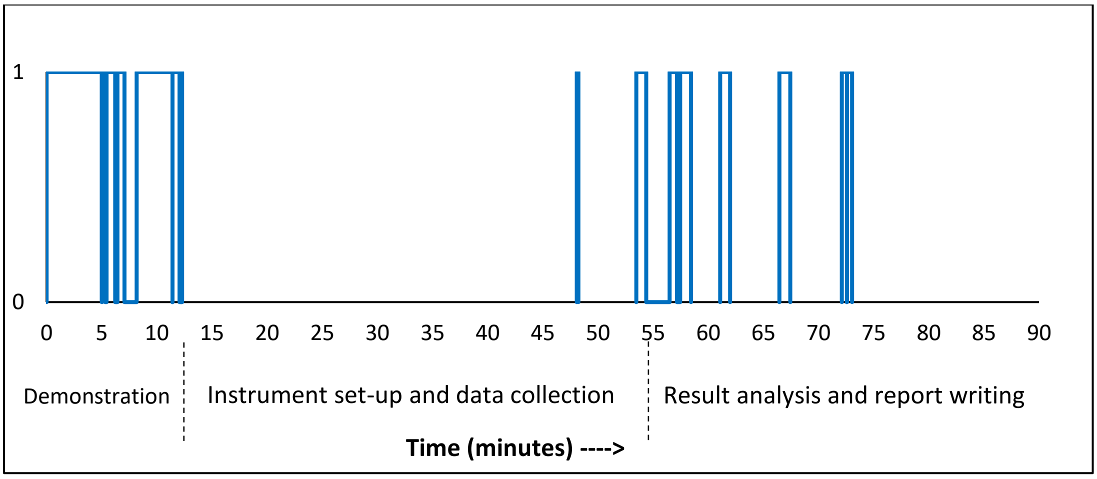
3.4.1.3 Video Analysis for occurrences of interactions

As a validation of the results obtained from the post-laboratory survey, a video analysis was conducted of the first-year students' laboratory conduct in the face-to-face laboratory using the GORP observation and reflection tool. Students were observed during their conduct of the laboratory activity to record the interaction patterns, their occurrences and also the duration of each interaction. The observation protocol used for this purpose is shown in Appendix E.

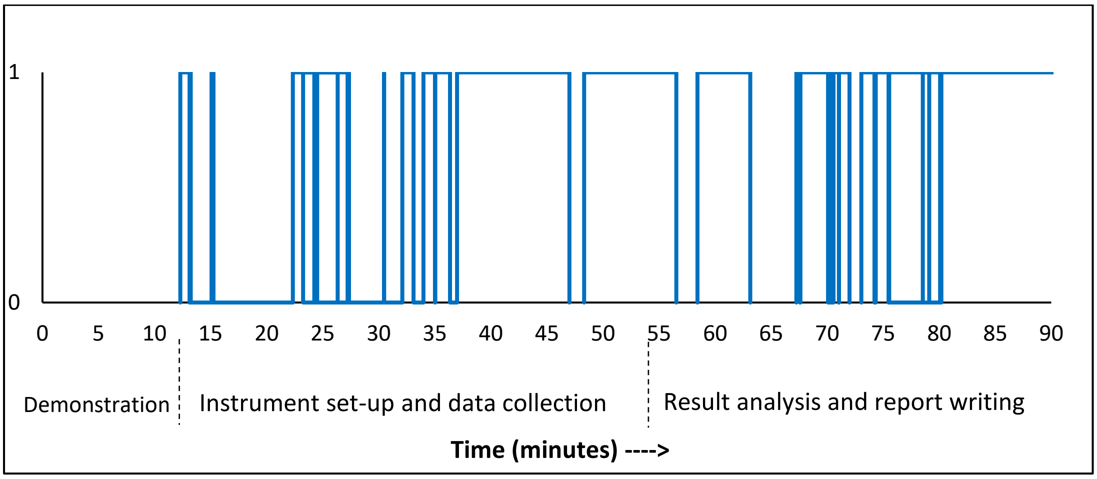
The video of the face-to-face laboratory session lasted 90 minutes. The analysis presented below is based on the observations made for one student group performing the activity. Each group comprised of four students, not assigned by the instructor. The delegation of tasks within group members was purely at the students' discretion. The laboratory sequence of activities comprised: initial demonstration from instructor for the experimental procedures; briefing of necessary data to be collected and expected analysis of results obtained; students' operating equipment and collecting necessary data; students analyzing results; and finally preparing and submitting a report with necessary data tabulated and some analysis.

The interactions recorded were exported from GORP to MS Excel for analysis. The three consecutive sub-figures in Figure 3.6 show the occurrences for the three interaction types: student-instructor, student-student, and student-equipment.

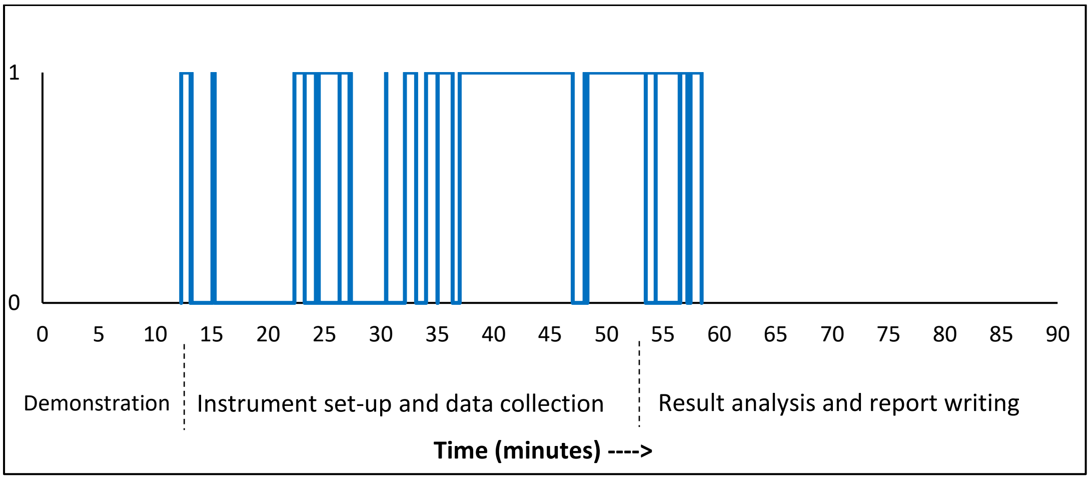
It is evident from Figure 3.6(a) that instructors were fully active during the demonstration of the laboratory procedures while occasionally initiating this interaction during instrument set-up and data collection and result analysis. Similarly, Figure 3.6(b) shows that students remained inactive during the instructor's demonstration of laboratory procedures but interacted with each other for the rest of the activities, that is, during instrument set-up and data collection as well as results analysis and report writing tasks. Finally, the third category of interactions, depicted in Figure 3.6(c), shows that students manipulated equipment only when setting it up and collecting the necessary data.



(a) Student-Instructor Interaction



(b) Student-Student Interaction



(c) Student-Equipment Interaction

Figure 3.6: Instances of occurrences of interactions during the 90 minute laboratory session: (a) student-instructor interaction (Instructor-initiated); (b) student-student interactions; (c) student-equipment interaction. Note: 1=Occurring and 0= Not occurring

Further analysis of the video was conducted to sum the number of occurrences for each interaction types during the 90 minutes. GORP has an interface to record each interaction as and when it occurred during the laboratory session. The number of occurrences recorded for each interaction type is shown in Figure 3.7.

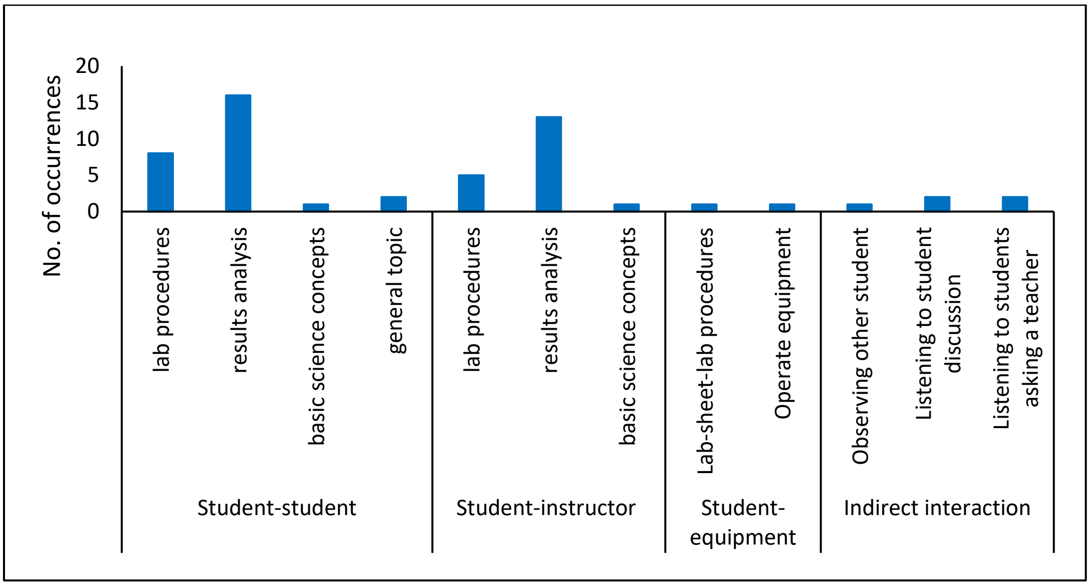


Figure 3.7: Occurrences of interactions during the laboratory session

Figure 3.7 indicates that the interactions occurring most were student-student interactions for results-analysis (16) and laboratory procedures (8). In the student-instructor interaction category, the most occurring interaction was the interaction for results-analysis (13). Results from Figure 3.7 validate the results obtained through the use of the post-laboratory questionnaire for the student-student interaction category reported in Figure 3.5. The results obtained for student-instructor interaction category in Figure 3.7 were all instructor-initiated interactions. This also confirms the fewer occurrences of student-initiated student-instructor interaction reported in the post-laboratory survey, shown in Figure 3.5. Although the number of occurrences for reading laboratory instruction sheets is reported only once in Figure 3.7, it was actually used throughout the conduct of the laboratory activities and is also reflected in Figure 3.5.

Figure 3.8 reports the duration of each interaction types observed in the video recorded for the first-year students' conduct of laboratory activities.

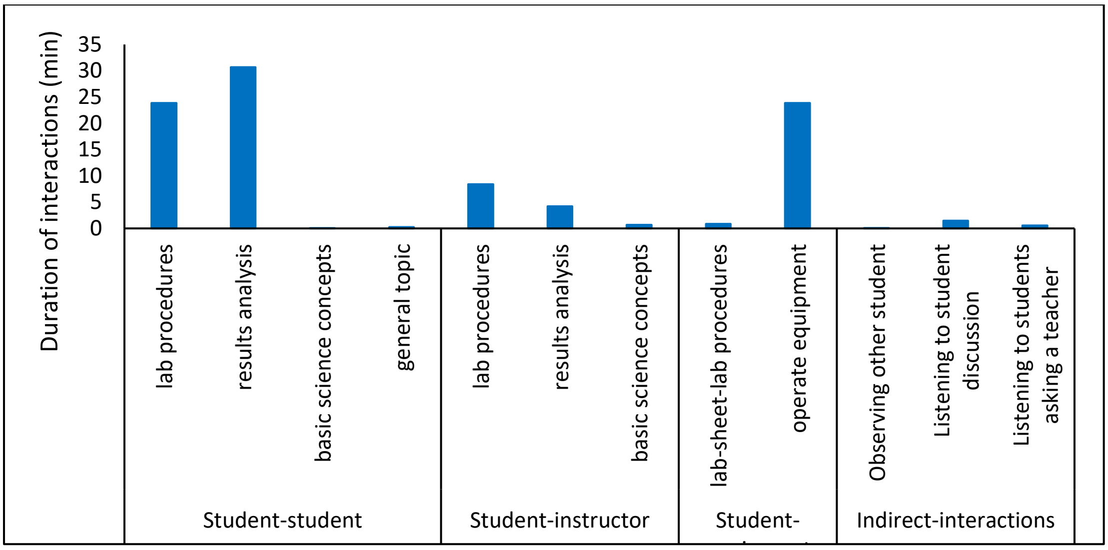


Figure 3.8: Time duration for each interaction type (90 minutes duration)

Figure 3.8 shows that the longest duration of interactions that occurred for was students' interactions among themselves for the laboratory procedures (24 minutes) and analyzing their results (31 minutes). The interactions between student and instructor for the laboratory procedures, which is dominated by the instructor demonstrating the laboratory activity to the students, occurred for the third longest duration which was approximately 8 minutes. The interaction with equipment and also the process of referring to the laboratory instruction sheet was a continuous activity throughout the conduct of the activity and for this reason this is not depicted in Figure 3.8. These results further justify the findings reported in Figures 3.5 and 3.7.

3.4.1.4 Comparison of first-year students' expectations with their actual experience of various interactions

First-year students' pre-laboratory responses indicate that they expect to learn laboratory procedures and results-analysis by interacting with peers and instructors. This suggests students envisioned that they would primarily be interacting with their peers and instructors. However, the post-laboratory responses shows that the most frequent interaction first-year students had was with fellow students. From the responses recorded in the post-laboratory survey, student-initiated student-instructor interactions appeared to be a rare event. The only expectation that matched their experience in the laboratory was the use of laboratory instruction sheets for learning laboratory procedures. Results obtained for first-year students through the use of the post-laboratory survey are validated by the observations reported from the video analysis conducted for the students' conduct of laboratory activities in the face-to-face laboratories.

3.4.2 Second-year students in Fluid Mechanics

3.4.2.1 Students' expectations of various interactions

With prior experience of laboratory work in the first-year engineering courses, it was anticipated that second-year students' expectations of interactions would be slightly different from the expectations captured in the responses of first-year students. Expectations of the four interaction categories for learning each laboratory activity expressed by second-year students is shown in Figure 3.9, which depicts the proportion of students (%) who selected an activity out of the thirteen choices that were provided to them.

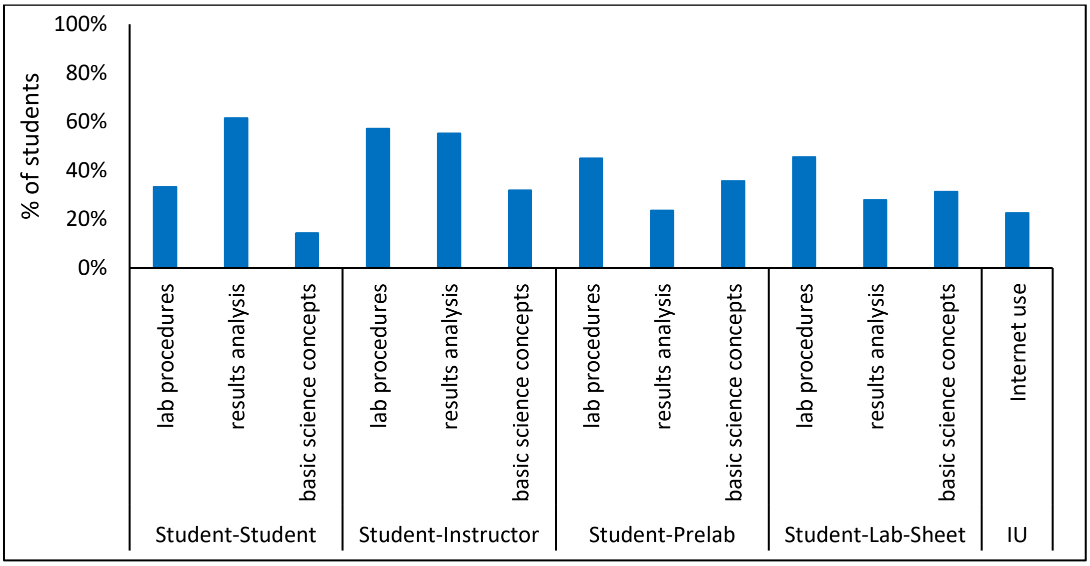


Figure 3.9: Pre-laboratory responses from second-year students (N=205). Note: Vertical axis represents % of students choosing a laboratory activity out of the thirteen choices available to students.

Like first-year students, second-year students also had higher expectations from student-student and student-instructor interaction categories for learning laboratory procedures and results-analysis; 61% students expected to learn results-analysis from student-student interactions, while more than 50% of students expected student-instructor interactions to be useful in learning laboratory procedures as well as the associated results-analysis. Interactions with prelab materials and laboratory instruction sheets also were thought to be important for learning laboratory procedures associated with the laboratory activity (approximately 45% students for both interaction categories).

A more detailed view of the rank given by students for the activities that were deemed important under each interaction category is shown in Figures 3.10, 3.11, and 3.12.

In Figure 3.10, the majority of students who had higher expectations from student-student interaction in learning results-analysis (61%), actually ranked this as an important interaction which they expected to experience during the conduct of the laboratory activity.

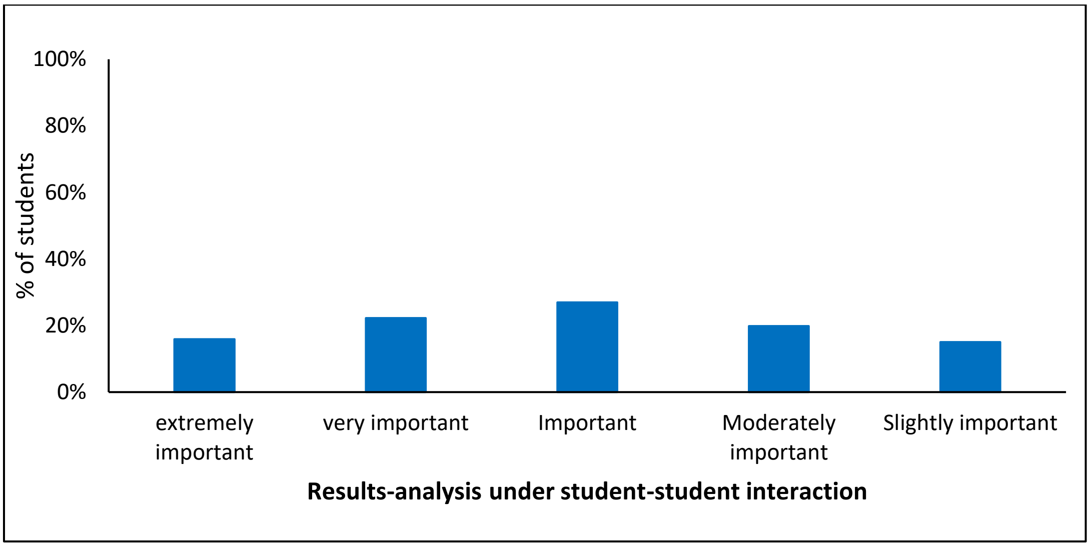


Figure 3.10: Rank analysis for results-analysis under student-student interaction. Note: Vertical columns represent the proportion of second-year students providing a rank out of the five rank choices. For calculating the proportion for each rank, total response under each rank was calculated and then divided by the total number of students who chose this activity. This figure is a further analysis of Figure 3.9.

Figure 3.11 depict students' expectation for student-instructor interaction in learning laboratory procedures and results-analysis. The highest proportion of students choosing to these activities expected them to be extremely important for effective conduct of the laboratory activity.

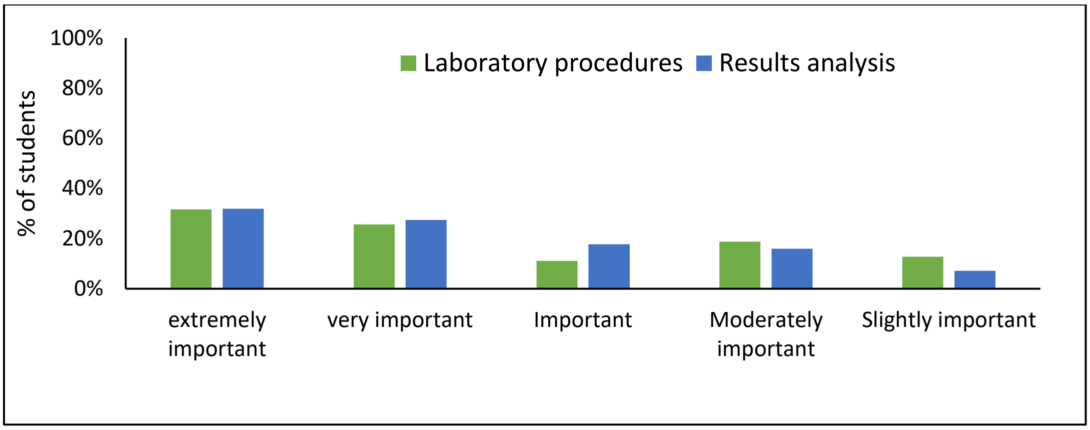


Figure 3.11: Rank analysis for laboratory procedures and results-analysis under student-instructor interaction. Note: Calculations in this figure are the same as for Figure 3.10. This figure is a further analysis of Figure 3.9.

Figure 3.12 shows that apart from student-instructor interactions, second-year students also expected to learn laboratory procedures from the prelab materials that were made available on University's Learning Management System and the laboratory instruction sheets that were available for reference during the conduct of the laboratory activities. However, the majority of students did not consider these interactions to be highly important for developing skills related to laboratory procedures.

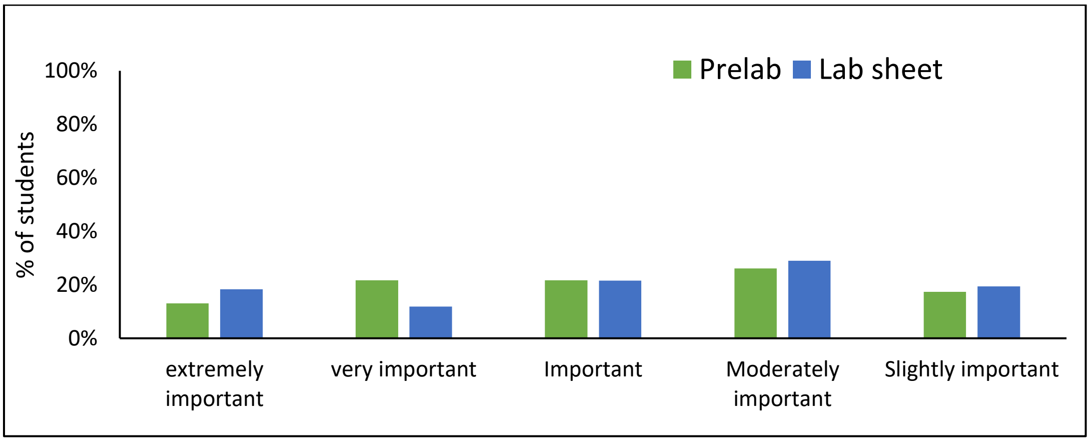


Figure 3.12: Rank analysis for laboratory procedures under student-prelab and student-lab sheet interaction categories. Note: Calculations in this figure are same as that for Figure 3.10. This figure is a further analysis of Figure 3.9.

3.4.2.2 Occurrence of interactions

Second-year students also reported their experience of various interactions in terms of occurrence at three levels, either 'many times', 'few times', or 'never' and their responses are shown in Figure 3.13.

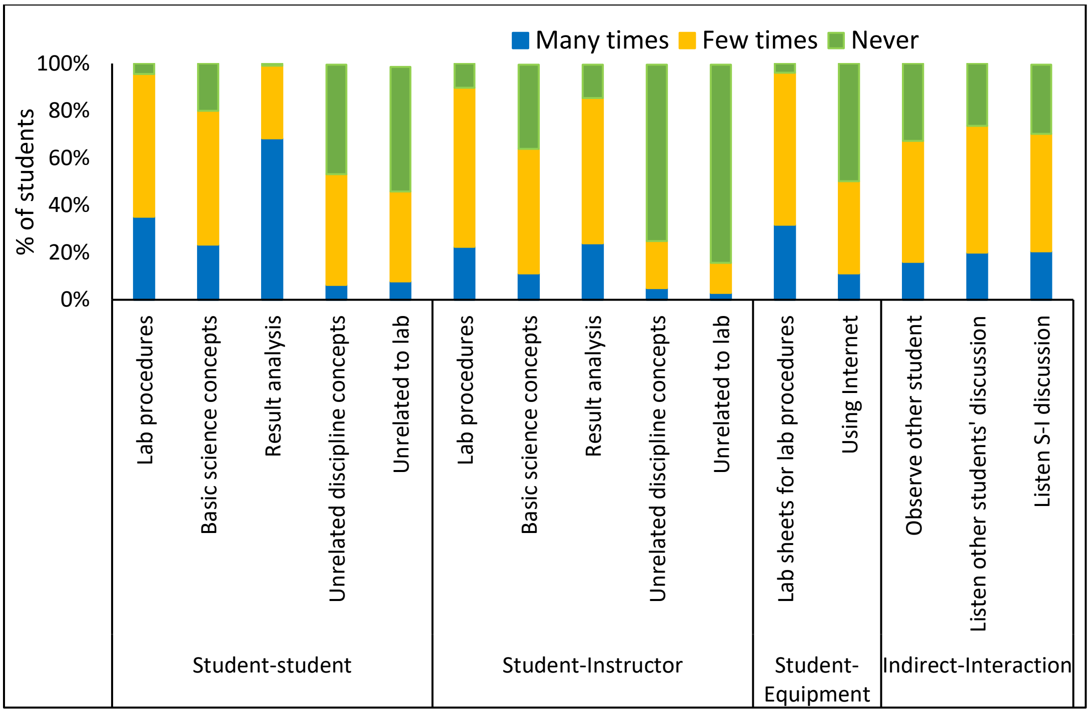


Figure 3.13: Occurrences of interactions reported by second-year students in the post-laboratory survey (N=205). Each bar in the figure represents the % of students responding for each laboratory activity at three levels of interactions either 'many times', 'few times', or 'never'.

The post-laboratory responses depicted in Figure 3.13 show that second-year students were mainly engaged with their peers for conducting the laboratory activities. All activities under student-instructor interaction occurred only few times throughout the laboratory session. Laboratory instruction sheets under the student-equipment interaction was the second most frequent interaction.

Figure 3.14 shows the interactions that students reported as 'many times' during their conduct of the laboratory activity and is extracted from Figure 3.13.

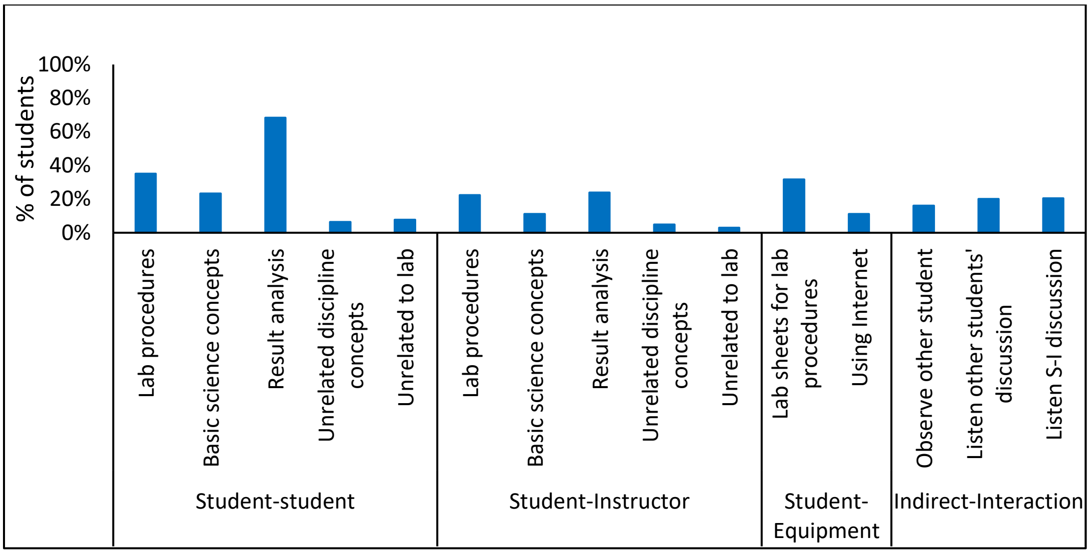


Figure 3.14: Occurrence of interactions that second-year students experienced 'many times' during their conduct of laboratory activity. Note: Vertical axis represents % of students who reported their interactions as 'many times'. This figure is a further analysis of Figure 3.13.

Approximately 68% of students reported their interaction with other students as occurring 'many times' for results analysis. For learning laboratory procedures and clarifying basic science concepts, students again interacted more often with peers than with instructors. Figure 3.14 shows that student-initiated student-instructor interaction was relatively less frequent when compared with other categories of interaction. More than 30% of students reported that they also most frequently referred to laboratory instruction sheets for learning laboratory procedures while manipulating the equipment.

3.4.2.3 Comparison of second-year students' expectations with their actual experience of various interactions during the laboratory activity

Comparing the results presented in sections 3.4.2.1 and 3.4.2.2 showed that the expectations of the various interaction and the actual occurrences of interactions experienced by second-year students during the conduct of the laboratory activity were different. It is worth mentioning here again that students express expectations of interactions with instructors in learning important laboratory activities but are involved only a few times in student-instructor interaction as initiators. Like first year students, second-year students also engaged mostly with peers for conducting the laboratory activities.

3.4.3 Third-year students in Applied Fluid Mechanics

3.4.3.1 Students' expectations of various interactions

The responses reported by third-year students for each of the interaction categories and their associated activities are presented in Figure 3.15. The vertical bars in Figure 3.15 shows the proportion of students selecting a laboratory activity under each interaction category as one of the important learning activities out of the thirteen choices provided in the survey. It is worth mentioning here that third-year students were given a revised version of the pre-laboratory survey questionnaire, where student-prelab category was replaced with student-apparatus category in order to understand students' expectations of their interaction with the apparatus they used.

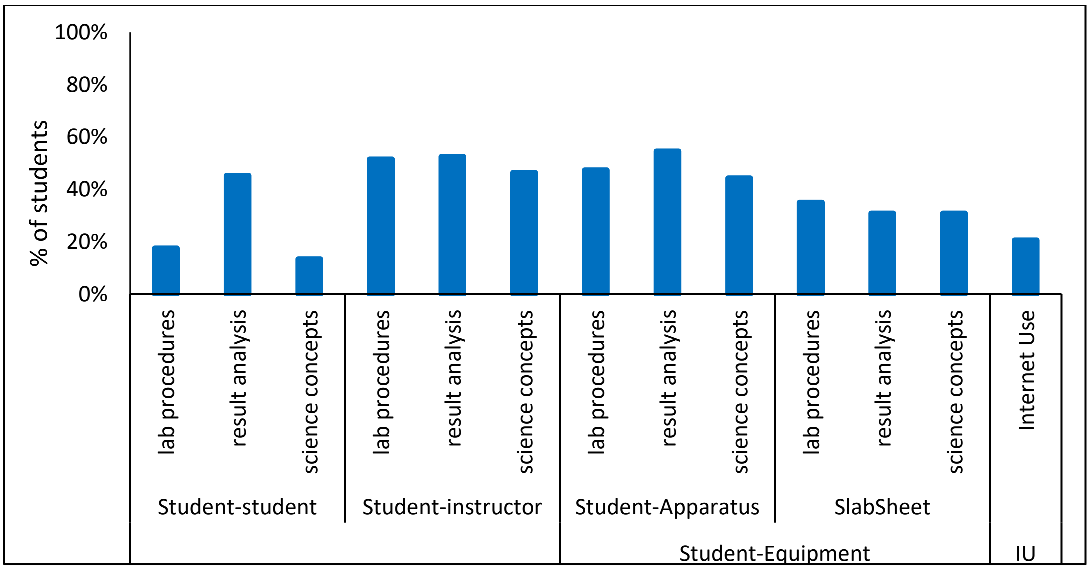


Figure 3.15: Pre-laboratory responses from third-year students (N=96). Note: Vertical axis represents % of students selecting a laboratory activity out of the thirteen choices provided to them.

In Figure 3.15, third-year students present different expectations for interactions as compared to first- and second-year students reported in Figures 3.1 and 3.9. In the student-student interaction category, the most commonly selected laboratory activity was for results-analysis (45%). Third-year students showed higher expectations for learning all associated laboratory activities from their interaction with instructors and also through manipulation of equipment. Students expected that they would learn laboratory procedures best by interacting with the instructor (52%), while, better results-analysis came from the manipulation of the equipment (54%). Like first- and second-year students, third-year students also reported results-analysis as the most expected learning from all interaction categories. It is also noted in Figure 3.15 that students expected to learn more from the laboratory instruction sheets about the laboratory activities than through peer interaction, except for results-analysis. This indicates that third-year students rely more on themselves than their peers.

Third-year students presented highest expectations for learning results-analysis with each interaction. The analysis of the response in terms of the ranks for this learning activity under each interaction category is shown in Figures 3.16 and 3.17.

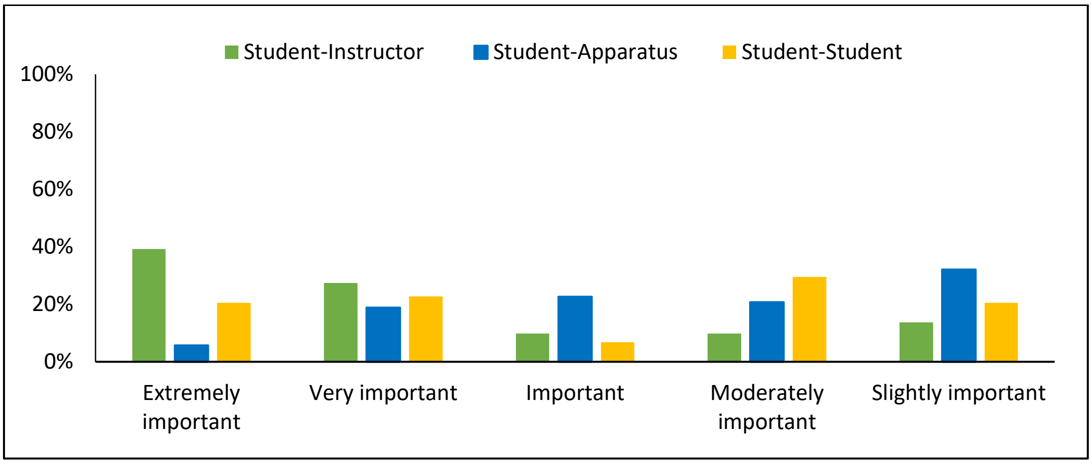


Figure 3.16: Ranks given by third-year students for 'results-analysis' under student-student, student-instructor, and student-apparatus (under student-equipment interaction category) categories. Note: Calculations in this figure are same as that for Figure 3.10. This figure is a further analysis of Figure 3.15.

In Figure 3.16, of the total number of students selecting results-analysis in the student-instructor interaction category, approximately 40% of the students reported that it would be extremely important to interact with instructors during the conduct of the laboratory activity. Student-apparatus interaction made the least contribution compared to other interaction categories in developing that skill. Although the proportion of students selecting the student-apparatus interaction (under student-equipment interaction category) for results-analysis was slightly higher than for student-instructor interaction category, the majority of the responses in the student-apparatus interaction category (approximately 32%) deemed it as only slightly important out of the five selected choices.

As seen in Figure 3.15, the majority of students (52%) held the opinion that for learning laboratory procedures related to the laboratory activity, students' interaction with the instructor in the laboratory would be important. Figure 3.17 presents the rank analysis of the expectations for this activity on the basis of rank provided by the third-year students. In Figure 3.17, of the total number of students responding for laboratory procedures in the student-instructor interaction category, the majority of the students' responses are on the higher rank side, reinforcing the result observed in Figure 3.15.

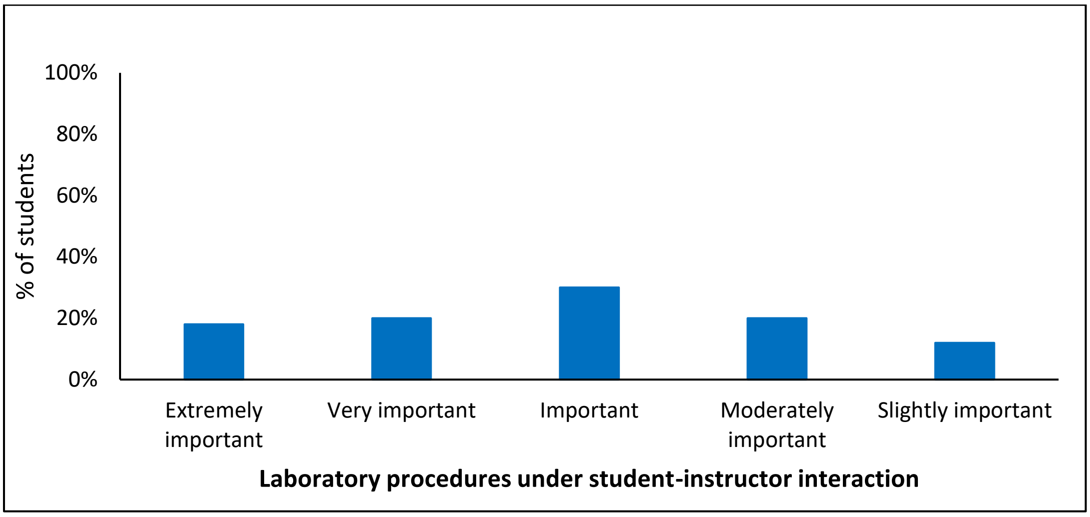


Figure 3.17: Third-year students' perception in ranks for laboratory procedures in the student-instructor interaction category. Note: Calculations in this figure are same as that for Figure 3.10. This figure is a further analysis of Figure 3.15.

From all the findings presented from the pre-laboratory responses, it can be deduced that third-year students expressed higher learning expectations from their interactions with the instructor for conducting all of the laboratory activities.

3.4.3.2 Occurrence of interactions

In the post-laboratory responses, students reported their occurrences of interactions across all activities associated with the four interaction categories. Figure 3.18 summarises the occurrences of interactions experienced by third-year students for all laboratory activities under the four different interaction categories at five levels of occurrences of interactions, that is, either 'very frequently', 'frequently', 'occasionally', 'rarely' or 'never'. It is seen that students' interactions in all categories were frequent for most of the laboratory activities. The least occurring interactions were with the instructors for topics that were either general or unrelated to the laboratory activity.

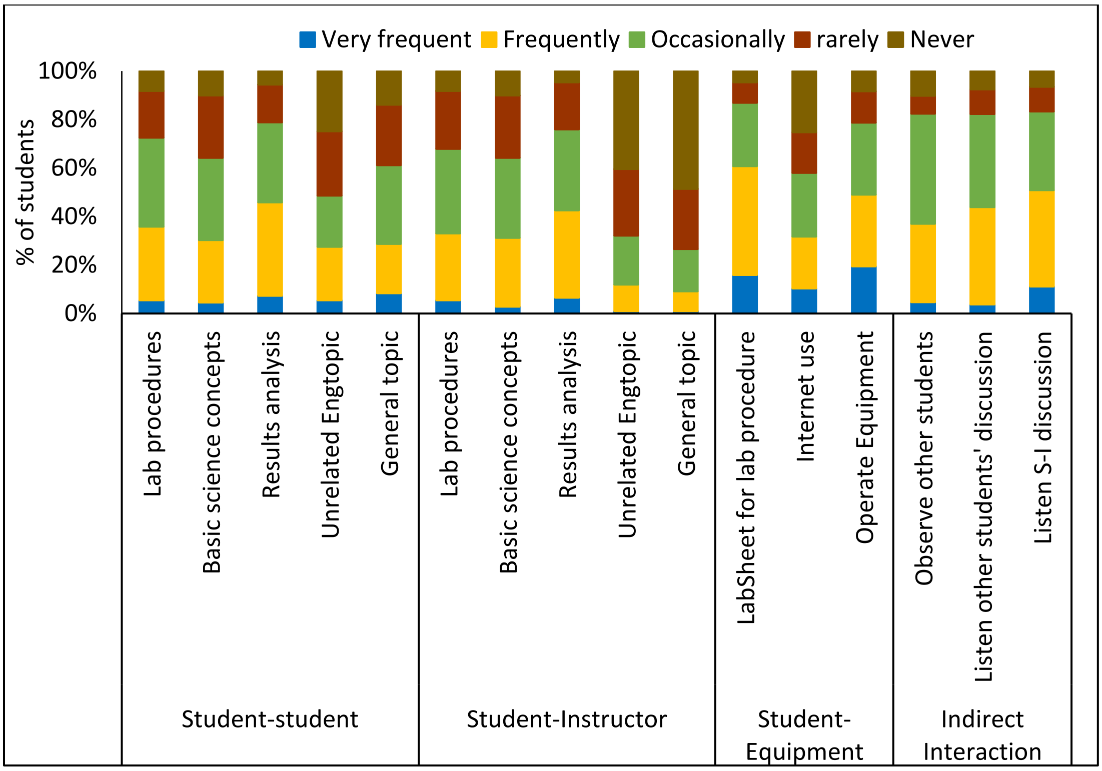


Figure 3.18: Occurrence of interactions experienced by third-year students (N=109). Note: Vertical axis represents the % of students responding for each laboratory activity at the five level of occurrences of interactions, that is, either 'very frequently', 'frequently', 'occasionally', 'rarely' or 'never'.

The findings in Figure 3.18 were further studied in detail to find the most frequent interactions under each interaction category. This analysis was done by adding the number of responses in the 'very frequent' and 'frequently' response categories and then converting them to a percentage. The results are plotted in Figure 3.19.

From Figure 3.19, in the student-student interaction category, the most frequent interaction was for learning result analysis (46%). Interaction for the results-analysis was relatively more frequent among students than between a student and their instructor (43%). It was also noted that learning laboratory procedures was better supported by their interaction with equipment (61%). This outcome is justified by the response recorded for the occurrence of manipulation of equipment under the student-equipment interaction category (49%). Learning through indirect interactions in the laboratory also appeared to be frequent. The most frequent interaction in this category was for the learning by listening to conversations between other students and an instructor in the laboratory. It is to be noted that the content of the conversation for indirect interaction is assumed to be laboratory specific.

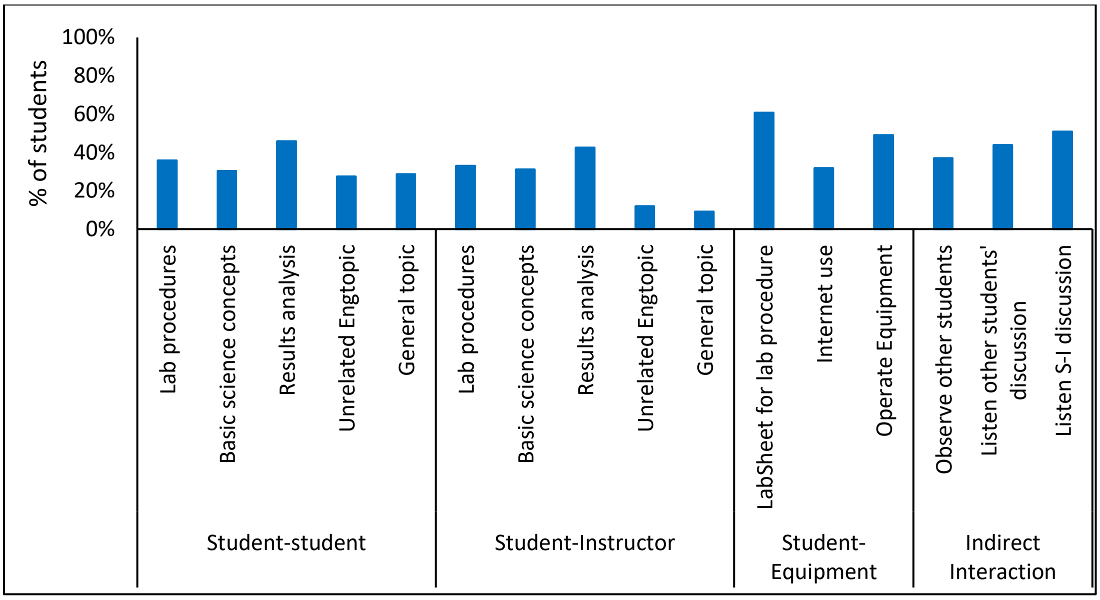


Figure 3.19: Most frequently occurring interactions in third-year students' responses reported in Figure 3.18, for each item in the four category of interactions. Note: Each vertical bar is the sum of the responses recorded for the categories: 'very frequent' and 'frequently'. This figure is a further analysis of Figure 3.18.

3.4.3.3 Comparison of third-year students' expectations with their actual experience of various interactions during the laboratory activity

Third-year students' expectations of various interactions were more inclined towards interactions with instructors and equipment. Higher expectations were shown for the student-instructor interaction for learning laboratory procedures, while student-equipment interactions were envisioned to be important for learning results-analysis. From both student-instructor and student-equipment interaction categories students' also expected to learn basic science concepts.

In contrast, students' reporting of their occurrences of interactions during the conduct of laboratory activities reveal that students mostly interacted with peers and, as they expected, they most frequently interacted with equipment, which included reading laboratory instruction sheets for learning laboratory procedures and manipulation of the equipment. As characteristic of independent learners, third-year students anticipated learning laboratory procedures and basic science concepts more from the use of laboratory instruction sheets than interacting with peers. Third-year students most frequently referred to laboratory instruction sheets for laboratory procedures during the actual conduct of laboratory activities. This result shows that students become more independent learners as they progress in their studies from first, second to third year in an undergraduate engineering program.

3.5 Discussion

Interactions among students, instructors and the equipment used in the laboratory activity emerged as integral components of the laboratory activity in the results reported by first-, second- and third-year students in undergraduate engineering laboratories. The following sub-sections summarise the findings reported regarding student expectations of various interaction types along with their reporting of actual occurrences in the pre- and post-laboratory surveys, respectively, as well as the video analysis conducted for the first-year face-to-face laboratory.

3.5.1 Students' awareness of the interactions occurring in the laboratory

The findings reported in the pre-laboratory responses by student cohorts from first-, second-, and third-year regarding each interaction type, represent the perception of interactions that undergraduate engineering students had when entering the laboratory premises. Figure 3.20 shows the average ranking provided by all three student cohorts for all interaction categories except for student-prelab interaction (under student-equipment interaction category).

Interaction with instructors is ranked highly by students in all three years of an undergraduate engineering degree, indicating that instructors are always important for laboratory learning. With progression in the study, the expectations from student-student interaction gradually increases from first- to third-year. The importance of laboratory instruction sheet drops off from first- to third-year of engineering degree. These results show that students become more as independent learners as they progress in their study. First-year students saw student-student interaction as an opportunity to learn laboratory procedures compared to other activities, which gradually changed to clarifying concepts related to the laboratory activity in the expectations of third-year students. First-year students express higher importance for the laboratory instruction sheet, but students in all three years commonly express least expectations of learning results-analysis by reading the laboratory instruction sheet.

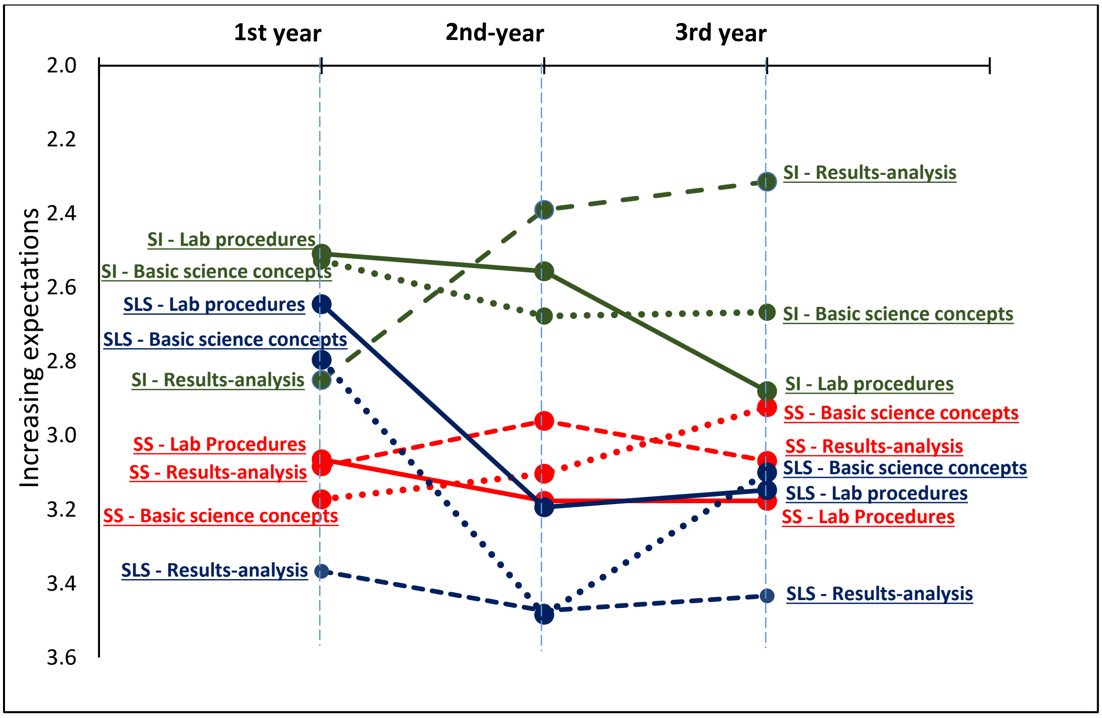


Figure 3.20: Average ranking for each interaction type reported in pre-laboratory surveys by first-, second-, and third-year students. Note 1: SS=Student-Student (red line), SI=Student-Instructor (green line), and SLS=Student-lab-sheet interactions (blue line) (under Student-Equipment interaction). Note 2: Vertical axis represents the average rank calculated out of five for each interaction type. Solid-line=lab procedures; dashed-line=results-analysis; dotted-line= basic science concepts.

Figure 3.21 shows the average ranking provided by first- and second-year students for the student-prelab interaction, under student-equipment interaction category. The responses reported suggest that first- and second-year students do not expect much from the prelab materials that are made available to students for their preparedness in conducting laboratory activity.

Third-year students were asked about their expectations of student-equipment interaction, focused upon manipulation of equipment (not shown in Figure 3.21) and they indicated high expectations for learning laboratory procedures and basic science concepts from this interaction. As the pre-laboratory survey varied slightly for third-year students from that used for first- and second-year students, a generalised conclusion for the expectations of students from student-equipment interactions is difficult to make. This can be resolved by looking at the students' actual behaviour during the conduct of laboratory activity when they progress from first- to third-year of their engineering degree.

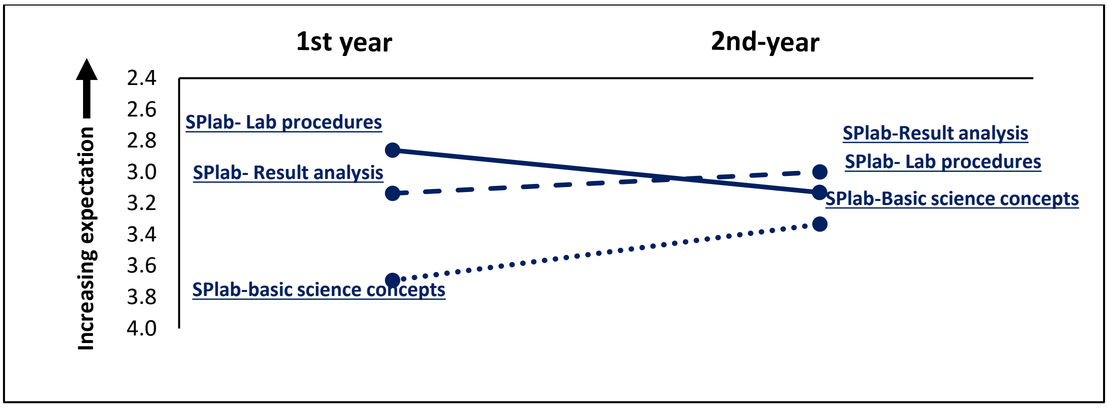


Figure 3.21: Average ranking for student-prelab (under student-Interaction) interaction for first- and second-year students. Note: SPlab=Student-Prelab under student-equipment interaction. Figure has been obtained using a similar method to that for Figure 3.20. Solid-line=lab procedures; dashed-line=results-analysis; dotted-line= basic science concepts.

3.5.2 Students' actual behaviour during the laboratory activity

Students' actual interactions during the conduct of laboratory activity is different from their expectations of interactions as reported before the laboratory work. The video analysis of first-year face-to-face laboratory reveals instructors are most active while students remain inactive during the demonstration of the laboratory work. Students become active only after the demonstration and show more interactions with other students and equipment than with instructors, although they report high expectations from instructors.

Figure 3.22 shows how students in all three years of an engineering degree engage in interactions during the conduct of the laboratory activities. It is important to note in this figure that the proportion of students whose response is summarised in this figure are those who reported their interactions in the 'many times' frequency category. Student-student interactions is most frequent in first- and second-year gradually becoming low in third-year. Third-year students most frequently used the laboratory instruction sheet for learning laboratory procedures related to laboratory activities. Indirect learning is more frequent among third-year students than it is for first- and second-year students. Student-instructor interaction, which is student-initiated, is low in all three-years. This finding indicates that students tend to become more independent as learners mostly relying on their peers during the conduct of laboratory activity. Students in their early years tend to perform the laboratory activity seeking least support from instructors, despite having indicated high expectation for the interaction with instructors. Similarly, at a higher stage, students demonstrate fewer interactions with other students in the laboratory and conduct the activity mostly through indirect learning and referring to the laboratory-instruction sheet.

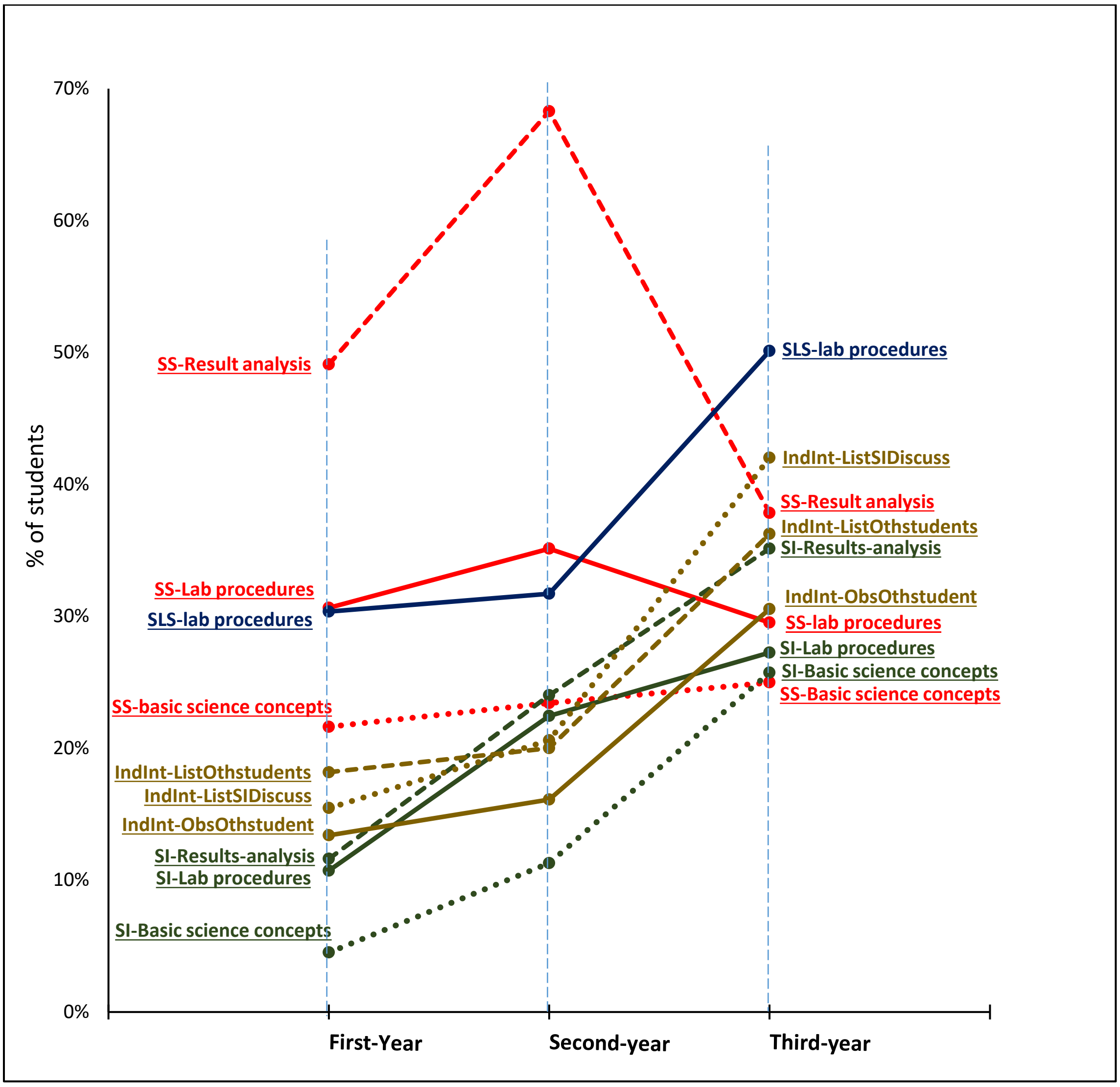


Figure 3.22: Analysis of most frequent interactions during the conduct of laboratory activities reported by first-, second-, and third-year engineering students. Note: SS=Student-Student (red line), SI=Student-Instructor (green line), and SLS=Student-lab-sheet interactions (blue line), IndInt=Indirect interactions (brown line). Solid-line=lab procedures; dashed-line= results-analysis; dotted-line= basic science concepts. For indirect interaction, Solid-line=observing other students laboratory work; dashed-line = listening to other student-student discussions; dotted-line= listening to other student-instructor discussions.

3.6 Chapter Summary

Actual occurrences of interactions reported during the conduct of the laboratory activities contradicts the expectations for various interactions before the conduct of the laboratory activities especially by first- and second-year students. There are high expectations from student-instructor interactions in all three-year student cohorts. Use of laboratory-instruction sheet and student-student interactions do not seem to be significant in students' expectations before the conduct of laboratory activities.

In summary

1. Students, both beginners as well as advanced level, show less confidence before the conduct of the laboratory activity, and expect to be guided mostly by instructors for their learning during the conduct of laboratory activities.
2. While peer-to-peer learning is a common behavior seen among first-year students, third-year students show more reliance on supplementary materials such as laboratory instruction sheets, than instructors and peers, for learning the laboratory procedures.
3. Directly or indirectly, students interact mostly among themselves. Interactions with instructors are less frequent and often instructor-initiated student-instructor interactions occur during the conduct of the laboratory activity.

Chapter 3 reported findings about students' expectations and the most frequently occurring interactions during the conduct of laboratory activities. It is deemed important at this point to understand whether the most frequent interactions also correspond to the interactions that students perceive to be important in laboratory learning. Chapter 4 investigates the relationship between students' pre-laboratory expectations and their actual perceptions of importance of interactions and satisfaction with the interaction experience after the conduct of laboratory activity.

Chapter 4

Students' reporting of importance and satisfaction for interactions in the face-to-face undergraduate engineering laboratories

In Chapter 3, comparison between students' expectations of the four interaction types and their actual frequency of occurrences of interactions during the students' conduct of the laboratory activity was made. This comparison was made for students from first, second, and third-year of an undergraduate engineering degree. This chapter presents the findings for students' expectations of interactions, their opinion about the importance of interactions and satisfaction with them after their conduct of the laboratory activity. A quantitative research method is adopted for analyzing the responses received from first- and third-year undergraduate engineering students.

4.1 Background and aims

In Chapter 3, it was shown that first-year students mostly engaged in interactions with their peers during their conduct of the laboratory activity. Their interactions with instructors were limited. Responses of second-year students were very similar to those of first-year students. Besides interacting with other students for all laboratory associated activities, both first- and second-year students also used laboratory instruction sheets for developing skills related to laboratory procedures. Third-year students' responded differently to first- and second-year students. For third-year students the most frequent interaction was student-equipment interaction, where they mostly engaged in the manipulation of equipment and referred to laboratory instruction sheets for developing skills related to laboratory procedures.

Chapter 3 did not consider whether the interactions were perceived as important as well as satisfying in the way they occurred or contributed in students' laboratory learning. This chapter therefore attempts to explore the students' opinion about the importance of various interactions in conducting laboratory related tasks in a face-to-face laboratory. The following sections report and analyse the responses received from first- and third-year undergraduate engineering students about their expectations of the importance of interactions before the conduct of the laboratory activities, opinions about the importance of interactions after the conduct of the laboratory activities, and their satisfaction with the four interaction categories for learning in face-to-face engineering laboratories.

4.2 Research Question

Chapter 4 provides answers to the following research question

RQ 2: How does student expectation relate to their opinion about the importance and satisfaction of various interactions in the face-to-face laboratories?

4.3 Research methodology

Quantitative research methods (Creswell, 2014) have been adopted to obtain pre-laboratory expectations of interactions as well as students' post-laboratory reports of the importance of interactions and satisfaction with interactions.

Responses of first-year and third-year student levels have been chosen in order to understand and compare the perceptions between students in their initial year of engineering degree and at a level where a growth in understanding of laboratory activities can be expected to have occurred to some extent.

4.3.1 Development of instruments

The questions in the surveys were again based on the work of Velasco et al. (2016). The pre-laboratory survey questionnaire, shown in Appendix C.2, comprised questions similar to Chapter 3, but differed in the student-equipment interaction. Student-equipment interaction category was further sub-divided into student-apparatus and student-lab-sheet interaction categories. The post-laboratory survey comprised Likert type questions. The purpose of the post-laboratory survey questionnaire was to understand students' reports of the importance of each interaction category when performing laboratory activities. Questions were broadly categorised into four groups representing the four interaction types: Student-student, Student-instructor, Student-equipment, and Indirect interaction. Details of the questions included in the post-laboratory survey are presented in Appendices C.1 and C.2 which respectively show the questionnaires for first- and third-year undergraduate engineering students in the face-to-face laboratory.

The activities and categories included in this questionnaire were similar to the question used to determine interaction frequencies (used in Chapter 3), but questions governing them were modified to allow students to report on the importance of each interaction.

All of the interaction categories further included a question about satisfaction with each interaction category. Responses were reported on a scale of 1 to 10, where 1 represents least important and 10, the most important. Similarly, 1 meant the least satisfied and 10 represented most satisfied.

For third-year students, the survey included similar questions to the first-year laboratory but the importance of the interactions were indicated by requesting them to select the five most important interactions that they experienced during the conduct of the laboratory.

First-year students were surveyed during their conduct of a laboratory in their Engineering Mechanics unit, while third-year students performed laboratory activities for the unit Applied Fluid Mechanics. Details of the experimental set up in the first- and third-year face-to-face laboratories are provided in Appendix C.

4.3.2 Data collection and analysis

The survey questionnaires were administered to first- and third-year students. 186 first-year and 97 third-year students responded. First-year students were surveyed in semester 2 of 2017 while third-year students were surveyed in semester 1 of 2018. First- and third-year cohorts are the same as those reported in Chapter 3.

Analysis of responses collected from first- and third-year students were conducted using MS Excel and SPSS. Graphical analysis is conducted using MS Excel. Correlations and significance are determined using the SPSS software version 25 (George & Mallery, 2018).

The following sections present results for the reported expectations, importance of interactions in carrying out the laboratory activity and the satisfaction for each interaction category. Responses of first-year students are presented first followed by the responses received from third-year students.

4.4 Results

The reliability of the post-laboratory survey questionnaire was calculated to check the internal consistency of the results across all activities in the post-laboratory survey. The Cronbach's alpha value was above 0.87 which indicates that the instrument used for the survey is reliable (Bland & Altman, 1997; Nunnally & Bernstein, 1994).

4.4.1 First-year students in Engineering Mechanics

4.4.1.1 Pre-laboratory expectations of the importance of interactions

Figure 4.1 shows first-year students' responses received for each aspect of the laboratory activity in the pre-laboratory survey administered to capture their expectations of interactions. The graph shows the net response received for each laboratory activity and then divided by the total number of students in the cohort to get the proportion of students expressing their expectation of an activity important for their conduct of the laboratory activities.

Like the previous cohorts of first-year students reported in Figure 3.1 of Chapter 3, students' pre-laboratory expectations were very similar, with a slight difference captured for laboratory procedures that students expected to learn from their interactions with instructors.

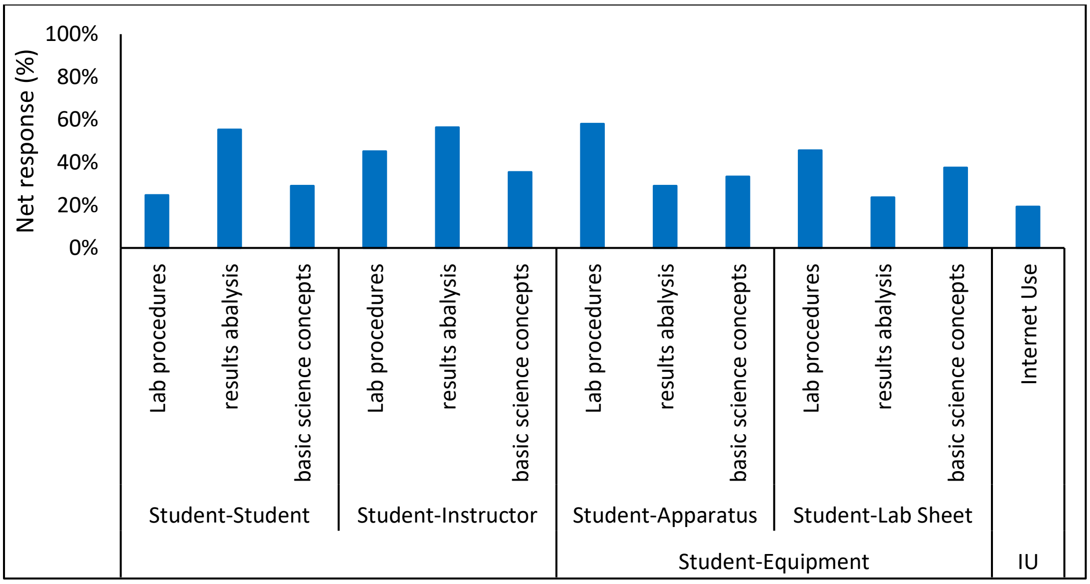


Figure 4.1: First-year students' expectations of the importance of various interactions (N=186). Note: Vertical columns represent the proportion of students selecting a laboratory activity deeming it important out of the thirteen choices provided. Note: IU=Internet Usage.

For improved understanding of students' expectations of the importance of various interactions before the actual conduct of the laboratory activity, first-year students' pre-laboratory responses were grouped based on their marks obtained for the laboratory activity (expressed in %) for the Engineering Mechanics unit. Three groups were formed of low-achievers (below 60%), moderate-achievers (61%-75%), and high-achievers (above 75%). Figure 4.2 shows the pre-laboratory expectations reported by students in the three achievement levels.

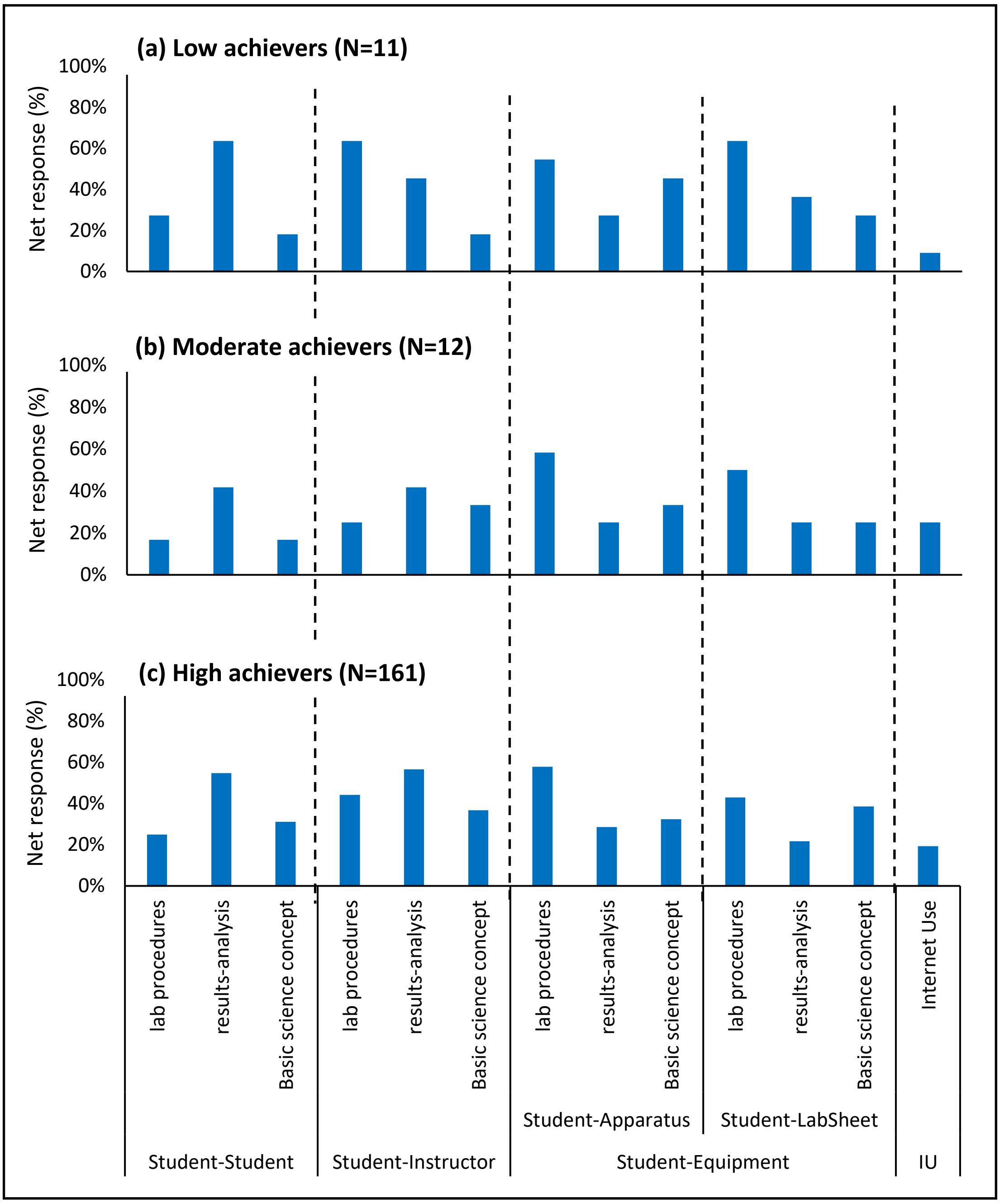


Figure 4.2: First-year students' pre-laboratory expectations based on the students' marks obtained for the laboratory activity (N=186): (a) Low-achievers (Below 60%), (b) Moderate-achievers (61%-75%), and (c) High-achievers (Above 75%).

The low-achievers' response, shown in Figure 4.2(a), indicates that students in this group expected mainly to develop skills related to laboratory procedures from their interactions with instructors and equipment. Developing skills related to results-analysis was clearly expected of their interaction with other students. Students in the low-achieving group expected to learn basic concepts from their manipulation of the apparatus.

The majority of moderate achievers' responses in Figure 4.2(b) show expectations of learning results-analysis from their interactions with other students and instructors, while interaction with equipment is expected to assist them with learning laboratory procedures. By contrast, high achievers, shown in Figure 4.2(c), expect to learn laboratory procedures from their interactions with instructors and equipment. Expectations of learning laboratory procedures from interactions with the laboratory instruction sheet is high among low achievers, while moderate and high achievers expect to learn this skill more from their interaction with the apparatus. Both moderate and high achievers expect their interactions with instructors and equipment to be important for learning the basic concepts related to the laboratory activity.

4.4.1.2 The importance of interactions in the laboratory

After the conduct of their laboratory activity, first-year students reported their view about the importance of interactions they had experienced during their conduct of the laboratory activity. Figure 4.3 charts the average of the ratings reported by first-year students for each laboratory activity under the four interaction categories on a scale of 1 to 10. It was found that all interaction categories were important for students when conducting the laboratory activity. However, the highest perceived importance was for operating the equipment under the student-equipment interaction category. Students also perceived their interaction with an instructor to be more important than student-student interaction for learning laboratory procedures and clarifying concepts. However, interaction with other students appeared to be more important than interacting with an instructor for results-analysis.

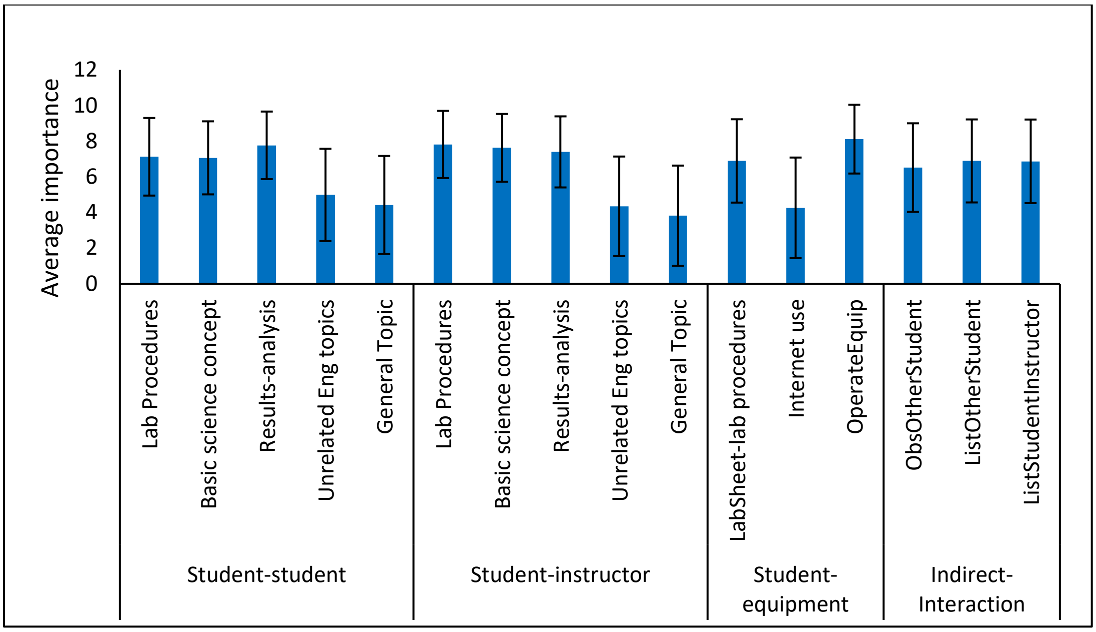


Figure 4.3: First-year students' opinion about the importance of interactions in face-to-face laboratory for different aspects of the laboratory work. (N= 186). The uncertainty bars denote one standard deviation about the mean.

The results show that first-year students valued laboratory learning obtained from student-student and student-instructor interactions. Laboratory learning that was obtained from indirect observation or listening to other students' laboratory activity was perceived to be less important relative to other categories of interactions. The similar magnitude of the uncertainty bars for each result in Figure 4.3 supports the validity of the foregoing discussions and conclusions based upon mean values.

The marks obtained by students for their laboratory activity in the Engineering Mechanics unit had no statistically significant relationship with the students' perceptions of the importance of the four interaction types. While Figure 4.3 shows the overall students' perceptions of importance of interactions, Figure 4.4 shows students' perceptions of important interactions averaged and grouped according to their performance in the laboratory activities for which they were surveyed. Based on the total mark obtained in the activities for the unit, students were divided into three groups: low-achievers (below 60%), moderate-achievers (61%-75%) and high-achievers (above 75%).

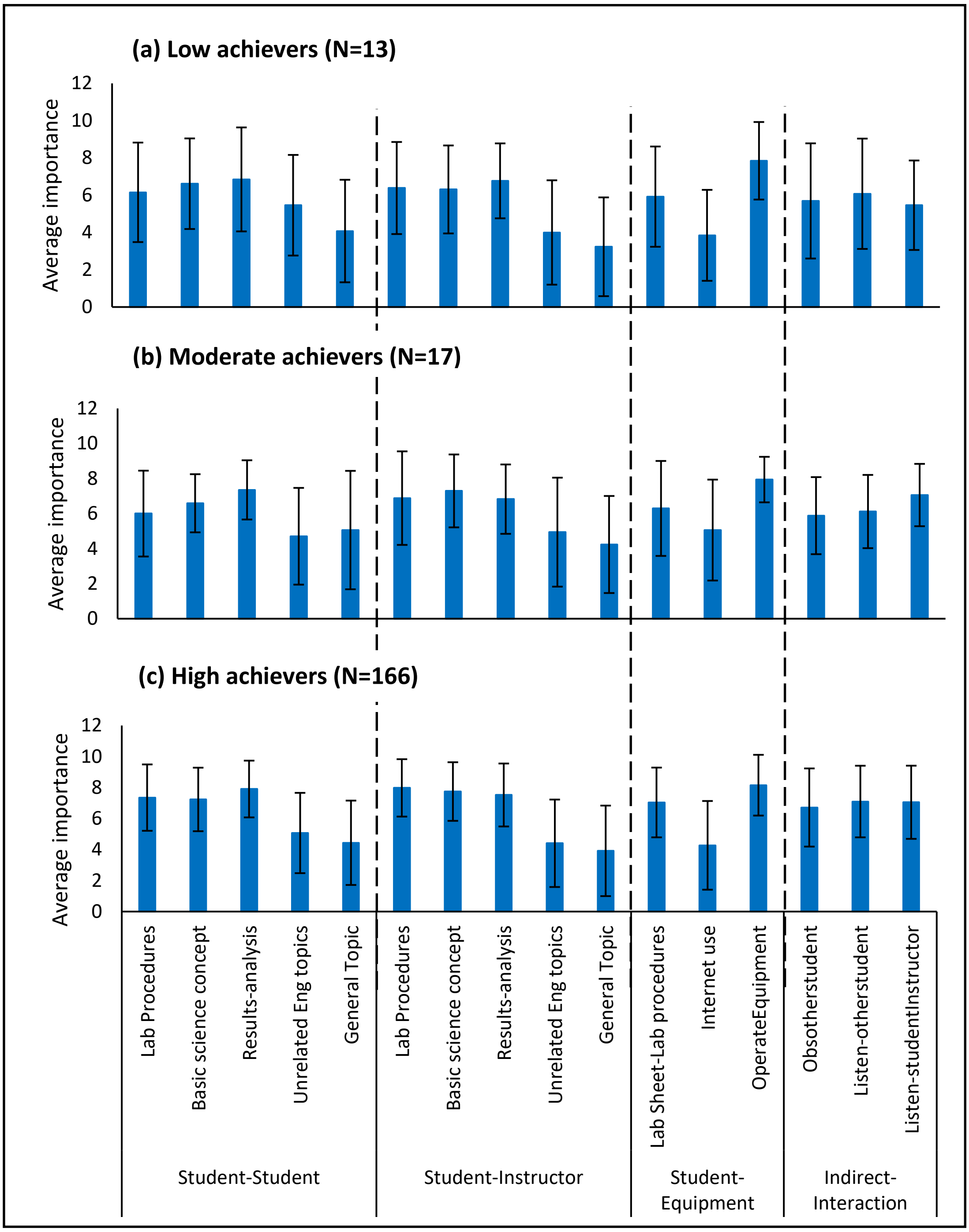


Figure 4.4: Perceptions of importance of interactions based on performance of first-year students in face-to-face laboratory (N=186): (a) Low-achievers (Below 60%), (b) Moderate-achievers (61%-75%), and (c) High-achievers (Above 75%). The uncertainty bars denote one standard deviation about the mean.

The majority of the students who participated in this investigation performed very well in the laboratory activities and therefore the number of students in the high achieving groups were the highest. The uncertainty bounds shown in Figure 4.4(c) reflect the same trends observed in Figure 4.3. Greater uncertainty seen in the results of Figures 4.4(a) and (b) may arise from the smaller student-number samples in these groups, or that the views of lower-performing students are much more variable. The main findings from Figure 4.4 are:

- Although the average importance perceived for importance of interactions varied across all achievement groups, students in all achievement groups perceived students' interactions with other students as the most important interaction for learning results-analysis. The importance of interaction with instructors was perceived differently by the three achievement groups.
- While high achievers perceived student-instructor interaction important for learning laboratory procedures, moderate achievers found this interaction important for learning basic science concepts.
- For low achievers learning results-analysis from instructors was the most important interaction in the student-instructor interaction category.
- In the student-equipment interaction category, students of all achievement groups commonly perceived manipulation of the apparatus as the most important interaction. Indirect interactions were perceived important more by the high achieving students than students in other achievement groups.

When comparing the first-year students' expectations for the four interaction categories reported in Figure 4.1 with the post-laboratory perceptions of importance of interactions, it was found that there were mainly similarities but some differences existed. For instance, expectation of learning results-analysis from student-student interactions was also reflected in their opinion about the importance of interactions after their conduct of the laboratory activity. On the other hand, expectations of learning results-analysis from student-instructor interactions was replaced in their perception by the importance of learning laboratory procedures from this interaction reported after the conduct of laboratory activity.

4.4.1.3 Satisfaction with various interactions for the conduct of laboratory activity

In addition to understanding the importance of the interaction types in the post-laboratory survey, students were also asked to express their satisfaction with the four interaction types. Average satisfaction reported out of the score 10 for each interaction category is shown in Figure 4.5.

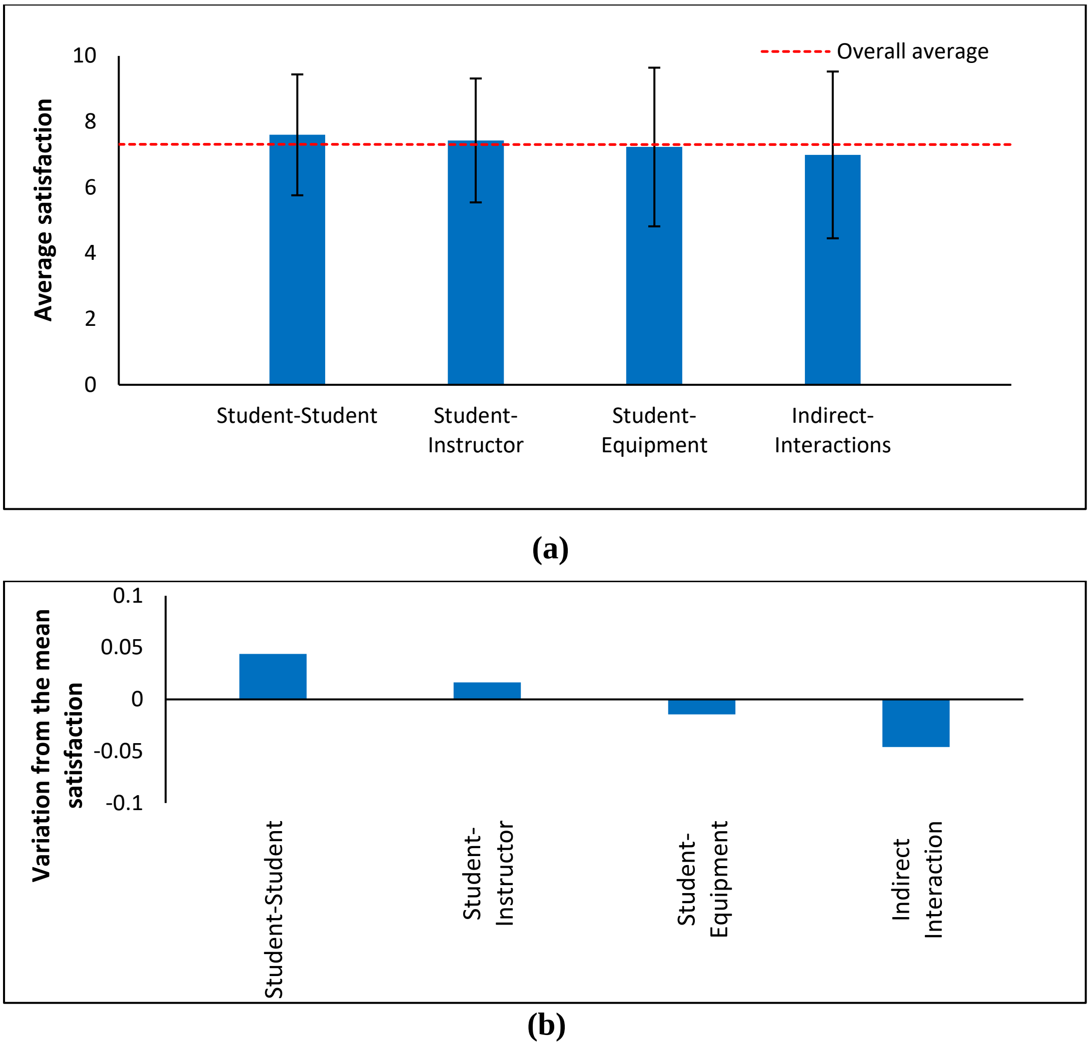
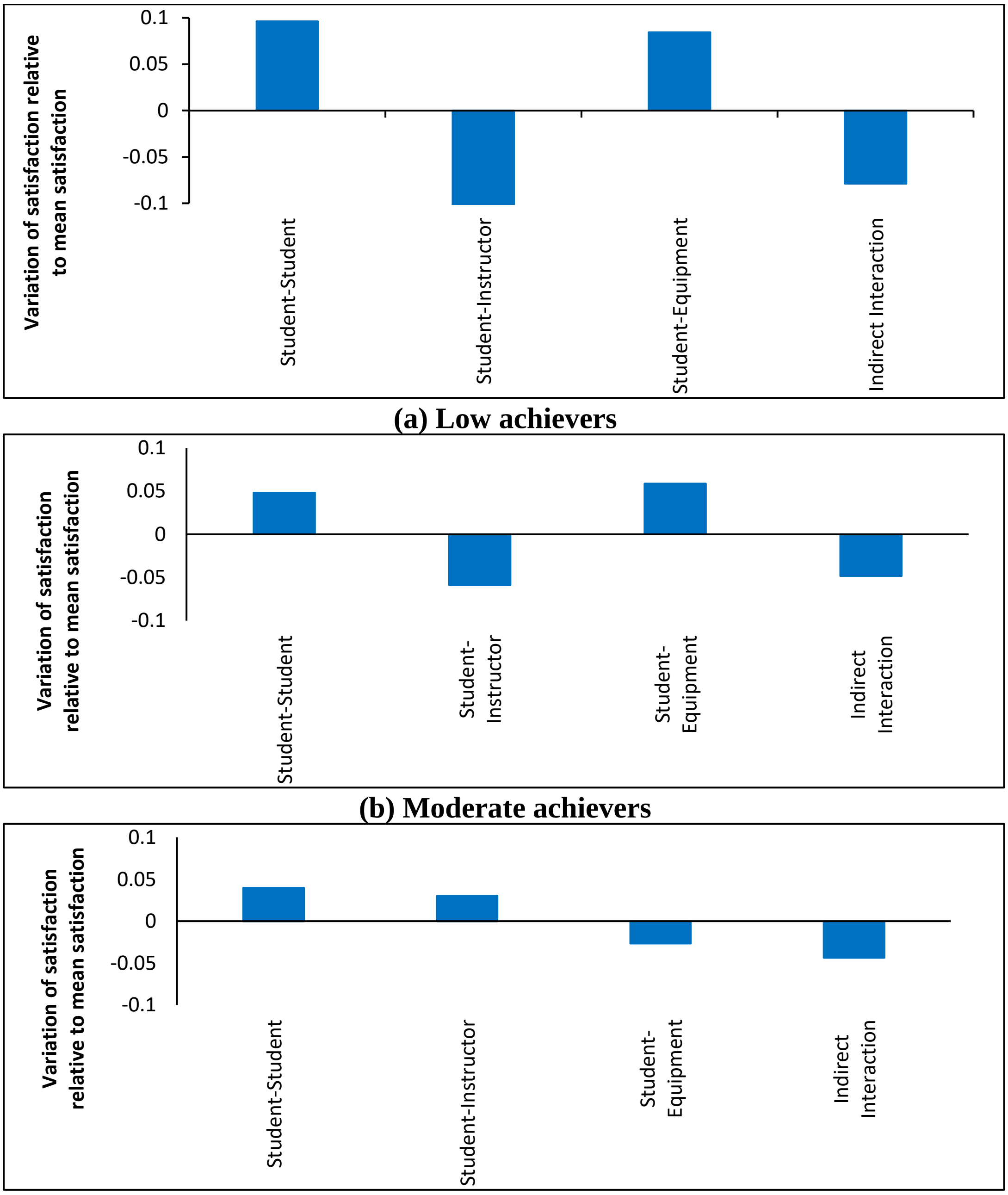


Figure 4.5: (a) Average satisfaction expressed by first-year students for each interaction type (N=186). Note: The red line represents the overall average score for satisfaction (7.31); (b) Satisfaction values relative to the mean satisfaction. The values in (b) have been obtained by using the relation $(x-\bar{x})/\bar{x}$, where x is the satisfaction score for each interaction and $\bar{x}$ represents the average score for all interaction categories. The uncertainty bars denote one standard deviation about the mean.

Figure 4.5(a) shows that the average satisfaction score for the student-student interaction was the highest among all four interaction categories. Also, the average score for student-student interaction exceeded the overall average satisfaction score for the four interaction categories. Average satisfaction scores for student-equipment and indirect interactions were slightly lower than the overall average satisfaction score. The uncertainty bounds in the average values of satisfaction for the four interaction categories indicate that the foregoing observations based on mean values should be treated with some caution and that conclusions drawn on this basis are therefore weak. A more detailed analysis of the satisfaction scores is conducted on the basis of the students' achievement in the laboratory activity and is discussed in Figure 4.6.



(a) Low achievers

(b) Moderate achievers

(c) High achievers

Figure 4.6: First-year students' satisfaction with various interactions based on their performance in the face-to-face laboratory activity: (a) Low-achievers (Below 60%), (b) Moderate-achievers (61%-75%), and (c) High-achievers (Above 75%). Note: The values have been obtained by using the same method as that for Figure 4.5(b).

Students' satisfaction with the four interactions was also analysed according to students' performance in the laboratory activity. Figure 4.6 shows students' satisfaction grouped according to their total mark obtained in the laboratory activity. The majority of the students fall under the high achieving group (166 out of 186 students). Figure 4.6 indicates that interactions with other students was satisfying to students of all achievement levels. Interactions with instructors were more satisfying to high achievers, while low and moderate achievers were more satisfied with their interactions with equipment.

Interaction with equipment for the laboratory activity was perceived important by the majority of the students (shown in Figure 4.4), however, lower satisfaction was reported for this category in Figure 4.6 by high-achievers. Therefore, a further attempt was made to analyse the factors that influenced students' satisfaction of four interaction categories for the conduct of the laboratory activity.

In the face-to-face laboratory, analysis of the significance of the factors from the four interaction types that contributes to students' satisfaction was conducted by performing a standard multiple regression using SPSS. Student satisfaction has been taken as the dependent variable while the four interactions are the independent variables. Findings of this analysis are shown in Table 4.1 and Table 4.2.

The significant factors that surfaced from this analysis also aligned with the activities that were highlighted in the importance of interactions shown in Figure 4.3.

Table 4.1 shows the predictor variables under the four interaction categories that had significant association with the students' satisfaction for the respective interaction category. The association of all factors is significant for $p<0.01$. For the student-student interaction category, students' interaction for the basic science concepts showed relatively higher association with student satisfaction than their discussion for results-analysis ($R^2= 0.226$ for basic science concepts and $R^2= 0.196$ for results-analysis). Similarly, for student-instructor interaction, students' interaction with an instructor for results-analysis ($R^2 = 0.389$ for results-analysis) had a slightly higher association with the students' satisfaction for this category. The use of laboratory instruction sheets and manipulation of apparatus both were associated at a similar significant level as the satisfaction for student-equipment interaction. Also, in the indirect interaction category, both the predictor variables depicted in the Table 4.1 were associated with the students' satisfaction at a similar level of significance, namely, $p<0.01$.

Table 4. 1: Model summary for student satisfaction as dependent variable

	Model	R	R^2	Adjusted R^2	Std. Error of the Estimate	Change Statistics R^2 Change	F Change	df1	df2	Sig. F Change
Student-student	Basic science concept	.476	.226	.222	1.631	.226	52.300	1	179	.000
	Results-analysis	.442	.196	.191	1.673	.196	44.293	1	182	.000
Student-Instructor	Results-analysis	.624	.389	.386	1.447	.389	115.459	1	181	.000
	Laboratory procedures	.567	.321	.317	1.526	.321	86.510	1	183	.000
Student-Equipment	Operate equipment	.448	.200	.196	2.143	.200	45.587	1	182	.000
	Lab sheet	.480	.230	.226	2.102	.230	54.467	1	182	.000
Indirect-Interaction	Listen other students' discussion	.519	.270	.266	2.151	.270	67.584	1	183	.000
	Listen Student-Instructor discussion	.496	.246	.241	2.192	.246	59.258	1	182	.000

Table 4.2 shows the beta coefficients for the predictor variables for students' satisfaction with four interaction categories. Beta coefficients for predictors under each interaction categories were positive and significant. The values of the standardised beta coefficients under the student-student and student-instructor interaction categories, show that results-analysis was a relatively better predictor for satisfaction with student-instructor interaction than student-student interaction (beta=0.624, $p<0.01$ for student-instructor interaction and beta=0.424, $p<0.01$ for student-student interaction). The opportunity to learn laboratory procedures from instructors was also significant for their satisfaction with the student-instructor interaction (beta=0.567, $p<0.01$).

Table 4. 2:Model coefficients - student satisfaction as dependent variable

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	T	Sig.
Student-Student	(Constant)	4.186	.521		8.034	.000
	Results-analysis	.434	.065	.442	6.655	.000
	(Constant)	4.519	.435		10.387	.000
	Basic science concepts	.427	.059	.476	7.232	.000
Student-Instructor	(Constant)	3.099	.480		6.460	.000
	Laboratory procedures	.555	.060	.567	9.301	.000
	(Constant)	3.145	.412		7.634	.000
	Results-analysis	.578	.054	.624	10.745	.000
Student-Equipment	(Constant)	2.748	.683		4.023	.000
	Operate equipment	.553	.082	.448	6.752	.000
	(Constant)	3.840	.485		7.915	.000
	Lab sheet	.491	.067	.480	7.380	.000
Indirect-Interaction	(Constant)	3.116	.495		6.293	.000
	Listening other students' discussion	.560	.068	.519	8.221	.000
	(Constant)	3.320	.501		6.624	.000
	Listening Student-Instructor discussion	.532	.069	.496	7.698	.000

In the student-equipment interaction category, both predictors shown in Table 4.2 were significant, of which the laboratory instruction sheet was a relatively better predictor for students' satisfaction (beta=0.480, $p<0.01$). Learning obtained from listening to other student's discussions and also their interaction with instructors, were significant predictors for students' satisfaction with indirect interaction.

It is found that opportunities to discuss basic science concepts underpinning the activity and discussing results-analysis with peers played a significant role in their satisfaction with student-student interaction. Similarly, interaction opportunities for laboratory procedures, results-analysis and discussing engineering topics with instructors during the conduct of activities were significant factors contributing to satisfaction with the student-instructor interaction. For students' satisfaction with the student-equipment interaction, availability of the laboratory instruction sheets and opportunity for hands-on manipulation of apparatus were significant. Finally, any learning achieved due to listening to other students' discussion and/or other students' discussion with instructors were significant for satisfaction expressed within indirect interactions.

4.4.1.4 Comparison of first-year students' expectations with their perceptions of importance and satisfaction with various interactions

Summarising the findings reported in sections 4.4.1.1, 4.4.1.2, and 4.4.1.3, it is found that first-year students' responses in the pre-laboratory survey reported expectations for learning results-analysis from the student-student and student-instructor interactions. However, after the conduct of the actual laboratory activity, students appeared to value these interactions for other activities, namely, learning laboratory procedures and basic science concepts underpinning the laboratory work. Expectations reported for the student-equipment interaction were confirmed in their perceptions after the conduct of laboratory. Statistical analysis conducted for the satisfaction with the four interaction categories revealed almost the same factors that were perceived by students as being important for the conduct of laboratory activity.

4.4.2 Third-year students in Applied Fluid Mechanics

4.4.2.1 Pre-laboratory expectations of various interactions

Figure 4.7 is the same figure presented in Chapter 3, as Figure 3.15. This figure has been included here to show the foundation for the analysis presented hereafter.

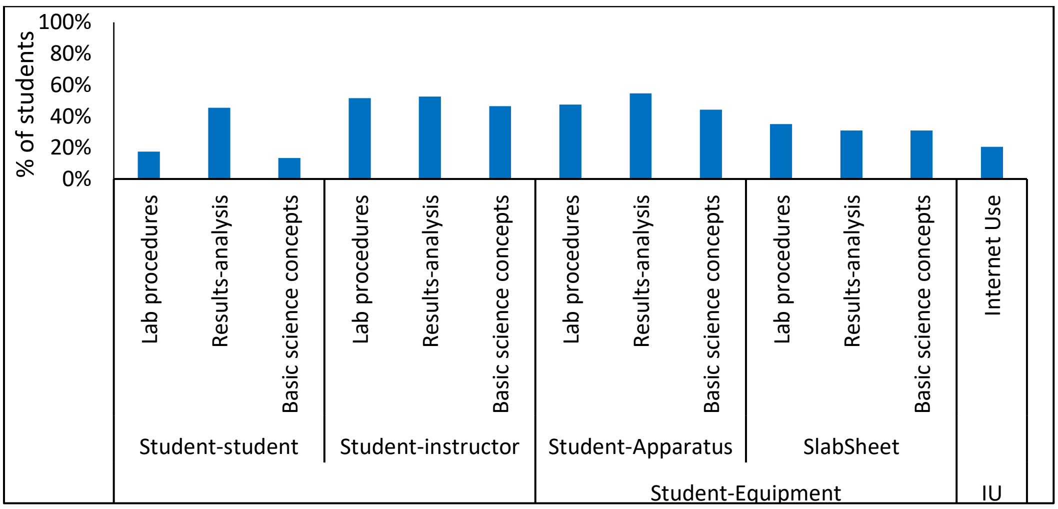


Figure 4.7: Third-year students' expectations of the importance of various interactions (N=97). Vertical columns represent the proportion of students selecting a laboratory activity deeming it important out of the thirteen choices provided. Note: IU=Internet Usage.

Figure 4.8 shows third-year students' pre-laboratory expectations grouped according to their overall marks for the Applied Fluid Mechanics unit, as the marks for the laboratory activity did not show sufficient variation to form groups. The three panels in Figure 4.8 show the pre-laboratory expectations of low-achievers (below 60%), moderate-achievers (61%-75%) and high-achievers (above 75%) respectively.

Students' expectations from the four interaction categories vary with their achievement level. Moderate achievers show independent learning behaviour for laboratory work with low expectations from student-instructor interaction and more expectations from interactions with equipment. Low and high achievers expressed high expectations for interaction with instructors.

The low-achievers responses, shown in Figure 4.8(a), indicates that they expected to learn from each of the interaction category. For instance, developing results-analysis skills was expected most from the interaction with other students as well as instructors, while interaction with equipment was expected to be important for learning basic science concepts. Interaction with instructors was expected to be important in learning laboratory procedures for low-achieving students.

Figure 4.8(b) shows that the moderate achievers had higher expectations of learning all laboratory related activities mainly from their manipulation of the apparatus. Interaction with instructors was also expected to be important for the laboratory activity.

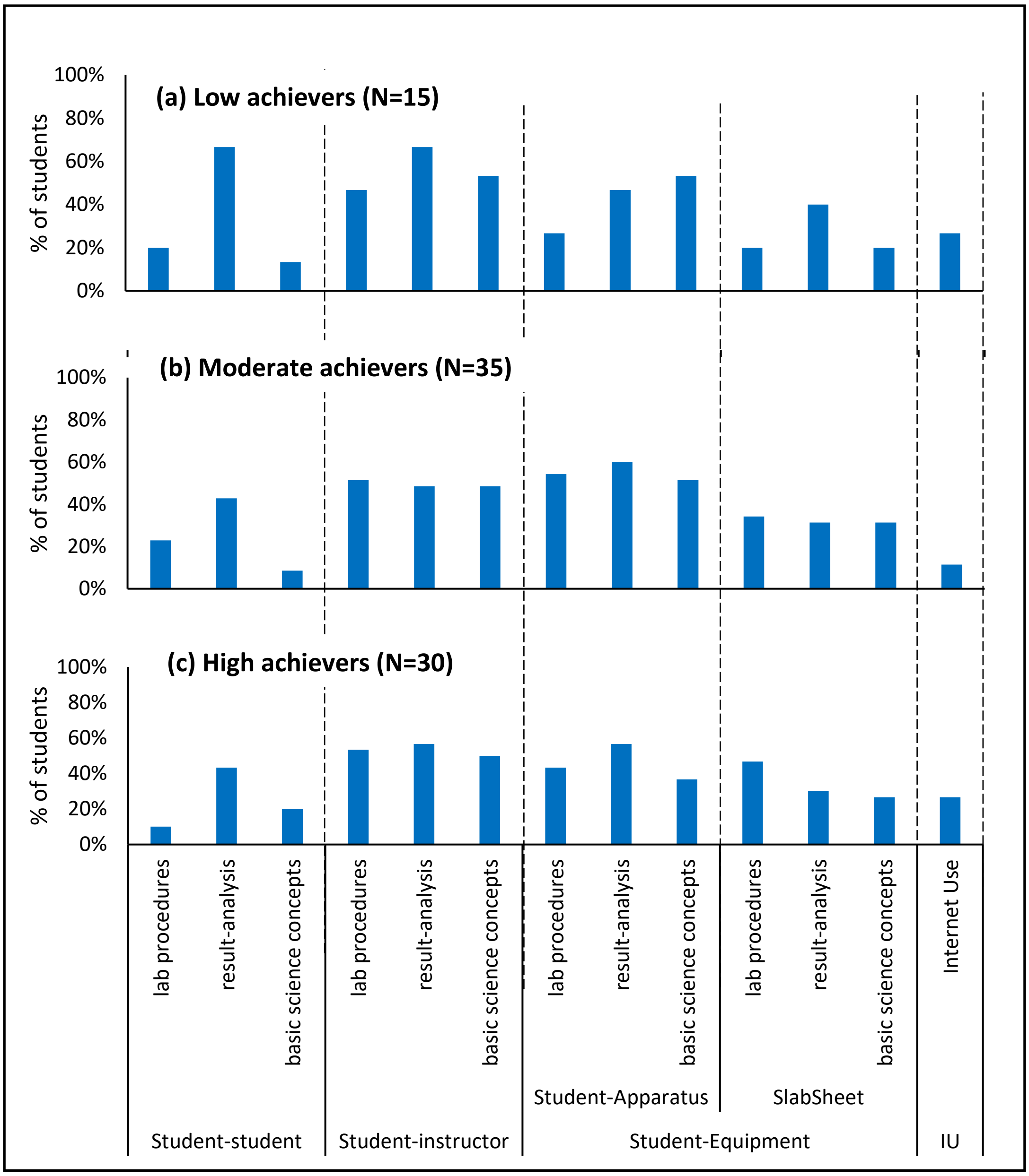


Figure 4.8: Third-year students' expectations of interactions based on their overall performance in the Applied Fluid Mechanics unit (N=97): (a) Low achievers (Below 60%), (b) Moderate achievers (61%-75%), and (c) High achievers (Above 75%).

The high achievers' response, in Figure 4.8(c), shows expectations from the interactions with instructors and equipment to be the most important for the laboratory activity.

As there is variation in expectations of interactions across students of different achievement levels, it is deemed important to understand and investigate whether the students' expectations aligns with their perceptions of the importance of these interactions after conducting the laboratory activities.

4.4.2.2 Students' opinions about the importance of various interactions for the conduct of the laboratory activity

Third-year engineering students received a survey questionnaire (shown in Appendix D.2) where, in addition to classifying the frequency of the interactions, they were requested to choose the five most important interactions they perceived important for their conduct of the laboratory activity. Figure 4.9 shows the importance perceived by third-year students for each interaction category and its associated activities. For third-year students, student-student and student-instructor interactions are the most important interactions. Opportunity to manipulate equipment was also reported important.

A comparison of third-year students' opinion about the important interactions under the student-student and student-instructor interactions revealed that students found their interactions with the instructor to be the most useful in learning results-analysis. For learning basic science concepts, students considered interactions with instructors to be more important than the interactions with other students. However, for learning laboratory procedures, students found using the laboratory instruction sheets under the student-equipment interaction to be more helpful than any other interaction. Indirect interactions and discussing general topics did not seems to be of much importance.

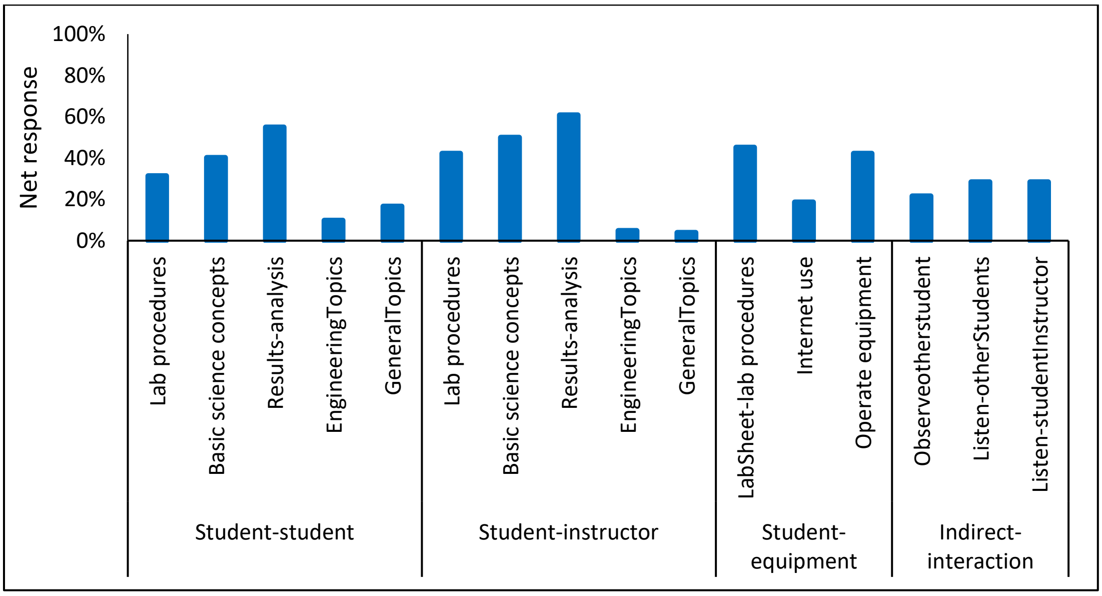


Figure 4.9: Third-year students' opinion about the important interactions (N=102)

The responses received from third-year students regarding the importance of interactions were further analysed on the basis of their overall performance in the unit

Applied Fluid Mechanics. Students' responses of the perceptions of the importance of interactions were grouped on the basis of their final mark obtained in this unit. This section reports the responses of 94 students out of 102; marks for the remaining eight students were not accessible. The marks were divided into four groups: unsuccessful (below 50%), low achievers (50%-60%), moderate achievers (61%-75%) and high achievers (above 75%). Figure 4.10 shows the patterns of responses received.

Student-student interaction is the most important interaction for students in the unsuccessful group. Interactions with instructors was reported to be important for learning results-analysis by students in all achievement groups except for students in the unsuccessful group who perceive it important for learning basic science concepts. Low and high achieving students report the use of laboratory instruction sheet for the laboratory activity to be more important than operating equipment. Students in unsuccessful and moderate achievers group report using laboratory instruction sheet and operating equipment to be equally important for the laboratory activity. Indirect learning was reported more important by students in the low achieving groups.

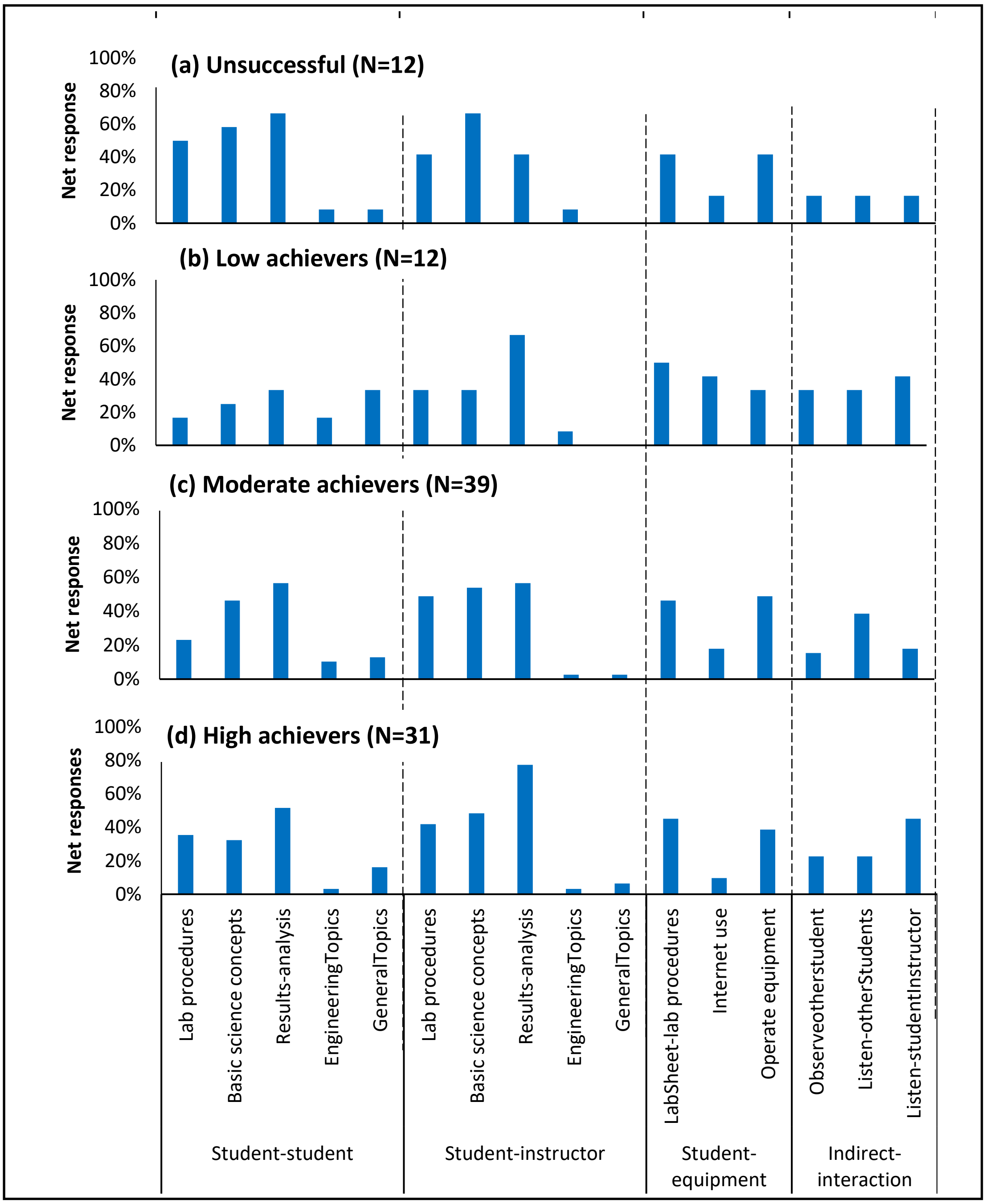


Figure 4.10: Third-year students' perceptions of important interactions based on their achievement in the unit, Applied Fluid Mechanics (N=102): (a) Unsuccessful (Below 50%), (b) Low achievers (50%- 60%), (c) Moderate achievers (61%-75%), and (d) High achievers (Above 75%).

4.4.2.3 Satisfaction with various interactions after the conduct of laboratory activity

Along with expressing their opinion about the importance of interactions, third-year students were also requested to provide their satisfaction (a score out of 10) for each interaction category. Figure 4.11 shows third-year students' average satisfaction score for each interaction category. Also shown is the overall average (red line) score for all interactions.

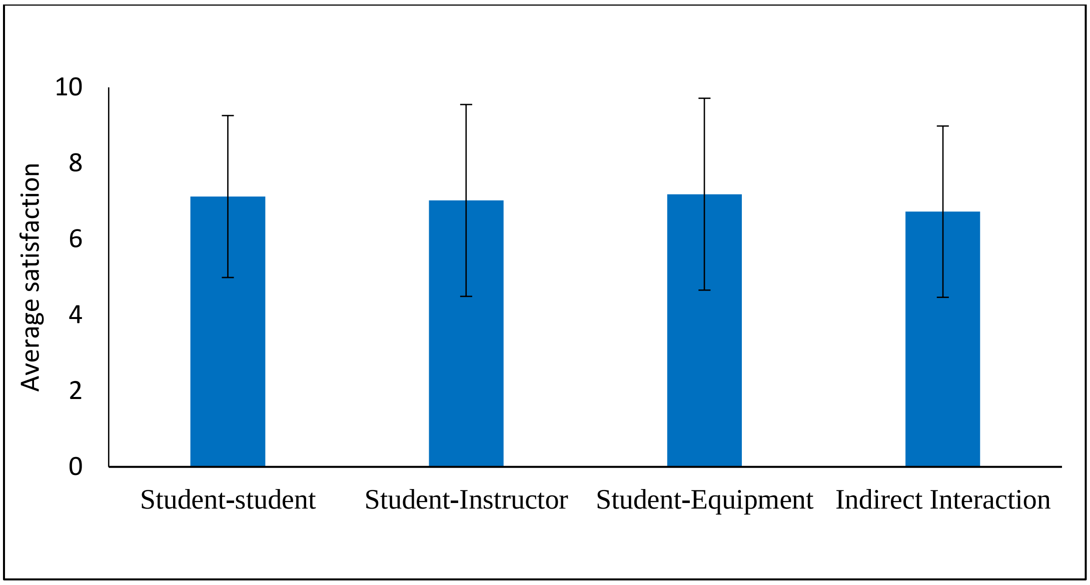


Figure 4.11: Average satisfaction expressed by third-year students for the four interaction categories (N=102). Note: Horizontal red line denotes the overall average satisfaction calculated for all interaction categories. The uncertainty bars denote one standard deviation about the mean.

Figure 4.11 reveals that the average satisfaction score for student-student, student-instructor, and student-equipment interactions were at a similar level. Similar magnitudes of the uncertainty bars in the figure indicates that the variation observed in satisfaction level is not significant. Accordingly, the following discussions of satisfaction levels should be treated with appropriate caution. Student-equipment interaction was the slightly more satisfying than other categories of interactions.

When satisfaction for each interaction was varied relative to the mean value of the satisfaction for all interaction categories, as shown in Figure 4.12, it revealed a slightly different picture of the satisfaction. Students were mostly satisfied with student-student interaction followed by student-instructor interaction, while the least satisfaction was seen for the indirect interaction and student-equipment categories.

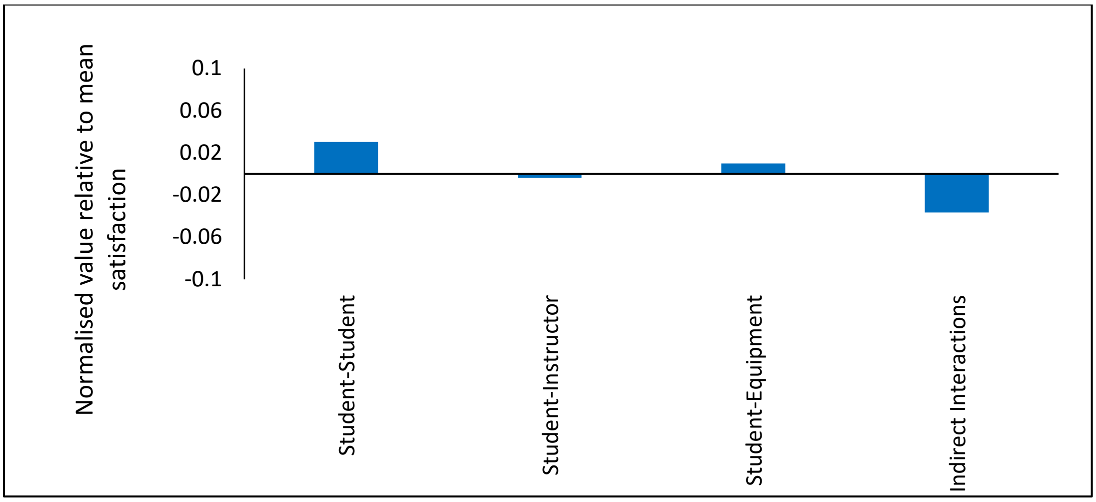
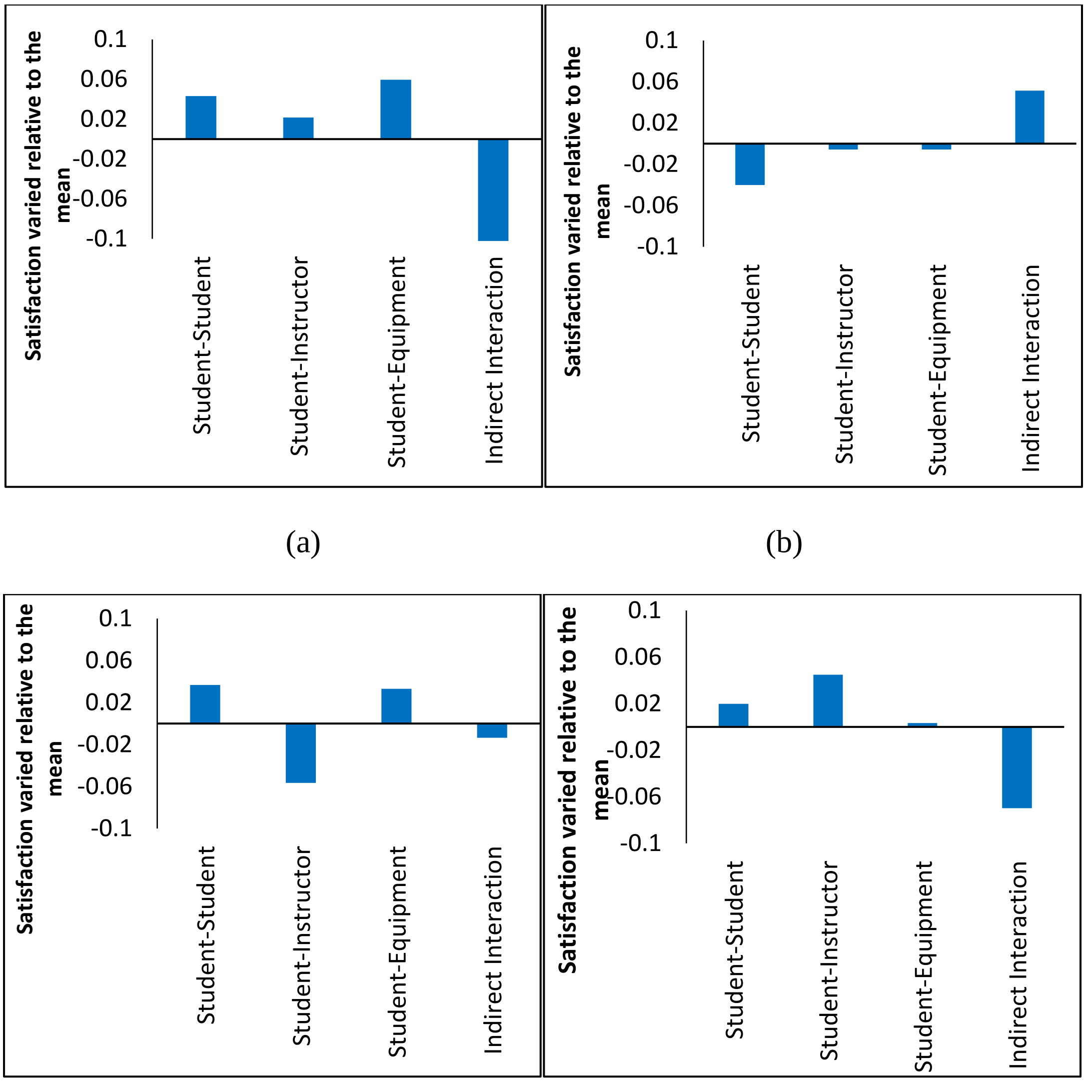


Figure 4.12: Satisfaction relative to the mean satisfaction value for the four interaction categories. The values have been obtained by using the relation $(x-\bar{x})/\bar{x}$***, where x is the satisfaction score for each interaction and*** $\bar{x}$ ***represents the average score for all interaction categories.***

A further attempt was made to understand third-year students' average satisfaction for all interaction categories on the basis of their overall mark for the Applied Fluid Mechanics unit. The grouping of students according to their mark in the unit was done in the same way as it was done for understanding the students' opinion about the importance of interactions. Figure 4.13 shows the satisfaction score relative to mean value of satisfaction expressed by students of the entire cohort.

Figure 4.13 indicates that for students who were unsuccessful in the unit interactions with equipment provided the most satisfaction. On the other hand, high achievers were most satisfied with their interaction with instructors. Interactions with other students and the equipment provided high satisfaction to moderate achievers while indirect interaction was the most satisfying experience to low-achieving students. Overall, no identifiable trends of satisfaction with student-achievement level in the unit was seen.



(a) (b)

(c) (d)

Figure 4.13: Analysis of the average relative satisfaction for four interaction categories based on the overall score for the Applied Fluid Mechanics unit: (a) unsuccessful (below 50%), N=13, (b) low achievers (50%-60%), N=12, (c) moderate achievers (61%-75%), N=42, and (d) High achievers (above 75%, (N=34). Note: The values have been obtained as described in Figure 4.12.

4.4.2.4 Comparison of students' expectation with their reports on the importance and satisfaction for various interactions

Third-year students expected to learn most from their interactions with other students and the equipment which includes both manipulation of the apparatus and using the laboratory-instruction sheet. By comparison with those, they did not expect to learn much from their interaction with instructors.

Responses after the conduct of the laboratory activity show students reported the high value for student-equipment and indirect interactions in the context of importance of interactions. The student-instructor interaction was not reported to be important except for the high-achieving students. This result shows some similarity with their expectations before conducting laboratory.

The majority of high-achievers indicated that learning from instructors is the most important as well as the most satisfying interactions. Low-achieving students were most satisfied with the indirect interactions while the high achievers were most satisfied with the student-instructor interaction. Similarly, moderate achievers were satisfied with student-student and student-equipment interactions.

In summary, for the conduct of laboratory work in general, third-year students expected to have direct or indirect interactions with other students and any opportunity for hands-on manipulation of equipment to be important. However, for better performance and achievement in the laboratory, interactions with instructors seem to be important, as the high-achieving students found this interaction to be important as well as satisfying.

4.5 Changes in students' expectations of interactions from first- to third-year of an engineering degree

Figure 4.14 summarises the difference in the expectations of first- and third-year students of various interactions for the conduct of laboratory activities. Pre-laboratory expectations of importance of interactions reported by first- and third-year students for the various interaction categories shows little change. Both cohorts expected most from the student-instructor interactions followed by student-student interactions. Expectations from student-student interactions drops from first- to third-year. The lowest expectation was reported for the student-equipment interaction which includes student-apparatus and student-lab sheet interactions.

Both cohorts expressed higher expectation for developing results-analysis skills from their interaction with instructors. First- and third-year students also provided similar ranks for their expectations of learning basic science concepts from their interactions with other students in the laboratory. In the student-equipment interaction category, developing results-analysis skills from the manipulation of apparatus was least expected by third-year students, while for first-year students it was the use of laboratory instruction sheet.

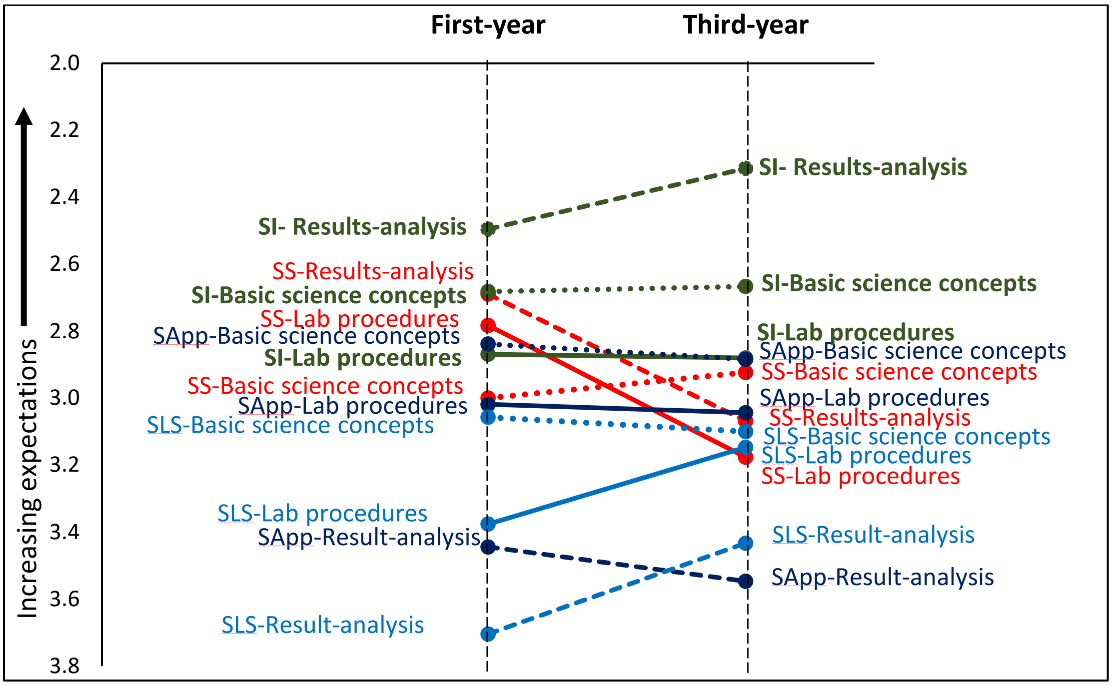


Figure 4.14: Expectations of the importance various interactions reported by first- and third-year students. Vertical axis represents the average of the ranks for each interaction. Note: SS=Student-Student (red line), SI=Student-Instructor (green line), and SLS=Student-labsheet interactions (light blue line); Sapp=Student-Apparatus interactions (dark blue line) under Student-Equipment interaction. Solid-line=lab procedures; dashed-line=results-analysis; dotted-line= basic science concepts.

Table 4.3 shows the list of interactions in their order of importance as reported by first- and third-year students. Responses for the opinion about the importance of interactions from first- and third-year students have been obtained in different ways. First-year students provided a rank on a scale of 1 to 10 for their opinion about the importance of an interaction. By contrast, third-year students chose five interactions that were perceived most important. For the first-year, interactions are ranked from highest to lowest, while for the third-year students, the interactions were chosen from most to least.

Table 4. 3: First- and third-year students' opinion about the important interactions. Note: Student-Student (red line), Student-Instructor (green line), and Student-Lab Sheet interactions (light blue line); Student-Apparatus interactions (dark blue line) under Student-Equipment interaction, Indirect interactions (brown line).

Rank	First-year	Third-year
1st	**Student-equipment (Operate equipment)**	**Student-instructor (Results-analysis)**
2nd	**Student-instructor (Lab procedures)**	**Student-student (Results-analysis)**
3rd	**Student-student (Results-analysis)**	**Student-instructor (Basic science concepts)**
4th	**Student-instructor (Basic science concepts)**	**Student-equipment (Lab Sheet for lab procedures)**
5th	**Student-instructor (Results-analysis)**	**Student-instructor (Lab procedures)**
6th	Student-student (Lab procedures)	Student-equipment (Operate equipment)
7th	Student-student (Basic science concepts)	Student-student (Basic science concepts)
8th	Student-equipment (Lab Sheet for lab procedures)	Student-student (Lab procedures)
9th	Indirect-interaction (Listen-other students' discussion)	Indirect-interaction (Listen-other students' discussion)
10th	Indirect-interaction (Listen-student Instructor discussion)	Indirect-interaction (Listen-student Instructor discussion)
11th	Indirect-interaction (Observe other students' activity)	Indirect-interaction (Observe other students' activity)
12th	Student-student (Engineering Topics)	Student-equipment (Internet use)
13th	Student-student (General Topics)	Student-student (General Topics)
14th	Student-instructor (Engineering Topics)	Student-student (Engineering Topics)
15th	Student-equipment (Internet use)	Student-instructor (Engineering Topics)
16th	Student-instructor (General Topics)	Student-instructor (General Topics)

The top five interactions (shaded) in Table 4.3 show that both first- and third-year students consider interaction with the instructor to be the most important, followed by student-equipment and student-student interactions. For both cohorts, student-student interaction is important for developing results-analysis skills. Both first- and third-year students consider student-equipment interaction to be important. Under the student-equipment interaction category, first-year students find the operation of equipment important for developing hands-on skills while for third-year students use of laboratory instruction sheet for conducting the activity is important.

Comparing the satisfaction reported by first- and third-year students (Figure 4.5(b) and Figure 4.12 and for the various interaction categories, first-year students are most satisfied with the student-student and student-instructor interactions, while third-year students are satisfied with all interactions except for indirect interactions. First-year high achievers are most satisfied with student-student interactions (Figure 4.6), while third-year high achievers indicate highest satisfaction for student-instructor interactions (Figure 4.13).

Overall, irrespective of their study level, students report high importance for the student-instructor interaction as well as valuing the opportunity to have hands-on manipulation of apparatus. Additionally, the student-student interaction is considered important by both first- and third-year cohorts, irrespective of the difference of opinion for the preference in learning of activities associated with laboratory. These findings highlight the importance of instructors' presence in the laboratory and also creating opportunities for students to collaborate during the laboratory activity.

4.6 Chapter Summary

Learning laboratory procedures, basic science concepts, and results-analysis are vital parts of laboratory activities. This is reflected in the responses received from first- and third-year students for their expectations of the importance of interactions before the conduct of the activity as well as their reporting of the importance of interactions after their conduct of the activity.

In summary,

1. Instructors play an important role in both beginner as well as advanced students' overall learning in laboratory work.
2. The most frequent student-student interaction (see chapter 3) does not imply that it is the most important interactions. However, it reflects the comfort level of students with other students for the conduct of the laboratory work.
3. Direct hands-on experience of manipulating apparatus and a well-designed laboratory instruction sheet play an important role in students' learning in laboratory work.

4. Indirect learning from other students' interaction with their peers or instructors is an important interaction for students learning in laboratory and the conduct of the laboratory activities.

.In general, the findings of this chapter show that students' expectations of the importance of interactions in the laboratory work aligned well with their reports of the important interactions and satisfaction for interactions after the conduct of the activity. Having established the findings for face-to-face laboratories in Chapters 3 and 4, Chapter 5 presents investigations conducted in a remotely-operated laboratory for first-year students' expectations of the importance of interactions, the actual frequencies of interactions, post-laboratory reports on the importance of interactions, and finally satisfaction with the interactions.

Chapter 5

Students' expectations of importance of interactions, frequency, and report of important interactions and satisfaction for interactions in a remotely-operated laboratory

This chapter focuses on first-year students' opinions and experiences on the four types of interactions: student-student, student-instructor, student-equipment and indirect interactions associated with laboratory learning in remotely-operated engineering laboratories. The results of the study are based on qualitative and quantitative analyses of results obtained through the use of survey questionnaires and video recordings of a remote laboratory session. This chapter includes results of first-year students' expectations from the four interactions and the frequency of occurrences for different aspects of the laboratory activity. Further results and discussion compare first-year students' reporting of the importance of each interactions and satisfaction for each interactions in a remotely-operated laboratory.

5.1 Background and aims

An overview of the various modes of engineering laboratories in practice today was presented in Chapter 2. The laboratory modes which involve real physical equipment are face-to-face and remotely-operated asynchronous laboratories. The main difference between these two laboratory modes is the way the activities are performed.

In face-to-face laboratories students are physically present in the laboratory for the hands-on manipulation of the apparatus. Instructors are also physically present in the laboratory to guide and instruct students during their conduct of the laboratory activities. On the other hand, in remote laboratories the apparatus for the activity is set up at a different location and generally accessible for students and instructors via an internet browser. Most mechanical-type asynchronous remote laboratories, which require significant manipulation of the physical parts of the apparatus, do not allow for students and instructors to synchronise their interactions while activities are being carried out.

The results of students' experience and opinion about the importance of interactions in face-to-face engineering laboratories were presented in Chapter 3 and 4. The results discussed in those chapters indicate the importance of the interactions experienced by students with their peers, instructors and hands-on manipulation of apparatus. Irrespective of the laboratory mode, students are expected to achieve the same level of learning outcomes from their conduct of the laboratory activity. Accordingly, it is important that students' experiences and perceptions are also studied for remote laboratories.

5.2 Research Questions

Chapter 5 investigates the following research questions for a remotely-operated laboratory

RQ 3 How do student expectations relate to the frequency of their interactions in a remotely-operated laboratory?

RQ 4 How do student expectations relate to their perception of the importance and satisfaction for interactions in a remotely-operated laboratory?

5.3 Research methodology

A mixed-method research design (Creswell, 2014) is used for investigating students' expectations and their actual experience of interactions in the remote laboratory. Students' expectations of the importance of interactions, their reporting of the actual importance of interactions and satisfaction with these interactions was studied through the administration of survey questionnaires, which were adapted from the face-to-face laboratory investigation. Similarly, the frequency of occurrences of interactions during the conduct of the activity were quantitatively studied by means of a video-recording analysis.

5.3.1 Development of survey instruments for a remotely-operated laboratory

For the quantitative study, a survey questionnaire was designed which comprised Likert-type questions. The questions in this survey were again based on the work of Velasco et al. (2016). The pre-laboratory survey for studying first-year students' expectations of interactions in the remote laboratory is exactly the same as for the face-to-face laboratory (as shown in Appendix C.1).

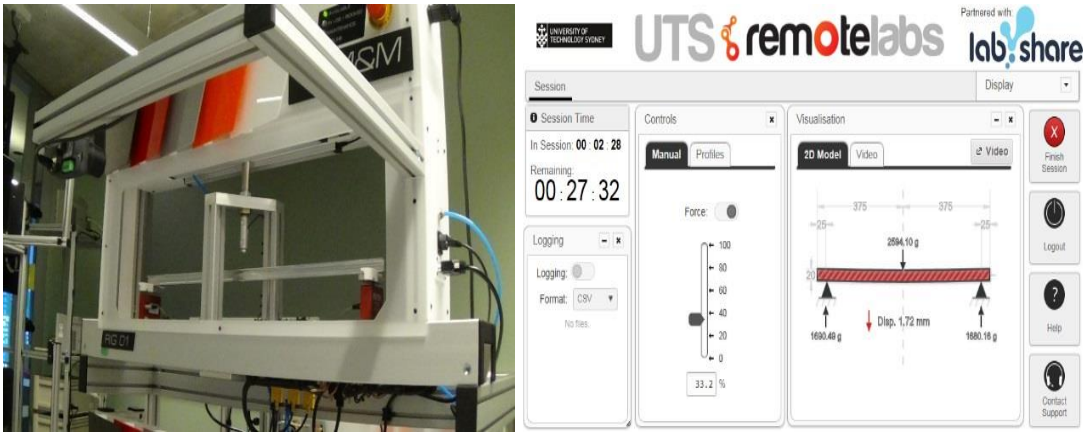
For the post-laboratory investigation of students' opinions and satisfaction with interactions, the questionnaire comprised similar questions to those of the face-to-face laboratory (as shown in Appendix D) in all categories of interactions except for the student-equipment category. As the laboratory work in the remotely-operated laboratory is different in its mode of conduct, the student-equipment interaction category contained questions such as the use of laboratory instruction sheet for the conduct of laboratory activity, use of the internet for laboratory-related tasks, feeling of operating real equipment, and the level of difficulty in operating equipment via the internet browser. The survey designed for the remote laboratory also contained a question on satisfaction within each interaction category. The questionnaire for remote laboratories is shown in Appendix G.

An additional set of questions for remote-laboratory students was tailored to capture their overall experience of working on a remotely-operated laboratory. This section had questions such as whether working in a remote laboratory was equally satisfying as in the face-to-face laboratory and whether they would like to do another laboratory activity remotely.

5.3.2 The remote laboratory activity

In the first category of remotely-operated laboratory studied, first-year students worked in groups of two or three on a set of equipment and had an instructor in the laboratory for the whole period of the activity. The instructor provided them with an initial demonstration of the laboratory activity and also supported them with their queries throughout the conduct of the activity. Students manipulated the apparatus that was distantly set up at an institution in Sydney. The remote laboratory activity investigated was from the Engineering Fundamentals unit.

The remote-laboratory equipment, involving an aluminium beam, shown in Figure 5.1(a), is situated in Sydney and is accessible over the web browser. Students log into the program using their University credentials and log out on completion of the task. Figure 5.1(b) shows the interface designed for the interaction between the students and the equipment in the remote laboratory.



(a) (b)

Figure 5.1: Remote-laboratory set-up (a): Apparatus for beam-bending activity, (b) Remote interface for students' interaction with the equipment.

The activity requires students to take recordings of the beam displacement for two types of loading condition. Each group chose one loading condition at the start and later switched to other loading condition, when the equipment was free to use. The laboratory activity is designed as a single log-in to the interface lasting for 30 minutes for each loading condition, which comprises only data collection. As part of the experimental procedure, students had to apply a force on the beam and record the displacement in the beam, changing force values between 0 and 100 (in %). The interface involved no other task to complete the work.

5.3.3 Data collection and analysis

In Semester 2 of 2017, the survey was conducted for first-year undergraduate engineering students working in the remote laboratory mode. Students who worked only in the remote laboratory comprised a small cohort of 26 students.

Initially data were collected from students who exclusively worked on the face-to-face and remotely controlled laboratories. An attempt was made to compare the remote laboratory learning experiences of students who had previously completed the equivalent face-to-face laboratory activity. Subsequently, a request to volunteer for the study was called for first-year students who had taken the face-to-face laboratory activity from an Engineering Mechanics unit. Eleven students volunteered to perform the same experiment which they had already conducted in the face-to-face mode. These students worked independently using only the support of the laboratory-instruction sheet that was provided to them. Students were given the choice to work alone or in groups. There was no instructor support during the conduct of the activity in another set up of the remote laboratory studied. However, a brief introduction to the activity and ways to establish the connection with the equipment was provided before the start of the activity. At the end of the activity, students completed a survey to report their experiences.

Video analysis in one of the remote-laboratory sessions was undertaken to investigate the frequency of interactions that occurred during the conduct of the remote laboratory activity. The video recording of the events was analysed using the GORP software.

Graphical analysis of data collected was conducted using MS Excel. Correlations and significance were determined using SPSS software.

The following section sequentially discusses the responses received for the remotely-operated laboratory. The section begins by discussing students' expectations of interactions before the actual conduct of the remote laboratory activity. This is followed by detailing the findings about frequency of occurrences for various interactions during the conduct of the activity. Finally, students' reporting of importance of interactions for both set up with and without instructors and satisfaction for the interactions after the conduct of the activity is presented.

5.4 Results

Reliability of the post-laboratory survey questionnaire was calculated to check the internal consistency of the results across all items in the post-laboratory survey. The Cronbach's alpha value was above 0.87 which indicates that the instrument used for the survey is reliable (Bland & Altman, 1997; Nunnally & Bernstein, 1994).

5.4.1 Student expectations of various interactions

This section provides results of students' expectations of their interactions to establish a baseline for responding to the two Research Questions 3 and 4. As in the face-to-face laboratory, students working in remotely-operated laboratory mode were also asked to choose and rank the top five most important interactions out of the thirteen choices (shown in Appendix C.1) in the laboratory before they commenced the laboratory work.

Figure 5.2 shows the students' responses received per item through the pre-laboratory survey. Students' expectations for various interactions in the remote laboratory indicated that of all the major interactions, students mostly expected to learn results-analysis. The proportions choosing this laboratory activity were the highest in each interaction category, except for their interaction with the laboratory-instruction sheet under the student-equipment interaction category. 73% of students anticipated to learning results-analysis from the student-instructor interactions, while for the student-student interaction category 54% of the students showed this to be their main expectation. Under the student-equipment interaction category, 58% of the students anticipated learning results from their manipulation of the apparatus and 62% of the students indicated to learn laboratory procedures by reading the laboratory instruction sheets provided for their conduct of the activity. Only 34% of students indicated the importance of using the internet in the remote-laboratory.

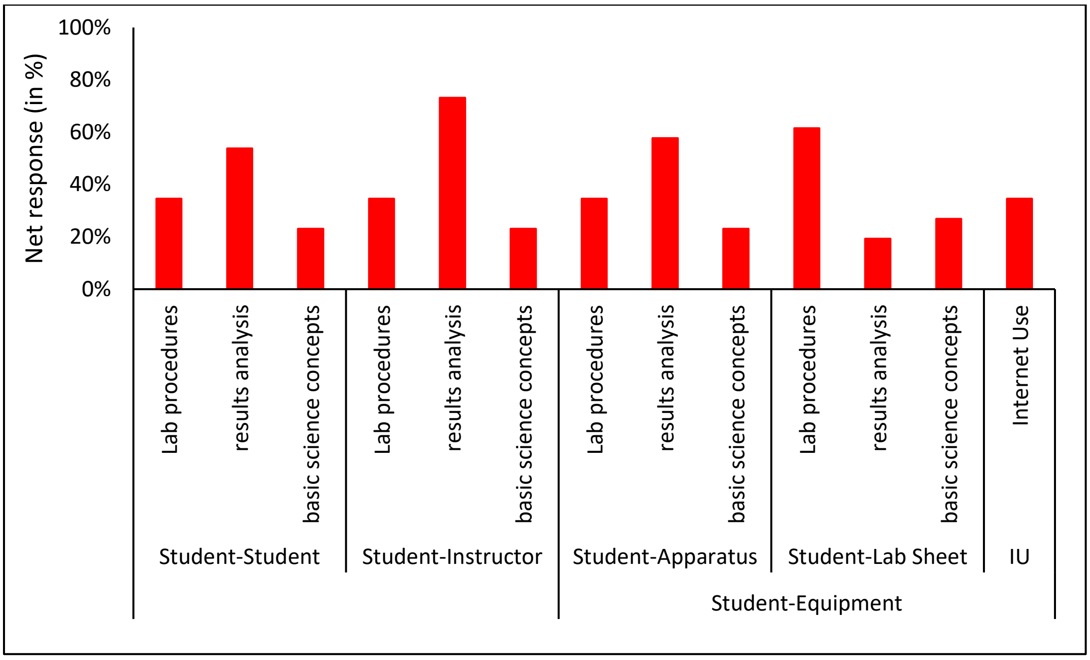


Figure 5.2: Pre-laboratory expectations of importance of first-year students from the interactions in the remotely-operated laboratory (N=26). Vertical columns represent the proportion of students who chose a particular laboratory activity as one of the five choices. Note: IU=Internet Usage

5.4.2 Frequency of occurrences of interactions during the conduct of a remotely-operated laboratory activity

This section presents results for Research Question 3. The frequency of occurrences of various interactions during the conduct of remote laboratory activity was obtained from a video recording conducted for a remotely-operated laboratory session which was scheduled for 60 minutes but did not last more than 45 minutes. This is due to the fact that remote laboratory activities did not include results-analysis and report writing tasks, a task that was mandatory in the observed face-to-face laboratory. Observations using GORP were exported to MS Excel for analysis. The analysis process was same as that conducted for the face-to-face laboratory.

Figure 5.3 depicts the instances of occurrences of observed interactions between student, instructor and remote equipment during the conduct of laboratory activity. In contrast to the results for the first-year face-to-face laboratory, it is evident that the instructor was actively interacting with students throughout the laboratory work. No student-instructor interaction was observed during the demonstration. On the other hand, students' interaction among themselves and with equipment existed only after the demonstration of activity by the instructor. Student-student and student-equipment interactions occurred purely for the data collection purposes because there was no requirement of needing assistance to physically set up the equipment for the activity.

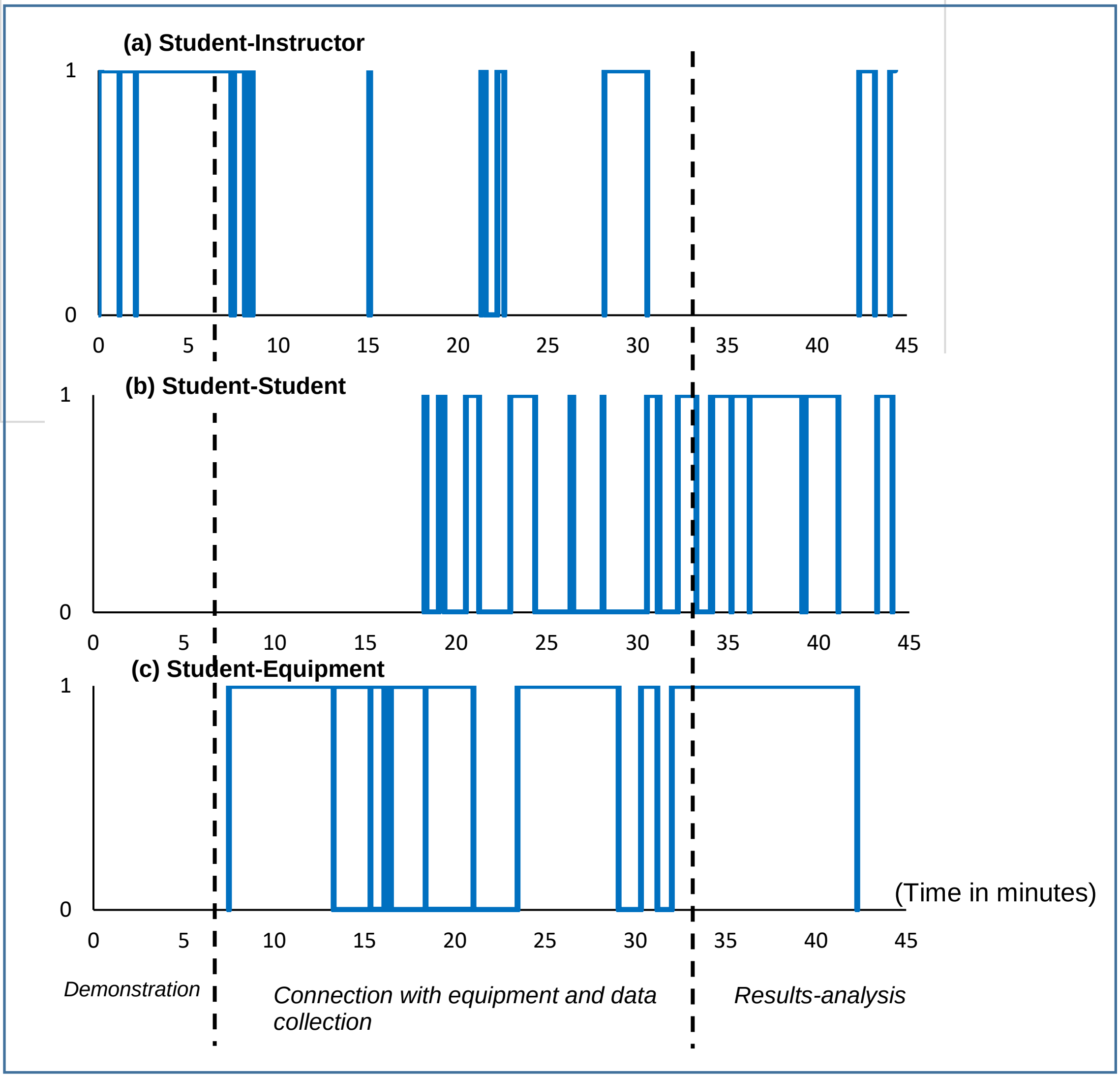


Figure 5.3: Instances of occurrences of interactions during 60 minute remote laboratory session (N=26): (a) SI=student-instructor interaction; (b) SS= student-student interactions; (c) SE=student-equipment interaction. Note: 1= Occurring and 0= Not occurring.

Figures 5.4 and 5.5, respectively, show the duration of each interaction type and the number of occurrences during the conduct of the laboratory activity. Analysing the duration of interactions, students appear to spend most of the laboratory time (approximately 30 minutes) manipulating the equipment following laboratory procedures given in the laboratory-instruction sheet. Based on the times of interactions, those interactions that seem significant are the interaction between students and instructor (9 minutes) and between student and student for discussion on results-analysis (approx. 7 minutes). Students' interaction with each other for conducting laboratory procedures, discussing the results obtained and student-instructor interaction for laboratory procedures are the most frequent.

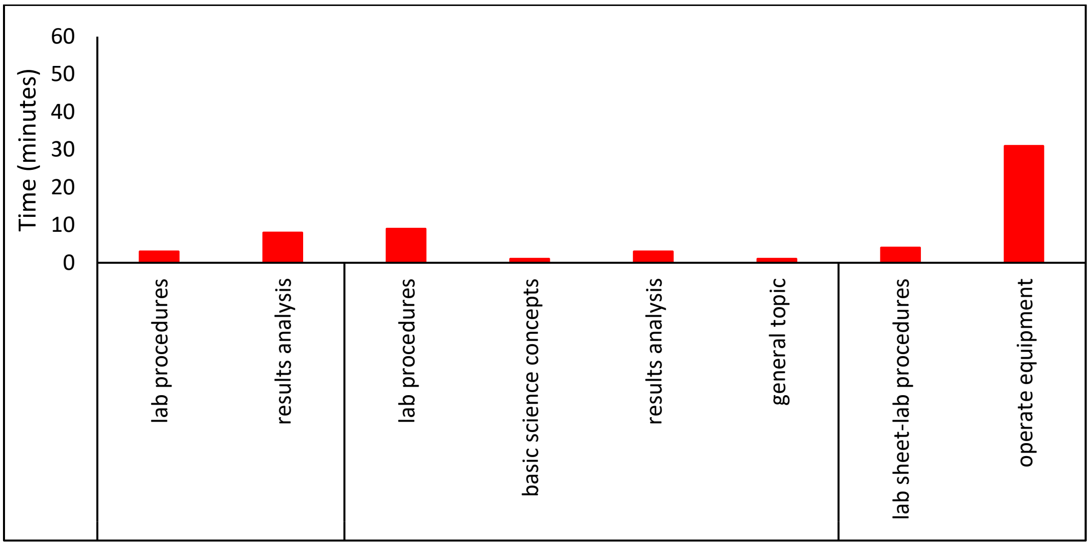


Figure 5.4: Duration of each interaction types over the 60-minute session (N=26)

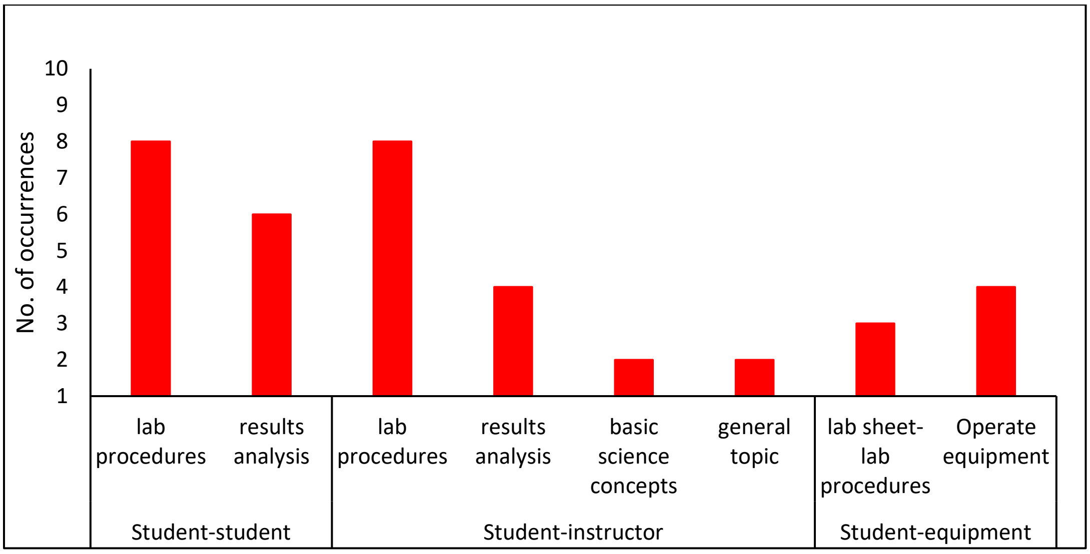


Figure 5.5: Number of occurrences of each interaction type over the 60-minute laboratory session (N=26)

5.4.3 Students' reporting their perception of the importance of interactions in the Remote-laboratory

The responses on the importance reported by students who worked in the remote-laboratory are presented here to answer Research Question 4. Although there were two different cohorts who worked in the remote-laboratory, their responses have been combined. The primary reason for doing so is the low number of participants in both cohorts and, secondly, the survey administered to both cohorts was the same. Figure 5.6 shows the overall view of first-year students regarding the importance of interactions after they had completed the laboratory activity.

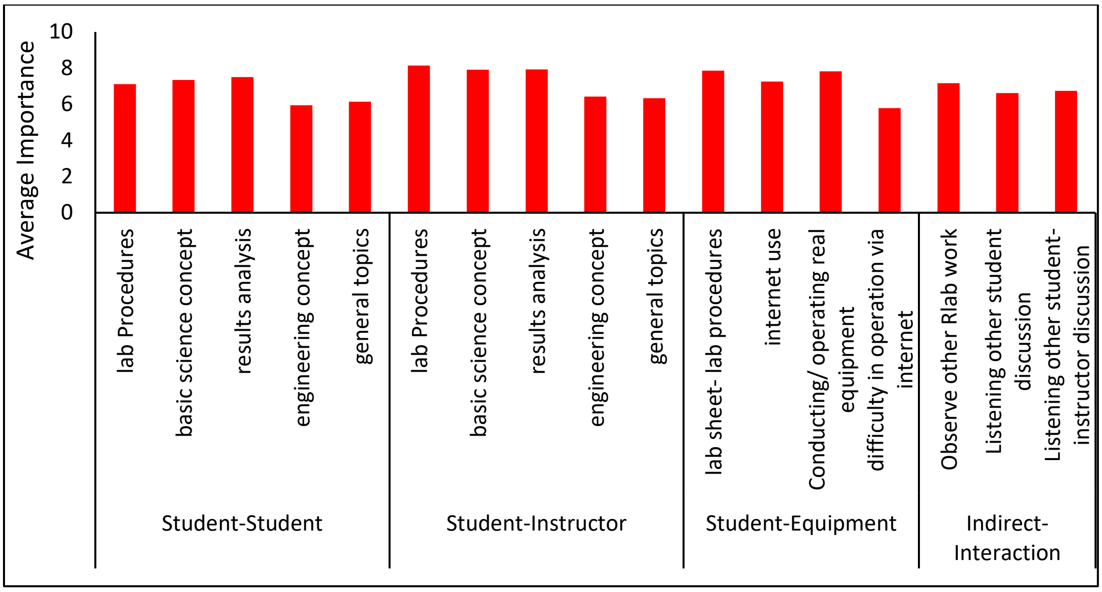


Figure 5.6: Average importance of various interactions reported by first-year students in the remotely-operated laboratory. Note: N (with instructor) =26 and N (without instructor) =11]

These results indicate that for learning all of the important laboratory activities students valued the instructor support more than the interaction with other students. The importance of operating the equipment was also evident in their responses. Students' responses also indicated that students experienced the feeling of operating real equipment although they were physically separated from the experimental rigs. In the student-equipment interaction category, the remote-laboratory users highly valued the use of the laboratory instruction sheet as well as the manipulation of the equipment.

In order to understand how students' views of the importance of interactions varied with or without an instructor present, the perceptions of students who performed the activity in the presence of instructors and those who performed the task in the absence of instructors are plotted in Figure 5.7.

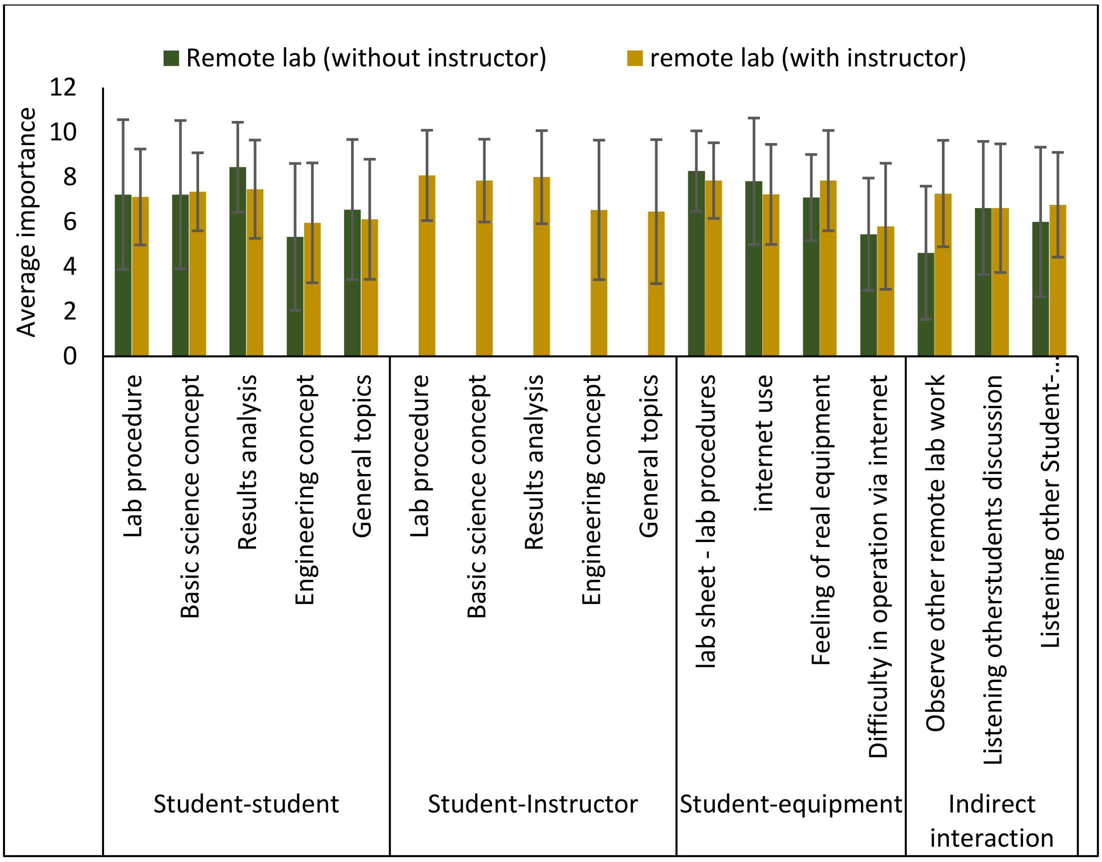


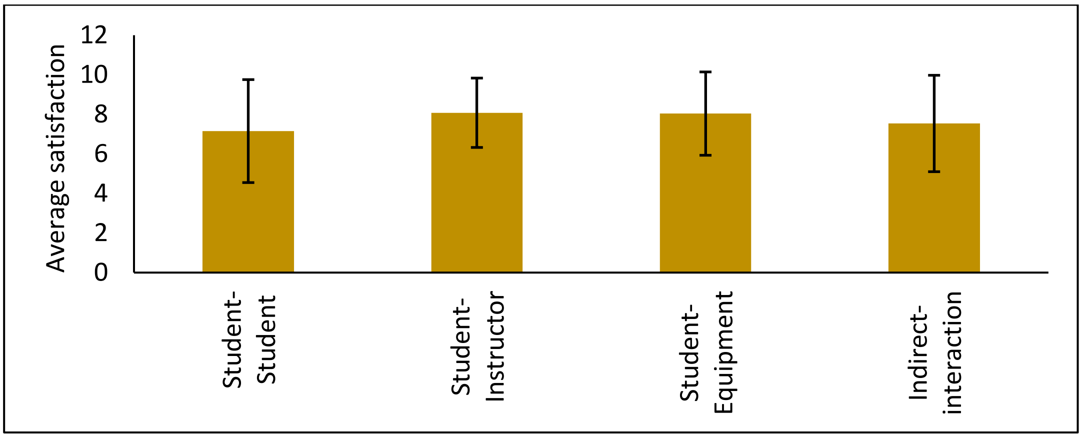
Figure 5.7: Students' reporting of important interactions for remote-laboratory work. Note: N (with instructor) =26 and N (without instructor) =11. The uncertainty bars denote one standard deviation about the mean.

In Figure 5.7, students in both groups (with and without instructors) expressed similar opinions about the importance of interactions. Note that students who performed remote-laboratory work without instructors could not express their opinion regarding the importance of student-instructor interaction. For results-analysis of the data obtained through the activity, students working without instructors felt student-student interaction to be more important. However, those who worked with the instructor's guidance expressed the importance of interactions with the instructors for learning skills related to results-analysis. The importance of using the laboratory-instruction sheet for learning laboratory procedures is considered relatively more important by students who performed laboratory work without the instructor. Similarly, students who worked with the instructor's guidance reported difficulty in operating remote laboratory rigs via the internet. These cohorts also reported high importance for indirect learning obtained from observing other students' remote laboratory work.

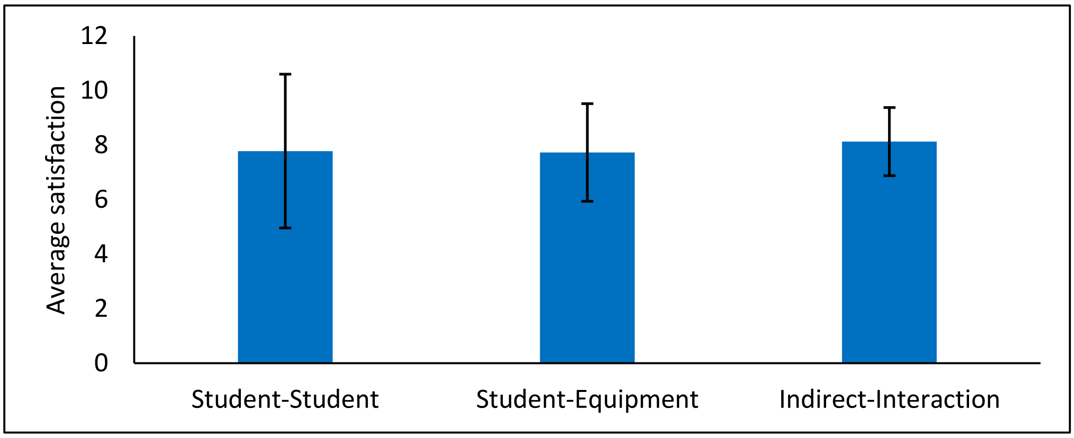
The high values of standard deviation in the response data for both cohorts may reflect the relatively small size of the cohorts studied, but they do reveal marked differences of views within the student cohorts.

5.4.4 Satisfaction for interactions experienced by first-year students performing remote laboratory activities

In addition to studying the importance of the interaction types reported through the post-laboratory survey, all students who worked with and without instructor's support in the remote laboratory were asked to express their satisfaction for the four interaction types. This also serves to answer Research Question 4. The two Figures 5.8 (a) and (b) shows responses of the students from the two groups. Average satisfaction expressed as a score out of 10 for each interaction category is.



(a)



(b)

Figure 5.8: Average satisfaction expressed by first-year students for each interaction type (a) with instructor (N=26) and (b) without instructor (N=11). The uncertainty bars in both figures denote one standard deviation about the mean.

Figure 5.8 shows that students' satisfaction for the student-instructor interaction and the student-equipment interaction were the highest for students who worked under instructor's guidance. The interaction between students and their peers (student-student) showed the lowest satisfaction. For students who worked independently in the remote laboratory, indirect interaction was the most satisfying interaction. This interpretation based on the mean values is supported by the magnitude of the uncertainty bars which indicate relatively less variation in the responses among students for student-instructor and student-equipment interactions in Figure 5.8(a) and indirect interaction in Figure 5.8(b).

Figure 5.9 shows the satisfaction expressed by remote laboratory students for the overall remote laboratory work experience. The results shown are from the combined responses of the students from the two groups.

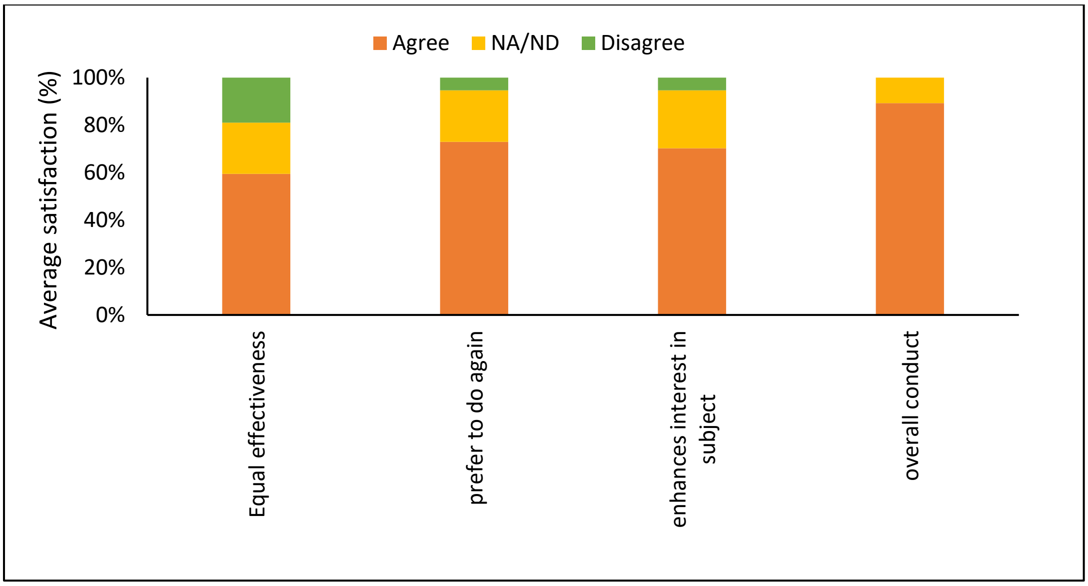


Figure 5.9: Satisfaction expressed by first-year students working on the remote laboratory for their experience of the remote laboratory work. Note: NA/ND= Neither agree/Neither disagree.

It is evident from Figure 5.9 that students enjoyed their remote laboratory experience. One possible reason for the high satisfaction was that it removed fear of damaging apparatus during its manipulation.

Overall students were very satisfied with the way that remote-laboratory work was conducted (89%). The response for remote-laboratory effectiveness is at a level similar to that of face-to-face laboratory that had approximately 60% of students in agreement, although 19% of the students gave a negative response. The majority of the students agreed (approximately 73%) that they would like to repeat their remote laboratory experience for other activities. Finally, 70% of the students believed that the remote laboratory experience enhanced their interest in the subject matter.

5.5 Comparison of first-year students' expectations of interactions with their reporting of importance and satisfaction with the interactions during the remote-laboratory activity

The responses for expectations of importance of interactions indicated that interactions with other students, instructors, and the manipulation of apparatus were considered important mainly for learning results-analysis, while the laboratory-instruction sheet is envisioned to be important for learning laboratory procedures.

Similarly, opinion about the importance of interactions as reflected by the responses from students performing remote laboratory activities indicated higher importance for instructor's presence and support during the conduct of remote laboratory activity. The importance of the laboratory instruction sheets for remote-laboratory activities was also indicated by their responses.

It is interesting to note that the value of student-student interaction was perceived to be relatively less important in remote-laboratory work. During the conduct of the laboratory work, student-student and student-instructor interactions were perceived important mainly for learning results-analysis.

In summary, students performing remote laboratory activities identified the importance of interactions with instructors and need for the laboratory-instruction sheet as an important resource.

5.6 Chapter Summary

The findings obtained for students' expectations of interactions, frequencies of interactions and perception of importance of interactions in remotely-operated laboratories align with the findings reported for face-to-face laboratories in Chapters 3 and 4. In summary,

1. Students expect instructors to lead their overall learning in laboratory.
2. From a student's perspective, it is important to provide students with: opportunities for student collaborations, the presence of instructors for guiding

the laboratory work, and a well-designed laboratory instruction sheet for the effective conduct of the remote-laboratory activity. A setup similar to that of face-to-face laboratories is preferred for remotely-operated laboratories and also considered important for the conduct of the laboratory work.

3. Students regard hands-on experience of manipulating apparatuses as an important interaction in laboratory learning and express the need for the redesign of the mechanical-type remote laboratories to provide students with a similar experience as experienced in face-to-face laboratories.
4. Indirect learning, that is, learning from other students' interactions in laboratory seems to be useful more for students who independently perform a remote-laboratory activity. However, the form of indirect interactions in remotely-operated laboratories are different to those in face-to-face laboratories due to the nature of the laboratory set-up. So, future designs of remote laboratories should provide students with opportunities to learn from other students' work and experiences.

Next, Chapter 6 compares between the face-to-face and remotely-operated laboratories to identify and understand the interactions that are the most important in the effective conduct of laboratory activities, irrespective of the laboratory mode.

Chapter 6

The Effects of Remote Laboratory Implementation on First-year Engineering Students' Experience

Statement of Contribution to Co-authored Published Conference Article

This Chapter is the content of a peer reviewed conference article "Effects of remotely-laboratory implementation in first-year undergraduate laboratory learning", published in the *125th Annual Conference of American Society for Engineering Education* in 2018.

I, Sulakshana Lal, as the primary author, conducted all the work of data collection and data analysis, including creating figures and tables, and writing and editing the manuscript.

I, as a Co-Author, endorsed that this level of contribution by the candidate indicated above is appropriate.

Anthony D. Lucey

Euan D. Lindsay

John M. Long

David F. Treagust

Mauro Mocerino

Marjan G. Zadnik

Chapter 4 presented findings for understanding the relationship between students' expectations of the interactions and their actual perception of importance of interactions and satisfaction with interactions in the face-to-face laboratories. Similarly, Chapter 5 presented results for the above aspects studied for students performing an experiment in a remote laboratory. Chapter 6 presents further analysis conducted for the results highlighted in Chapter 4 and Chapter 5. Analysis is conducted both quantitatively as well as qualitatively. Quantitative results compare students' perception of importance of interactions and their satisfaction in both the remotely-operated laboratory and the face-to-face laboratory. Similarly, qualitative results show students' preferences for laboratory mode. This chapter concludes with first-year engineering students' perceptions about their experiences with a remote laboratory.

The content presented in this chapter has been published as a peer-reviewed conference-proceedings paper and a modified version of the published paper is presented in this chapter.

6.1 Background and aims

Recent practices in laboratory education involve two commonly used modes of laboratory: face-to-face and remotely-operated. The effectiveness and suitability of a mode for laboratory work for first-year students in terms of better learning of practical skills depend to some extent on the form of the interactions that are possible in the two laboratory modes. In other words, the skills attainable through laboratory education are direct consequences of the interactions that occur in laboratory work.

An engineering student is expected to be aware of technical advancements but at the same time acquire hands-on and social skills that characterize a professional engineer (Most & Deisenroth, 2003). Engineering laboratories are designed so as to prepare students with all the necessary personal and professional skills through properly planned layered instructions designed for each year or semester. Of all the years of engineering studies at undergraduate level, the first-year is often the most crucial. At this level, students build their foundation of engineering concepts which are later built upon in subsequent years of their degree. The concepts and skills that students are expected to learn in the first-year also greatly influence the retention (or attrition) rates of students in engineering degrees (Bennett et al., 2015; Carlson et al., 1997; Prendergast, 2013).

Education researchers in the field of remote laboratories have mostly focused on studying the viability of this laboratory mode for educating and preparing students for the future workforce (Fabregas et al., 2011; Tho et al., 2017). Remote laboratories have been tested and studied for their effectiveness in meeting their desired goals (Nickerson et al., 2007) but only a few studies have focused on the actual learning processes that are involved in reaching those goals (Corter et al., 2011).

Today, many engineering disciplines are benefitting from significant developments in terms of the technology used in remote laboratories (Machotka & Nedic, 2006; Maxwell et al., 2017; Starks, 2017; Teng Considine et al., 2016). Despite this fact, the use of remote laboratories has not been able to reach its anticipated level. This field is still struggling to be widely accepted by students and the institutions where they study (Bourne et al., 2005; Salzmann et al., 2014). Students are generally found to be excited about working in a technology integrated environment (Chiang et al., 2011), but their main preference still remains to manipulate equipment in person and get direct experience (Ma & Nickerson, 2006) of handling equipment. However, studies have shown that remote laboratories do provide similar learning outcomes as face-to-face laboratories (Ogot et al., 2003; Teng Nedic et al., 2016) and, on occasions, comparatively better learning outcomes for students and with better reflective ability (Lindsay & Good, 2005).

This chapter is focused on assessing the appropriateness of remote laboratories for first-year engineering students. It is based on a comparison made between students' experience and perception about the interaction possibilities and their relation to the expected learning outcomes from their work in both remote and face-to-face laboratories. Results of students' perceptions of importance and satisfaction reported for various interactions in face-to-face and remote laboratories from Chapters 4 and 5 are presented to enable the reader make the comparison highlighted in this chapter. This chapter also considers how remote laboratories can be integrated into engineering courses from the students' viewpoint, in order to preserve the essential learning of practical skills and also to make students better prepared for future engineering practices.

6.2 Research Question

This study therefore endeavours to address the following research question through the lens of interactions in the engineering laboratory:

RQ 5: What are the effects of implementing remotely-operated laboratories on first-year undergraduate students' experience?

6.3 Research Methodology and Participants

Both quantitative and qualitative research method are adopted in the investigation of this chapter. The quantitative research method is used to analyse the results from Chapters 4 and 5. The survey questionnaires used in Chapter 4 and Chapter 5 included questions about the four categories of interaction type, that is, student-student, student-instructor, student-equipment, and indirect interaction. The focus in the questionnaire was on aspects such as the interactions of students, their perceptions of importance of interactions and their satisfaction in terms of the interactions experienced during their work in face-to-face and remote laboratory modes. The type of remote laboratory and its associated tasks that is discussed in this chapter have been given in Chapter 5 and also Appendix H. Qualitative data is obtained from a semi-structured interview (Alan, 2013; Creswell, 2014) conducted for students who performed experiments in both face-to-face and remotely-operated laboratories. The participants whose responses are discussed in this chapter are those included in Chapters 4 and 5.

The following sections present findings from analysis of data obtained from first-year engineering students who performed similar experiments in face-to-face and remote laboratories. All quantitative results reported are based upon post-laboratory survey responses in each laboratory mode while the qualitative results arise from the questions asked in the semi-structured interview about students' experiences and opinions of both laboratory modes from the interaction perspective.

6.4 Results and Discussion

6.4.1 Survey responses of students' experience and satisfaction for the interactions

This section sets a baseline for responding to the research question addressed in this chapter. The average of responses reported by students for each item in each category of the interactions in the questionnaire was calculated in both modes of the laboratory. The results are shown in Figure 6.1.

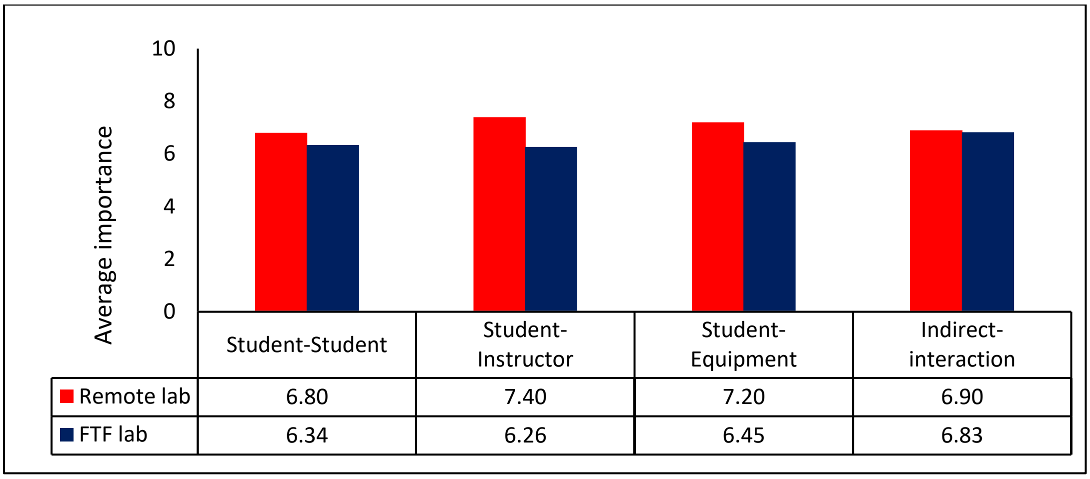


Figure 6.1: Average importance perceived for each interaction type (Note: FTF= face-to-face)

It is evident from Figure 6.1 that students' perception of importance of interactions were reported more important in the remote laboratory than in the face-to-face laboratory. Interaction between a student and an instructor substantially influenced the students' perception of their learning in the remote laboratory, while the most important interaction in the face-to-face laboratory were the indirect interactions that happened in the laboratory. Student-equipment interaction was the second most important interaction for students in both laboratory modes. In the remote laboratory student-student interactions were the least important interaction while in the face-to-face laboratory it was the student-instructor interactions.

Students also expressed their satisfaction for each interaction type, as shown in Figure 6.2.

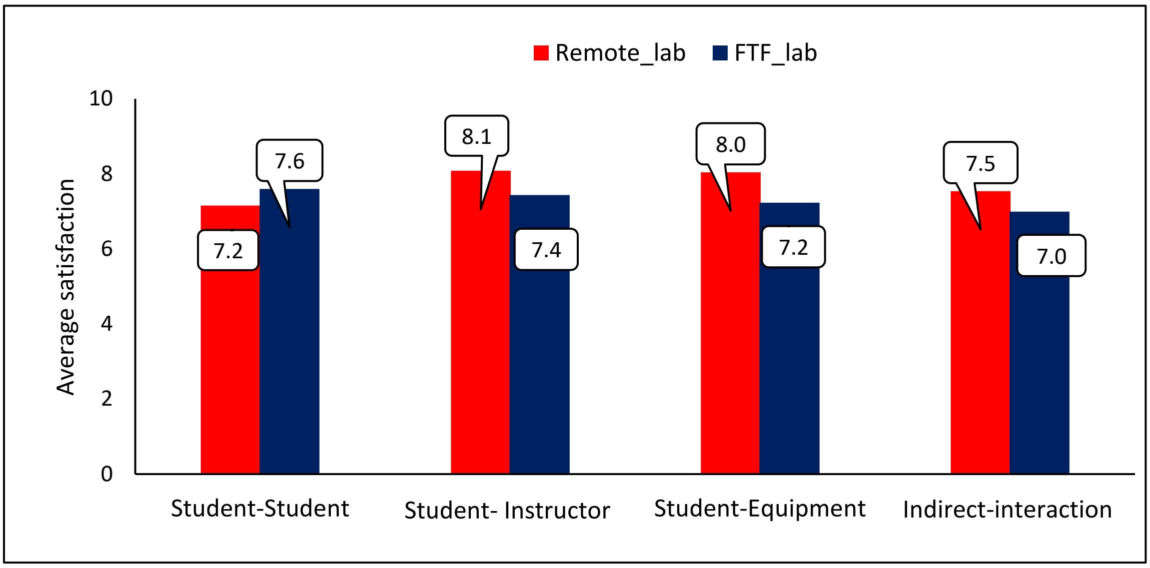


Figure 6.2: Satisfaction expressed for each interaction type (Note: FTF= Face-to-face)

Taken overall, Figure 6.2 shows that students' satisfaction with the remote laboratory exceeds that for the face-to-face laboratory. The satisfaction for student-instructor interaction and student-equipment interaction in the remote laboratory has the highest values of 8.1 and 8.0 respectively.

However, the interaction between students with peers was reported as being more satisfying for students in the face-to-face laboratory (7.6). The lowest satisfaction is for indirect interaction in the remote laboratory but this was also higher than that of the face-to-face laboratory.

6.4.2 Students' perceptions about the importance of interactions with instructors and peers

When students who performed experiments in both laboratory modes were questioned about their perception of the importance of interactions, responses were slightly contradictory when compared to the results of the survey presented above.

Students who performed the remote laboratory realised the need for the presence of an instructor during their work but those who worked only in the face-to-face laboratory replied that a thorough instructional manual could replace the need of an instructor in the laboratory. However, the instructor in the laboratory was an essential component perceived by students working in both laboratory modes. Summarizing the students' responses to the verbal questions asked in the interview revealed that instructors provided a sense of support and security to students in a laboratory environment because they were able to acknowledge correct learning. After working in the remote setting students' comments included the following:

"I realized how much I relied on the tutor"

"……..had questions about the values in the experiment and was unsure of the theory…. Could have used the help of a supervisor who knew the topic rather than the broad range of the internet"

Although students worked in a group of two in the remote laboratory, they still preferred the face-to-face laboratory setting where multiple groups (each of four students) interacted with each other as suggested by

"It was better to work in a group than trying to figure it out on my own"

"………………….. If you're going down the wrong path and you interact with them and they go, hold on"

"…. Work with different kinds of people and how to separate between just people you just get along with and people you work well with"

6.4.3 Students' perceptions of the interaction with the equipment

Based on the interview responses, satisfaction for the remote laboratory was apparently due to the simplicity of the task undertaken. In contrast, students preferred to do the complex physical set up of equipment personally and get direct experience of handling equipment. After working in the remote laboratory, some of the student responses in regards to hands-on experiences of the experimental rigs were:

"actually being able to physically use the materials…….. Gives some form of safety,….. Awareness in the workplace that ... never be exposed to otherwise……. know how to use machines so you can prepare for future tasks."

"…. In the lab it's sort of reinforcing that procedural aspect in terms of your own memory,… .,, it's no longer this 2D picture on a wall,……"

Despite the availability of the laboratory manual with detailed instructions, students in the remote laboratory setting, did seek help from the instructors. Students' good experience of the remote-laboratory experiment partly comes from the support they received during their laboratory work. Notwithstanding a good experience of working in a remote laboratory, students were of the opinion that learning concepts was still better in face-to-face laboratories and responded, for example, as stated below:

"..in the laboratory, you can apply.....see the application through the physical data that you've collected and then reapply that and re-derive them, which shows your full understanding"

"...learned a lot more about the concept,... Actual application of the theory... find what the variables represented...actually see it in real life."

6.4.4 Summary of students' responses

It was an interesting coincidence that the majority of the students in both groups had previous awareness of a remote operation of equipment. Those who did have some knowledge were unaware of the use of remote laboratories in the education sector. When they were asked to compare their experience in the two laboratory modes, the majority of students were glad to have experienced the remote laboratory, while some appeared confounded. Students believed they were learning essential skills in the face-to-face laboratory and were more sceptical of the remote laboratory in terms of skills attainable from the laboratory activity. Being first-year students, they considered that face-to-face laboratories were essential to acquire the basic skills and knowledge at their level. Some of the concerns and benefits of the remote laboratory as reported by students are tabulated in Table 6.1.

Table 6. 1: Benefits and concerns expressed by students for the remote laboratory

Benefits of remote laboratory	
• Easy to operate • No need of physical co-location • Flexibility in time and operation • Convenient to begin the experiment • Better human error analysis possible • Good for experiments with less setup	• No stress of safety hazards • Technology enhances better result analysis • Feel of real face-to-face experiment • Easy to record data from the experiment • Glimpse of future engineering practice • Independent operation possible
Concerns for remote laboratory	
• No opportunity to set up experiment personally • Difficult for teamwork and lack of real-time instructor support • Assumption that machines are perfect and chances of working on erroneous data • Lack of OH & S knowledge, and support in emergency • Limited view of the equipment • Time delay between instruction and results	• Feel insecure working alone in remote lab • Physical separation from equipment • Difficulty in logging-in to the system due to internet problem • Not appropriate for experiments with significant setup • Lack of assurance for accurate results obtained • Better if implemented above first-year level studies

6.4.5 Students' opinions about integrating remote laboratories into engineering studies

As evidenced from the responses recorded in the survey forms, it is important to note that students were pleased to have experienced the technology-mediated engineering laboratory work. Students valued the use of modern technology in education as this provided them with a view of the prospective engineering practices in future jobs or profession as well as gaining experience of using the technology. However, they were also concerned that at their level of study, working in a remote laboratory could affect the development of many important skills that are required during their journey to become an engineer. During the interviews, some of the questions were deliberately asked to understand what, according to the students, would be an appropriate way to include the use of remote laboratories in engineering degree studies. Some of the suggestions received from students are as follows.

"I think for a pre-lab it could be a really good idea"

The reason provided for this opinion was that students often found themselves unprepared to conduct the activities when they first enter a laboratory. If a remote laboratory could be made pre-laboratory work, students could familiarize themselves with the instruments and the associated task. This could further enhance their work in the face-to-face laboratory.

".... Midway through the second year, third year onwards, ... Once those basic concepts have been cemented....then maybe remote labs would perhaps be best...."
An argument presented by another student in support of the above response was:

"..We've got the concepts, we've theorized with them and now we can learn to apply them…here's the application, here's a remote lab, here's an application for a physical lab"

Students were very reluctant to lose the opportunity to handle equipment personally, interact with peers and also interact with the instructor. All these activities, according to them, were integral to their learning of practical skills as engineering first-year students. Another suggestion for inclusion was:

"may be it would be worth having a mix of both"

This statement clearly indicates that students also wanted to continue taking advantage of the technology applied to enhance their learning. However, being in the first-year, the students were also concerned about losing any opportunity that would help them to acquire skills essential at their level of study.

6.5 Students' perceptions of the effects of remote laboratory implementation

Students' experiences expressed in regard to remote laboratories, as first-year engineering students, throw light on some important issues which could be significant in the future integration of the remote laboratories in engineering studies. In the first-year of their engineering degree, students believed that their essential learning can only come from face-to-face laboratories. Remote laboratories did provide them with a similar environment to the face-to-face laboratory and they were pleased to have experienced them. However, elements such as the real-time interaction between students with their peers, instructors and most importantly the instruments were felt to be missing in the remote laboratory and this absence was a matter of concern for them. They stated that each interaction type had a significant role to play in their learning during the first-year of engineering studies and also for building a strong foundation of engineering concepts for further engineering studies in their degree.

Students' responses further indicated that internet-mediated interactions could also interfere with their acquiring some of the expected learning outcomes such as instrumentation, communication, experimentation, ethics and safety matters, and learning from failures (ABET, 2017).

Remote laboratories provide a platform where technological advancement in the engineering field can be experienced and at the same time has many benefits that have reformed commercial engineering works in the modern era. Students demonstrated their agreement with this fact and were ready to accept this as a part of their curriculum when they have a solid base of the concepts and are sure of the directions in their future careers.

6.6 Chapter Summary

Remote laboratories are convenient to operate and allow flexibility in terms of time and operation. These laboratories also provide a glimpse into future engineering practices and experience of technology use. They generate a feeling of a real experiment and the live video feed of the equipment in this mode plays an important role in this experience.

In answer to Research Question 5, students hold the opinion that first-year engineering studies should still involve hands-on work, although working in a remote laboratory is a beneficial experience. Performing hands-on experiments builds confidence and helps students better clarify the concepts of theory learned in lectures. They believe that when the foundation of engineering concepts is strong, adjustment and adaptation to any form of engineering work becomes possible. Teamwork in a laboratory not only makes the work easier and faster but also teaches students the valuable skill of establishing personal relations between team members and communication skills. Face-to-face laboratories emphasise teamwork, whereas in a remote laboratory this is a matter of choice and needs.

Students' quantitative reports indicate that they are satisfied with the experience gained from the remote laboratory work and find the interactions slightly more important than in the face-to-face laboratory. Students benefitted more from the instructors in the remote laboratory while physically operating the equipment enhanced learning in the face-to-face laboratory.

However, students' qualitative results displayed a contradictory perception of the remote laboratory. Students' comments indicated that a remote laboratory can take away some essential learning experiences that are necessary and only possible through the physical touch of the equipment. They wished to work in the remote environment only when they have concepts strongly developed and are sure of the directions or specializations they will choose in their future careers. Students' concerns suggested that working in a remote laboratory in the early years of an engineering degree could deprive them of learning some basic but essential laboratory skills.

Hence, this chapter highlights some important issues relating to remote laboratory implementation in the first-year of an engineering degree. Students' experiences and responses have identified the need to consider whether remote laboratories can provide the opportunity for students to acquire all of the essential laboratory skills. Further consideration is needed if remote laboratories are to be blended into regular engineering studies so that students are able to experience quality laboratory learning and also be prepared for modern industry demands and a globally-connected workplace culture.

A common aspect in both face-to-face and remotely-operated laboratories is the importance of the laboratory instruction sheet for the conduct of the laboratory experiment. In the following Chapter 7, students' perceptions of the laboratory instruction sheets in face-to-face and remotely-operated laboratory modes are presented.

Chapter 7

Student Perceptions of Instruction Sheets in Face-to-Face and Remotely-Operated Engineering Laboratory Learning

Statement of Contribution to Co-authored Published Journal Article

Chapter 7 is the content of a journal article "Student perceptions of instruction sheets in face-to-face and remotely-operated laboratories", published in the *European Journal of Engineering Education* in 2019.

I, Sulakshana Lal, as the primary author, conducted all the work of data collection and data analysis, including creating figures and tables, and writing and editing the manuscript.

I, as a Co-Author, endorsed that this level of contribution by the candidate indicated above is appropriate.

Anthony D. Lucey

Euan D. Lindsay

John M. Long

David F. Treagust

Mauro Mocerino

Marjan G. Zadnik

Chapter 6 presented an investigation of the effects of implementation of remotely-operated laboratories for first-year students. Perceptions of students who had experience in both face-to-face and remotely-operated laboratories were sought for that purpose. The present chapter further analyses the results of Chapters 4 and 5 and offers a student perspective on the function, utility, and importance of laboratory instruction sheets in Engineering along with their preferred design for both face-to-face and remote laboratory modes. Face-to-face laboratories for first-year were traditional and process-driven, while remote laboratories required students' to operate equipment distantly through a web interface. Both qualitative and quantitative investigations are made to study first-year students' perceptions. An important finding of this chapter indicates the need for the instruction sheet to meet different content requirements and emphases that depend upon the laboratory mode and different levels of student academic achievement.

The findings presented in this chapter have been published as a peer-reviewed European Journal of Engineering Education paper and a modified version of the published paper is presented in this chapter.

7.1 Background and aims

The nature of the laboratory mode considerably influences the types of student experience during the conduct of the laboratory task (Corter et al., 2007; Ma & Nickerson, 2006). In the face-to-face laboratory, students interact with their peers, instructors, and equipment to carry out the assigned activities. By contrast, in the remote laboratory students only interact with the equipment in real time while conducting their experimental investigation (Lowe et al., 2012). Students performing an experiment in a remote laboratory are able to interact with other students and instructors but this is asynchronous and different to that in the face-to-face laboratory because it is generally mediated by internet-supported platforms (Machotka & Nedic, 2006; Teng et al., 2016; Zubía & Alves, 2011). However, the Netlab, a remotely-operated laboratory developed by the University of South Australia, allowed for up to three students to synchronise their laboratory work and provided all students with full control over the equipment (Machotka & Nedic, 2006).

The interactions that occur during laboratory-learning activities have been observed and valued both in on-campus and distance-mode education (Anderson, 2003). Each interaction type makes a unique contribution towards students attaining the learning outcomes of the laboratory activity (Ogot et al., 2003). It is generally the blend of interaction types that make the laboratory experience valuable for students' learning and their satisfaction.

The interactions that occur in an Engineering laboratory are influenced and often guided by the laboratory instruction sheet (sometimes referred to as the laboratory manual) which is an integral component of the laboratory specification and its conduct (Gregory & Di Trapani, 2012; Khan & Alghazzawi, 2011). This holds true for both face-to-face and remote laboratory work. The laboratory instruction sheet is the basis for the demonstration of the laboratory work by the instructors, whereas, it is a guide for students to carry out the laboratory experiment (Watai et al., 2005). Whenever a new laboratory is created conceptually and then practically realised, both of these processes incorporate the design of the laboratory instruction sheet (Coppens, 2016; Selvaduray, 1995). Nikolic et al. (2015) have reported on students' satisfaction for the laboratory work, which was significantly influenced by laboratory instruction sheets that described the laboratory procedures and all related aspects in '*good length'.*

Craven (2003) studied the influence of traditional and project-based laboratory instruction sheets on students' performance, while Patterson (2011) reported on the effects of multimedia laboratory instructions on students' learning. The impact of design of instruction sheets has been reported in the work of Reid and Shah (2007). The depth of information and clarity of instructions in the laboratory instruction sheet can effectively provide ideas about the nature of the laboratory work and also its expected learning outcomes (Coppens, 2016). However, the importance of the laboratory instruction sheet in relation to the interactions that occur in the laboratory has not received sufficient attention in the research literature. Students in both face-to-face and remote laboratory modes rely heavily on the laboratory instruction sheet, not only for procedural aspects of the activity undertaken but also for the development of conceptual understanding as well as the synthesis and interpretation of results; these elements can also be enabled by the interactions that occur in laboratory work. The present chapter serves to increase understanding of the multifaceted function of the instruction sheet and how this might depend upon whether the laboratory activity is undertaken in face-to-face or remote-access mode.

Related research that has been carried out so far has focused on the effects of interactions on students' learning outcomes (Högström et al., 2010; Lindsay & Good, 2005; Sher, 2009). Much less emphasis has been given to the factors that influence the interaction types that occur in engineering laboratories. Chapters 3, 4, and 5 have shown that students' interactions with equipment are considered the most important and most frequently occurring as well. There are multiple components involved with this interaction depending upon the laboratory mode. In face-to-face laboratories, student-equipment interaction involves the students, the laboratory instruction sheet and the equipment. Remotely-operated laboratories provide the option of using the capabilities of the internet in addition to the laboratory instruction sheet and the equipment.

Students' interactions with their laboratory instructors are also important. Students are given demonstrations of the experiment to be conducted, apprised of safety matters involved and briefed on the learning objectives to be attained by performing the experiment (Watai et al., 2005). During these processes students and instructors continuously interact with each other (Kirkup et al., 2016). The frequency and intensity of the interactions are likely to be influenced by the clarity and comprehensiveness of the laboratory instruction sheet (Braun et al., 2018). Students frequently ask instructors' for help in matters that are either not covered in the laboratory instruction sheet or are not readily understood. The interactions between students and instructors make important contributions to students' acquiring essential engineering laboratory skills (Kirkup et al., 2016).

Finally some studies have advocated reform of the laboratory instruction sheet but these are mainly focused on content revision (Craven, 2003; Hou et al., 2017; Khan & Alghazzawi, 2011) or suggest various access mechanisms to laboratory instruction sheets for better achievement of learning outcomes (Maldarelli et al., 2009; Patterson, 2011).

This chapter first explores the intricate relationship between the interactions that occur in laboratory and the laboratory instruction sheet because these can play a major role in both the performance and satisfaction of students in each of face-to-face and remotely accessed laboratory work. Thereafter, consideration is given to how the design of laboratory instruction sheets might depend upon student performance and laboratory mode.

7.2 Research Question

The overarching purpose of this Chapter is to provide insights on

RQ 6: What is the importance of the instruction sheet when students are conducting laboratory activities in face-to-face and remotely-operated laboratory modes?

This research question is answered by addressing the following constituent research questions:

RQ 6.1 *How important do students perceive the laboratory instruction sheet before and during the laboratory activities in face-to-face and remotely-operated laboratory modes?*

RQ 6.2 *How important is the laboratory instruction sheet as a determinant of students' level of satisfaction with their laboratory work in face-to-face and remote-access laboratory work?*

RQ 6.3 *Do students identify different requirements of laboratory instruction sheets for face-to-face and remote-access modes of conducting laboratories?*

This chapter is structured as follows. A conceptual framework of the relationship between the instruction sheet, laboratory interactions, and laboratory activities is first developed. The first investigative component addresses students' perceptions of the importance of the laboratory instruction sheet based on survey instruments (Research Question 6.1). The second investigation examines the relationship between student satisfaction and the laboratory instruction sheet via a correlation analysis (Research Question 6.2). The third component of the study addresses students' perceived needs of the laboratory instruction sheet using quantitative and qualitative methods (Research Question 6.3). Throughout these three components, results from face-to-face and remote-access modes are compared and contrasted. Finally, a discussion of these interrelated components is presented and overall conclusions are then drawn.

7.3 Overview of laboratory instruction sheets in face-to-face and remote engineering laboratories

The laboratory instruction sheet used in engineering laboratories generally presents the theory (often as a recapitulation of theory already covered in the associated lecture course) that underpins the experiment, describes procedures for carrying out the experiment and usually includes tables to guide data collection and figures that illustrate the laboratory activity (Kirkup et al., 2016; Selvaduray, 1995).

The components listed above generally appear in a logical order in the laboratory instruction sheet. The laboratory sheet opens with the title of the experiment or investigation. It then sequentially introduces the set of equipment that will be used to carry out the experiment. A brief background of the underlying theory that governs the experimental phenomena being studied is then presented. This background is deliberately included to provide students with a link between their practical work and lecture-based learning. Detailed step-by-step instructions for carrying out the actual work then follows. The remainder of the laboratory instruction sheet comprises tables to collect data and discussion questions that promote reflection on the validity and the meaning of their results, the first to assess the correctness of their implementation of procedures and the operation of the equipment, while the second is to check that students have understood the concepts that the practical work is designed to prove or illustrate. Some laboratory sheets also incorporate references for students to follow up on or address any query they may have during the experiment. While the foregoing is a general description, the contents of a laboratory instruction sheet and its use will vary depending upon the mode in which the laboratory work is conducted.

In the face-to-face laboratory, students are physically co-located with the experimental apparatus and carry out the experiment under real-time supervision by the instructor and in collaboration with laboratory partners. Instructors present or overview the contents of the laboratory instruction sheet and remain available to provide help when required and ensure that laboratory-sheet instructions are followed correctly and that all activities are completed (Kirkup et al., 2016). A thorough demonstration from the instructor and availability of peers with whom to collaborate initiates the laboratory work. Accordingly, the laboratory instruction sheet is supported through both student-instructor and student-student interactions.

By contrast, students working in an asynchronous remote laboratory do not have real-time support from the instructor or laboratory partners. Further, they manipulate the equipment through an internet-mediated interface. Therefore, the principal source of support for students is the laboratory instruction sheet. The laboratory instruction sheet for a remote-laboratory experiment will usually contain a modified set of components such as an underpinning theoretical background for the experiment, steps to establish a connection with the equipment, detailed procedures to carry out the experiment and some set tasks to assess learning from the experiment.

In the present study, the laboratory sheet used for the remote laboratory experiment did not have a description of the experimental arrangement. Accordingly, students did not learn how to set-up the equipment but only how to operate it. This is in marked contrast to face-to-face laboratory work wherein the laboratory instruction sheet encourages and expects students to familiarise themselves with the equipment used and the associated instrumentation. A brief account of the experimental design in both laboratory modes and outline of the associated laboratory instruction sheets that were studied in this chapter are provided in Appendix H.

7.4 Relationships between student interactions and the laboratory instruction sheet

The laboratory instruction sheet is an integral component of engineering laboratory learning because it provides a foundation for the student activities and interactions that occur during the laboratory work. Figure 7.1 is a modified diagram of the conceptual framework depicted for the overall thesis shown in Chapter 1. The shaded area shows the focus on the relationship between the student performing experiment in the face-to-face and remotely-operated laboratory modes and the instruction sheets for the laboratory activity linked via a set of interactions. Thus, in the course of conducting a laboratory, the student may engage in three distinct types of interaction, namely, student-student interactions, student-instructor interactions, and student-equipment interactions. These interactions then support the student’s conduct of the laboratory namely, the laboratory activity, data collection and results analysis that are defined or guided by the content of the laboratory instruction sheet.

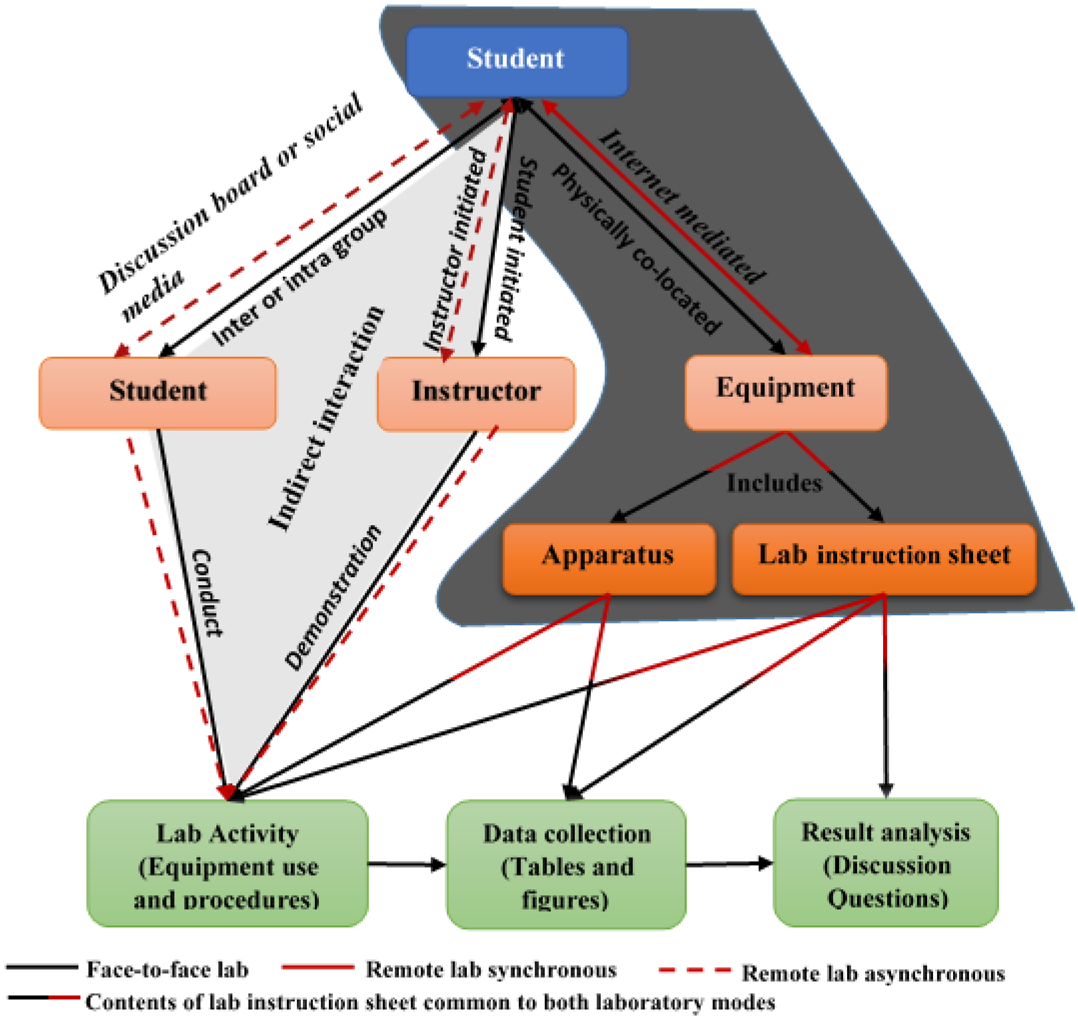


Figure 7.1: The relationship between laboratory instruction sheet and the interaction types in face-to-face as well as remote laboratory modes

In the first of the investigations reported in this paper, the importance of the laboratory instruction sheet as a resource for the student is compared to that of the aforementioned interactions in which the student engages. Thereafter, ~~we~~ the focus is on the interactions shaded in grey in Figure 7.1 to contrast student experiences between face-to-face and remote activities because it might be expected that student-equipment interactions would be most affected by the difference in laboratory mode. However, in Figure 7.1, differences between face-to-face and remote-access laboratory modes occur as a result of whether the action link or interaction is synchronous or asynchronous (Heradio et al., 2016; Jara et al., 2012). These interactions and their operation in the two modes are expanded upon in the following sub-sections.

7.4.1 Interactions occurring in laboratory work

Three main types of interactions - student-student, student-instructor, and student-equipment – have been categorised (Anderson, 2003; Lowe et al., 2012; Moore, 1989; Sher, 2009). The student is the pivotal point in all interaction categories. There is a fourth category, termed indirect interaction, which happens when a student learns or is assumed to learn by observing other students' interactions with their peers or by listening to conversations or discussions occurring either between students or between students and an instructor in the laboratory. Each interaction category makes a distinct contribution to students' laboratory learning (Fila & Loui, 2014; Lal et al., 2018; Lowe et al., 2012; Park et al., 2017).

7.4.2 ***Factors affecting the interactions***

The three interactions that occur during laboratory work arise through the activity prescribed in the laboratory instruction sheet. However, there are also important factors that influence the way that the elements - student, instructor, and equipment - interact with each other; these factors are: location, initiation and medium.

Location refers to the arrangements made in which the interactions occur in the laboratory. In the face-to-face laboratory, students, instructors and the equipment are all situated in the same physical facility and share synchronous interaction. By contrast, the only real-time interaction in the remote laboratory is between students and the equipment, this being guided by the laboratory instruction sheet (Ng, 2007; Sonnenwald et al., 2003) because students remotely access and control real equipment through a web interface.

Initiation relates to interactions between the student and the instructor. It is either instructor initiated or student initiated (Bright et al., 2008; Sher, 2009; Stang & Roll, 2014). Instructor-initiated interaction mainly takes place during a demonstration of the laboratory activity (most often at its start), whereas student-initiated interaction often takes place when students have difficulties with a laboratory task and therefore seek help from the instructor or have questions that may extend their understanding of the task. When the instructor is physically absent in a remote-access laboratory, initiation can only be due to the student. However, instructor- and student-initiated interactions can exist in the remote laboratory context when it is mediated by an internet supported platform.

Finally, medium refers to the platform that permits student interaction with the equipment. Students are physically present with the equipment in the face-to-face laboratory, whereas in the remote laboratory student interaction with the equipment is mediated by an internet browser and a user-interface that allow students to establish a connection with and operate the equipment. In the remote laboratory, students interact asynchronously (Corter et al., 2007) with other students and instructors generally on internet-mediated institutional platforms such as discussion boards or social-media platforms such as Skype and Facebook (Heradio et al., 2016; Jara et al., 2012; Jeschke et al., 2008).

7.4.3 *Association between the interactions and the laboratory instruction sheet*

In engineering laboratories, the laboratory instruction sheet is the most comprehensive source of information for students, providing essential information on the operation of the equipment and its sequencing during the laboratory session. The laboratory activity also has two other important components embedded: data collection and results analysis that are related to the laboratory work. These are also guided by the laboratory instruction sheet.

Student-equipment interaction includes interaction with the apparatus for its manipulation and also interaction with the laboratory instruction sheet and other (non-human) resources such as the internet. Equipment use and instructions for procedures contained in the laboratory instruction sheet initiates both student-student and student-instructor interactions for manipulating the apparatus and all other laboratory-related tasks. In a face-to-face laboratory, student-student interaction may occur between members of the same group or between different groups. The instructor interacts with the students during a demonstration of the laboratory procedures which is based on the laboratory activity described in the laboratory instruction sheet. Student-student and student-instructor interactions further give rise to indirect interactions. The data collection and results analysis information from the laboratory sheet initiates the student-equipment interaction. Thus, in the face-to-face laboratory, the contents of the laboratory instruction sheet influence all four interaction categories. By contrast, in the remote laboratory, the instruction sheet directly guides and influences the student-equipment interaction, but it has very limited and indirect influence over the other three categories of interactions, namely student-student, student-instructor, and indirect interactions. For both laboratory modes, the laboratory instruction sheet contains tables and figures and also discussion questions. These are designed to assist students with data collection and data analysis to arrive at the results that can illustrate or reinforce the concept that the laboratory is designed to impart to the students.

It is important to note that in the face-to-face laboratory all three interactions shown in Figure 7.1 are inter-related, which then implies that the activities (in the row below) are also interlinked. On the other hand, the remote laboratory provides opportunities for students to work independently and explore all aspects of the experiment but without the opportunity of directly collaborating with peers or seeking guidance from instructors. The present work specifically reports on students' use of the instruction sheet for laboratory-related tasks, which will indirectly involve students' interaction with all the other essential elements of laboratory work discussed above.

7.5 Research participants and methodology

7.5.1 *Participants*

First-year engineering students working in face-to-face and remote laboratories, belonging to two different Australian Universities, were surveyed during their conduct of a laboratory for Engineering Mechanics Unit MCEN1000 and Engineering Fundamentals, SEB101 (Long, 2015) respectively. Of the 37 students performing the remote-laboratory experiment, 11 students were from the cohort of 186 students who also undertook the face-to-face laboratory experiment. The student cohorts were in their first year of general Engineering that preceded engineering-discipline specialisation and comprised a range of ethnic backgrounds.

7.5.2 *Survey instruments and analysis tools*

The survey tools for pre-laboratory expectations and post-laboratory perceptions of importance of interactions discussed in this chapter are presented in the Appendices of Chapters 4 and 5. These surveys were designed to measure facets of the interaction types as opposed to measuring students' attainment of learning outcomes targeted by the design of the laboratory activity, for example, instrumentation, experiment, data analysis, learn from failure and so on (Feisel & Rosa, 2005)

Laboratory-instruction sheet survey: An instrument to seek students' perception of the laboratory sheet in both face-to-face and remote laboratories was developed. This instrument contained questions about aspects related to the laboratory instruction sheets for both laboratory modes. There was an additional open-ended section to allow students to offer their thoughts on improving the current laboratory sheets and also to provide additional recommendations for improvements. Appendix I shows the laboratory-sheet survey questionnaire. This survey was given to students after their completion of the laboratory activity.

Analysis tools: SPSS software version 25 (George & Mallery, 2018) was used to perform the regression analysis and to calculate correlation coefficients. For qualitative analyses, NVivo version 11 (Leech & Onwuegbuzie, 2011) was used to conduct a frequency analysis of responses provided by students.

7.6 Results

7.6.1 The relative importance of laboratory instruction sheets

This section provides responses for Research Question 6.1.

7.6.1.1 Pre-laboratory expectations of various interactions

Students in both laboratory modes were asked to pick and rank the top five most important interactions – seen in the survey form of Appendix C.1 - in the laboratory before they commenced their experiment. In this survey, 'use of the laboratory instruction sheet' was included as a further type of student interaction to those in the first row of Figure 7.1 in the sense that students can also be thought of as interacting with the laboratory instruction sheet. In particular, ~~we sought to~~ an attempt was made to determine the importance of the laboratory instruction sheet relative to the well-established interactions identified and discussed in Section 7.4 as a resource for undertaking laboratory work.

Figure 7.2 compares the students' responses received per item in the pre-laboratory survey in both remote and face-to-face laboratories. In Figure 7.2, the responses from the students of two different laboratory modes have been overlapped (shown by the white dots with a purple base) and the differences have been shown outlined with a green circle. Within each type of interaction (except Internet Use), the responses are grouped under activities that could benefit from the interaction, namely, laboratory procedures (LP), results analysis (RA) and clarification of basic science concepts (BSC).

As shown in Figure 7.2, students in both laboratory modes believe that use of the laboratory instruction sheet is the most important for carrying out laboratory procedures. Remote laboratory students thought of it as more useful (by 16%) compared to those in the face-to-face laboratory. Students do not believe that the laboratory instruction sheet will be important in carrying out results analysis with the instructors anticipated to be relied upon for this purpose for students from both laboratory modes. It is noteworthy that the laboratory instruction sheet is seen to have the potential to assist students in clarifying basic science concepts at a similar level to that expected from instructors in both laboratory modes; however, it is also noted that this expectation was dominated (by 11%) by responses from the students in the face-to-face laboratory. Remote-laboratory students used internet comparatively more (by 15%) than the face-to-face laboratory students. Figure 7.2 also indicates in general that the interactions valued most during the laboratory work are directed to laboratory procedures and the analysis of results.

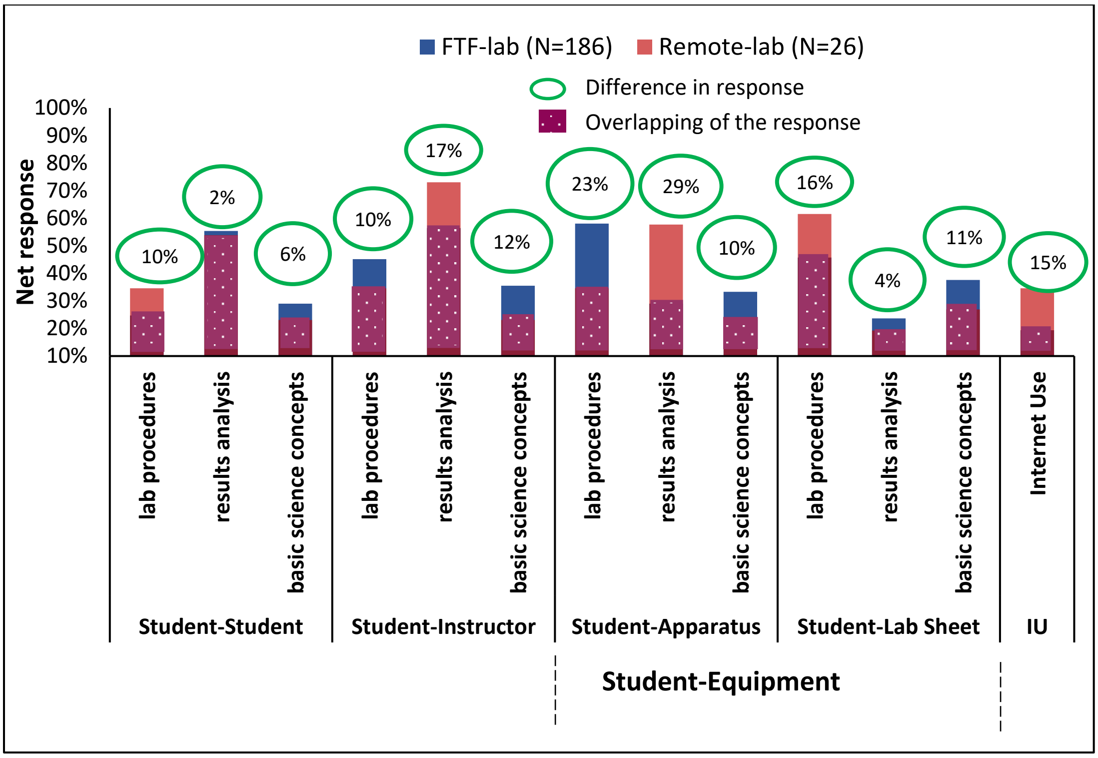


Figure 7.2: Comparison of the pre-laboratory survey responses in both laboratory modes (FTF = Face-to-face laboratory and IU denotes Internet Use). Note that the vertical-axis scale indicates the percentage of students within the cohort who selected the sub-category as one of their five choices.

7.6.1.2 Post-laboratory responses for perception of importance of interactions

The post-laboratory survey sought students' perception of the importance of the three major interaction categories described above for both laboratory modes. Figure 7.1 showed that the only synchronous interaction type that is common to both laboratory modes is the student-equipment interaction and the initiator of this interaction is the laboratory instruction sheet. Therefore, the focus is on the student-equipment interaction in the discussion below. Cronbach's alpha value was calculated to check the internal consistency of the results in the post-laboratory survey. The alpha value was above 0.87, which indicates that the instrument used for the survey is reliable.

The average of the ratings for the importance (out of 10) for all interaction items were calculated and compared across the face-to-face laboratory users and remote laboratory users. These results are shown in Figure 7.3. Student-equipment interaction elements are deemed important by students in both laboratory modes. When responses within this category are compared among the two groups of students it is seen that the remote-laboratory users highly valued the use of the laboratory instruction sheet as well as the manipulation of the equipment (7.86 and 7.82, respectively). On the other hand, students in the face-to-face laboratory considered manipulation of the equipment more valuable than referring to the laboratory sheet for the student-equipment category (6.9 and 8.11, respectively); however, this finding continues to emphasise the importance of the laboratory instruction sheet.

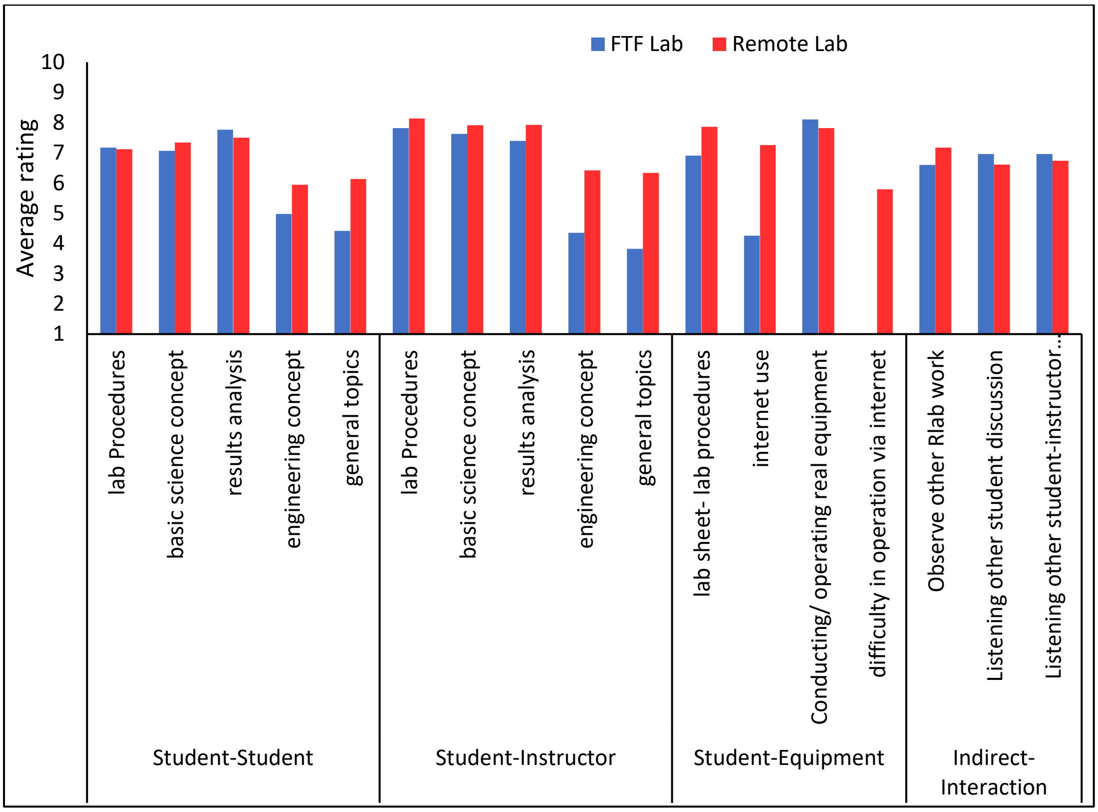


Figure 7.3: Comparison of the average importance perceived for various interactions (data obtained from the post-laboratory survey of students) (FTF= Face-to-face laboratory)

In addition to judging the importance of the interaction types in the post-laboratory survey, students were also asked to express their satisfaction for the student-equipment interaction. Responses reveal that the students in the remote laboratory were slightly more satisfied than the students from the face-to-face laboratory. Students working in the remote laboratory recorded higher satisfaction (8.03) compared to the face-to-face group (7.23). The relationship between student satisfaction and student-equipment interactions is examined in more detail in Section 7.6.2.

7.6.1.3 Summary of findings regarding Research Question 6.1

Students in both laboratory modes perceived student-instructor interaction to be the most important interaction before and after the conduct of laboratory activities. In the context of student-equipment interactions, for face-to-face laboratory students operating the equipment is more important than referring to the laboratory instruction sheet. However, for students in remote-laboratory, referring to laboratory instruction sheet is as important as operating the equipment. Student-equipment interaction is the most satisfying interaction for students in both laboratory modes.

7.6.2 Effects of the laboratory instruction sheet on students' satisfaction

This section provides answers to Research Question 6.2. By merely reviewing the survey responses it is difficult to predict influence of one factor on the satisfaction expressed for student-equipment interaction. Accordingly, in order to explore the reasons for items within the student-equipment interaction category that influenced students' satisfaction, a statistical analysis was conducted. For the face-to-face laboratory, regression analysis was performed. The total response received from the face-to-face laboratory group was divided into two equal groups of approximately 50%. This was done primarily to develop a regression model using the first 50% of the data and then validate the model with the remaining 50%. By contrast due to the fewer participants (N=37) in the remote laboratory, no attempt to perform a regression analysis was made, but instead, correlation coefficients were calculated. The results of these analyses are as follows.

7.6.2.1 Face-to-face laboratory

For the face-to-face laboratory, a stepwise multiple regression analysis (Tabachnick & Fidell, 2013) was performed to predict the student's satisfaction based on their use of the laboratory instruction sheet, the operation of the equipment and the use of the internet for performing the experiment; i.e. The activities within the student-equipment grouping of Figure 7.3.

Student satisfaction was considered as the dependent variable and the other three variables: use of laboratory instruction sheet, the operation of the equipment and the use of internet were used as the predictor variables. For both the sample groups, the variable that contributed most significantly was entered first in the calculation followed by the variable that was the second significant contributor but at the same time had its F-statistic value greater than 0.05.

Calculations revealed that use of the internet when conducting the experiment had no significant contribution to student satisfaction for the student-equipment interaction while the use of the laboratory sheet and the operation of the equipment demonstrated did. Therefore, the results have been presented only for use of laboratory sheet and the operation of the equipment.

Table 7.1 contains the regression coefficients obtained for both groups of data. The table further shows that both the predictor variables, use of laboratory instruction sheet and the operation of the equipment, were significantly associated with the students' satisfaction with the student-equipment interaction. In the first sample, the association was (R^2 = 0.316, $p < 0.01$) and for the second sample the association increased slightly (R^2 = 0.313, $p < 0.01$).

The equation showing the relationship of the predictor variables with the dependent variable is

SE_satisfaction = 1.268 + (.412*SE_useoflabsheet)+(.370*SE_operate-equipment)

Where the coefficients are the unstandardized β coefficients.

Table 7. 1:Model summary for student-satisfaction as dependent variable

						Change Statistics				
Sample	Model	R	R^2	Adjusted R^2	Std. Error of the Estimate	R^2 Change	F Change	Df1	Df2	Sig. F Change
Second 50% sample	1	.467	.218	.209	2.169	.218	24.548	1	88	.000
	2	.559	.313	.297	2.045	.095	11.972	1	87	.001
First 50% sample	1	.508	.258	.250	2.038	.258	31.972	1	92	.000
	2	.562	.316	.301	1.967	.058	7.761	1	91	.006

Table 7.2 shows that the beta coefficients for the operation of equipment and use of laboratory sheet when examined separately using both sample groups were positive and significant, (β=0.467, $p < 0.01$) and (β= 0.508, $p < 0.01$) respectively. Further, when both variables were considered together in the two sample groups, it was again found that the beta coefficients for both variables were positive and significant. In the first 50% sample, it was (β=0.268, $p < 0.01$) and (β=0.391, $p < 0.01$) respectively for

operation of the equipment and the use of laboratory sheet. Similarly, in the second sample group it was (β=0.349, $p < 0.01$) and (β=0.330, $p < 0.01$) respectively.

Table 7. 2: Model coefficients - student satisfaction as dependent variable

Sample	Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
			B	Std. Error	Beta		
Second 50% sample	1	(Constant)	3.052	.881		3.466	.001
		Operate equipment	.535	.108	.467	4.955	.000
	2	(Constant)	1.858	.899		2.066	.042
		Operate equipment	.399	.109	.349	3.659	.000
		Use of lab sheet	.329	.095	.330	3.460	.001
First 50% sample	1	(Constant)	3.498	.688		5.085	.000
		Use of lab sheet	.535	.095	.508	5.654	.000
	2	(Constant)	1.268	1.040		1.219	.226
		Operate equipment	.370	.133	.268	2.786	.006
		Use of lab sheet	.412	.101	.391	4.063	.000

Based on these results, it can be concluded that for both the variables, the operation of equipment and the use of laboratory instruction sheet had a significant association with the students' satisfaction with the student-equipment interaction. Considering the beta coefficients of the two predictor variables when observed separately, it can be concluded that the use of laboratory instruction sheet was a relatively better predictor of student satisfaction for the student-equipment interaction.

7.6.2.2 Remote laboratory

Assessment of the correlations between the three items under the student-equipment interaction in Figure 7.3 and the satisfaction for this interaction type showed that use of the laboratory sheet for conducting the experiment was significantly correlated with the feel of performing a real experiment ($r= 0.588$, $p< 0.01$), which further had a significant correlation with student satisfaction for the student-equipment interaction ($r=0.546$, $p<0.01$). However, there was no direct significant correlation between the use of the laboratory instruction sheet and student satisfaction for the student-equipment interaction ($r = 0.3$, $p = 0.137$).

7.6.2.3 Summary of the findings regarding Research Question 6.2

For the face-to-face mode, the importance of the laboratory sheet correlates directly with student satisfaction but for remote-access, this is not evident. However, it is indirectly linked via student satisfaction with the operation of the equipment; this perhaps suggests that students will comfortably 'learn by operating the equipment' without the need for instructions because they do not fear damaging the equipment (Vuthaluru et al., 2013) and its immediate repercussions that would be the case in a face-to-face laboratory. Accordingly, use of the laboratory instruction sheet in the remote-laboratory mode does play a role in providing students with the feeling of working in a real hands-on laboratory. Similar findings have been reported in the work conducted by Jona et al. (2011).

7.6.3 Identification of different requirements in the design of laboratory instruction sheets from a student perspective

The foregoing results have demonstrated that the laboratory instruction sheet is an important resource that should be carefully designed when developing laboratory learning activities. In this section, ~~we~~ Research Question 6.3 is primarily addressed, the answers to which serve to inform the design of laboratory-instruction sheets.

Accordingly, results are presented of an investigation that serves to identify, from a student perspective, the factors that may underpin the appropriate design of effective laboratory instruction sheets. In particular, it focused on whether its design might be dependent upon the laboratory mode and/or the level of students' abilities in the overall subject of which the laboratory comprises a part of the curriculum. Thus, a further survey, designed to elicit students views on the levels at which different aspects of the laboratory activity were aided by the instruction sheet, was conducted using the same groups as those in Sections 7.6.1 and 7.6.2. A total of 150 responses were received from students who had completed the laboratory.

A further question in the survey requested that students identify their satisfaction with the laboratory instruction sheet that they used. In addition, students were also invited to give suggestions for improvement of the laboratory instruction sheet through a set of open-ended questions that pertained to a different aspect of the laboratory activity (see the full questionnaire in Appendix I).

7.6.3.1 Dependence upon laboratory mode: face-to-face versus remote-access

7.6.3.1.1 Students' agreement with the effectiveness of the instruction sheet

Figure 7.4 shows the first-year-student responses from face-to-face and remote laboratories. In the main, students selected agreement with the item statements in the questionnaire and therefore Figure 7.4 shows only students' agreement or strong agreement for the items in the survey.

Contrasting the results between face-to-face and remote laboratory modes indicates that students in the remote mode were less inclined to read the laboratory instruction sheet or rely upon it for procedural aspects of the laboratory activity (75% agreement compared with 86% agreement for the face-to-face mode students). This may suggest that in the remote-laboratory students were more inclined to 'discover' how to use the equipment through operating it while the face-to-face students felt it necessary to follow given instructions lest the equipment was damaged (Vuthaluru et al., 2013). However, the remote-laboratory students expressed greater engagement with the instruction sheet for understanding the concepts explored by the laboratory activity (81% agreement compared to 59% agreement for the face-to-face mode students). This may arise from a greater reliance on the written explanation of concepts than that for the face-to-face students who could also obtain such understanding by interacting with other students and/or the laboratory instructor. Nevertheless, the remote-mode students showed a lower level of agreement on the statement that asked whether all of the necessary information was contained in the instruction sheet (60% agreement compared with 88% agreement for the face-to-face mode students). This result may suggest that they had accessed other sources of (online) information to supplement their understanding of the activity whereas the face-to-face students undertook the activity expecting to use only the instruction sheet and their instructor as the resources needed to complete the activity.

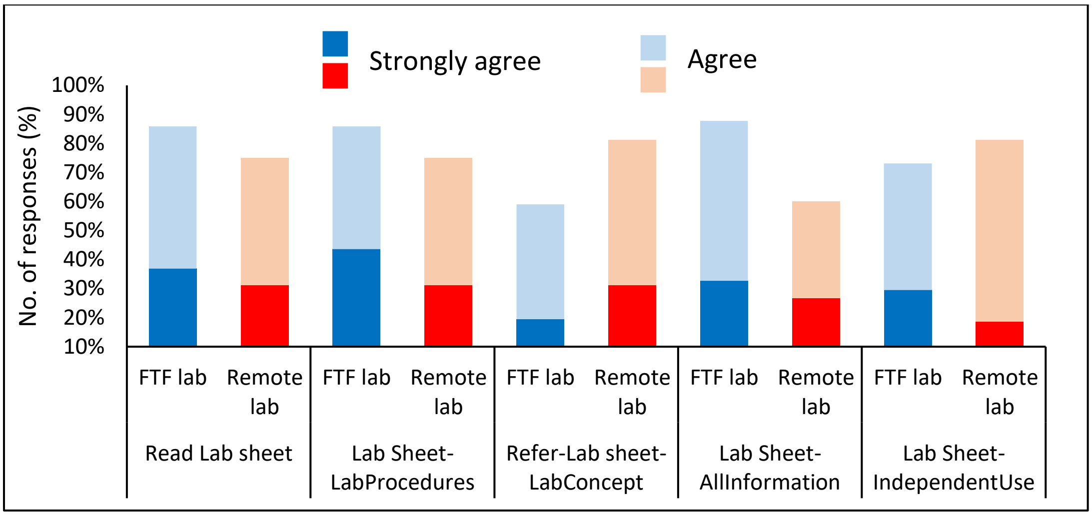


Figure 7.4: Student levels of agreement with various aspects indicating the usefulness of the laboratory instruction sheet: comparison of FTF (face-to-face) and remote-laboratory modes.

Finally, both cohorts showed high levels of agreement with the statement that the laboratory sheet enabled them to undertake the laboratory activity independently, with the remote-mode students at a slightly higher level of agreement, as might be expected given that it was the only resource provided to them, (with 81% agreement compared to 74% agreement for the face-to-face mode students).

Responses to the question on satisfaction (not plotted in Figure 7.4) showed that the remote-mode students reported a similar level of satisfaction with the content of the instruction sheet as the face-to-face mode students (with 88% agreement compared to 86% agreement for face-to-face mode students). This appears to contradict their view that, relative to the view of students in the face-to-face mode, the instruction sheet did not contain all the information required to complete the laboratory. Again, this result may indicate that the remote-mode students were unafraid to use other sources of information to help them undertake the activity.

7.6.3.1.2 Student opinions on the importance of the instruction sheet

In order to understand the quantitative comparison above, a number of students who conducted *both* the face-to-face laboratory and the corresponding remote-laboratory activity were randomly selected and asked about their perceptions of the laboratory instruction sheet they used for performing the experiment online; below are some of the responses received.

"That would make the instructor obsolete whereas in the physical labs that we've done we kind of needed the instructor"

"if it's a remote project there will be a much more condensed manual…. And that would help you more"

"Well generally reading through the lab material itself and also the sort of material that comes with the lectures, which only prepares you as much as you need to really"

"I feel like the instructor's almost a fall back. Like 90% of the time I can understand it just from the book but if I don't understand it from the book then like I need someone to explain it"

"….you don't necessarily need a tutor [instructor] because if you can do it online and there is a clear instruction online of how to do it, that's pretty much the only thing that I get from tutors usually during the lab"

Overall, the qualitative responses indicate that students considered the laboratory instruction sheet to be sufficient for carrying out the laboratory work if the laboratory instruction sheets are well designed (Braun et al., 2018; Nikolic et al., 2015). They were therefore suggesting that to perform activities in the remote laboratory setting, students only required the laboratory instruction sheet and access to operate the equipment. Such statements indicate that there needs to be a higher level of care in preparing the laboratory instruction sheet for remote laboratory work. The sheet should be comprehensive and effective enough to establish an authentic connection experience for students working in a remote laboratory. This may seem a little contradictory to the quantitative results of Figure 7.4. The student-satisfaction levels that appeared to indicate that, in the absence of a completely comprehensive instruction sheet, students undertaking the laboratory remotely were able to complete the laboratory by, presumably, accessing other materials that supported their completion of the laboratory.

7.6.3.2 Dependence upon student achievement in terms of marks obtained for the unit

To determine whether students' levels of agreement with the different aspects of the laboratory instruction sheet might also depend upon student achievement in terms of the marks obtained for the unit, the same data for the face-to-face laboratory students used to generate Figure 7.4 were grouped according to their final grades in the unit (the total mark for the unit was 100) into four groups: unsuccessful (below 50%), low achievers (50%-60%), moderate achievers (61%-75%), and high achievers (75% and above). A similar breakdown of the cohort was not possible for the remote-laboratory students due to the small number of participants. The results of this investigation are presented in Figure 7.5.

It is evident from Figure 7.5 that there are both similarities and differences in the response patterns across the low, moderate, and high achieving groups. The level of agreement for using the laboratory sheet for the laboratory procedures is similar across all groups with the slightly stronger agreement coming more from the low achieving groups.

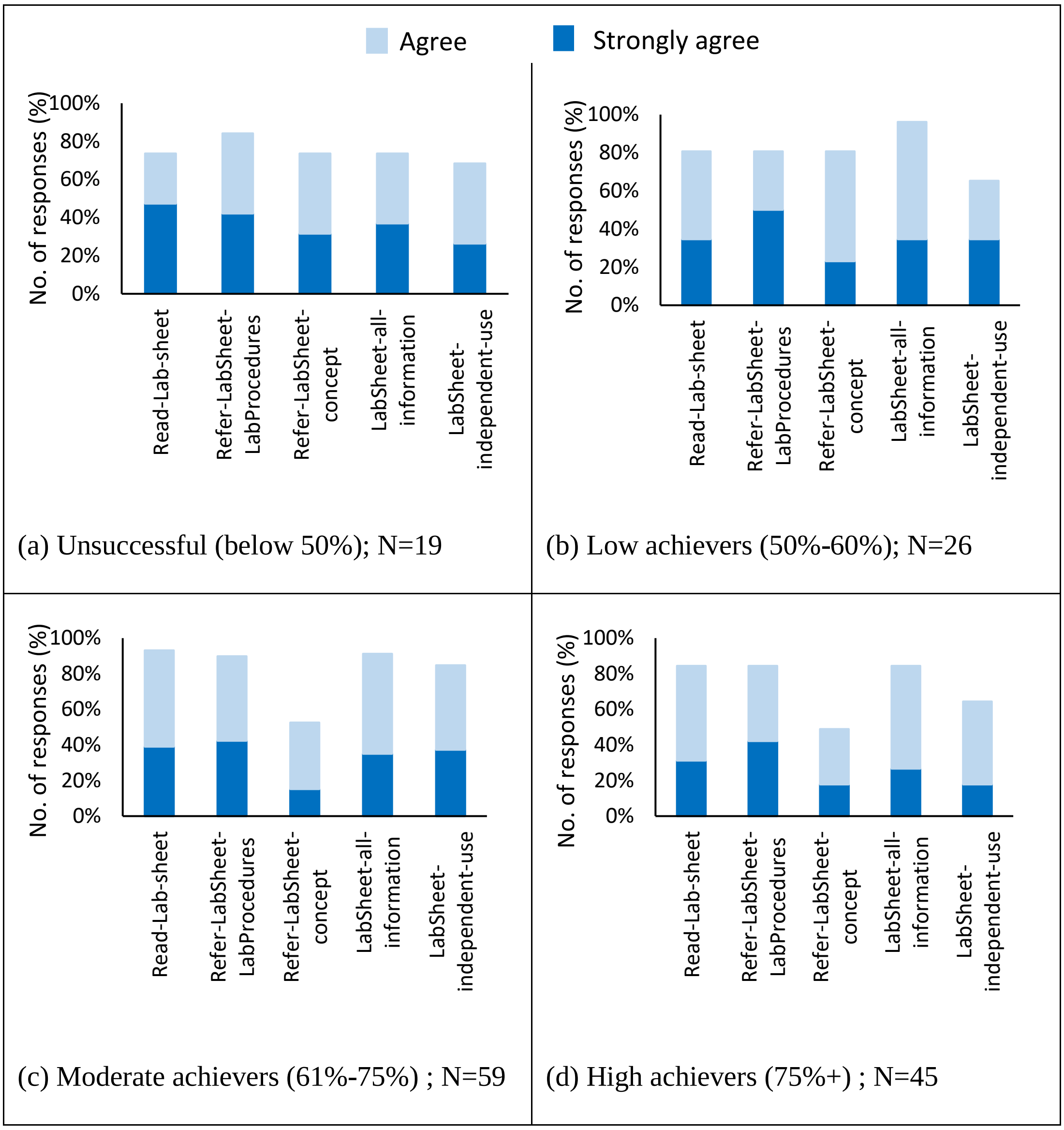


Figure 7.5: Face-to-face laboratory students' responses to the utility of the laboratory instruction sheet categorised on the basis of students' marks in the practical examination

The low-achieving group clearly seem to rely on the laboratory sheet for understanding conceptual matters related to the laboratory work as compared with the moderate and high achieving groups; this suggests that more able students apply understanding gained from the lecture-based components of their studies to the laboratory. It is also noteworthy that for independent conduct of the laboratory work using the instruction sheet, the moderate achievers showed higher agreement with the statement than both the low- and high-achieving groups. It might be speculated that the low-achieving group relied heavily on the instructor to enable them to complete the activity while the high-achieving group used the instructor's expertise to maximise their understanding of the laboratory work.

Responses to the question on students' level of overall satisfaction with the content of the instruction sheet (data not presented here) showed that the low and moderate achievers indicated slightly higher satisfaction than the high-achieving group. This finding may suggest that high-achieving students will always seek further information to advance their knowledge and performance levels. Conversely, this suggestion may be reinforced by the fact that low-achieving groups showed comparatively greater agreement to the item about the laboratory sheet containing all related information for the laboratory work.

Finally, the first group in Figure 7.5, who did not secure pass marks in their practical examination have an almost similar level of agreement for all items.

7.6.3.3 Students' suggestions for improvement in the laboratory instruction sheet

The foregoing results show that there were varying responses to the information content, conceptual content and overall satisfaction with the laboratory instruction sheet from students in both laboratory modes. As this was predicted during the design phase of the questionnaire, sections seeking suggestions for the improvement in the laboratory-instruction sheet were included (as optional) in the questionnaire (see Appendix I). Thus, questions were included to seek suggestions on improvements in the areas of conceptual content, instructions for carrying out the laboratory work and finally the data collection and analysis of results. Suggestions and comments received from students in the face-to-face and remotely controlled laboratory modes are respectively reported as follows.

7.6.3.3.1 Suggestions for the face-to-face laboratory instruction sheet

A qualitative analysis of the responses was conducted using Nvivo version 11 to look for repetitions in the suggestions. Under the three sections mentioned above, the repeated suggestions were further grouped. The most common suggestions for each section are as follows.

For the <u>theoretical concept</u> section, there were comments which said that there should be a more detailed theory with a better explanation of the equations used. Further stress was given by stating that the theory presented should be easy to understand. Some suggested that the inclusion of diagrams for better explanation of the theory could enhance students' work in the laboratory.

Similarly, for the laboratory procedures section, although the content was considered good enough that it required no further additions, there were some suggestions which said that the instructions needed to be more detailed and should have more images and diagrams for a better understanding of the procedures. Further comments said the instructions on the laboratory sheet should be very specific and concise.

For the data collection and results analysis section, students, in pursuit of a higher level of performance, suggested providing better graphs than those that were given in the laboratory sheet, while others wished for clearer tables for data collection. A few students expressed difficulty in collecting data from the experiment or analysing their results, stating that the laboratory sheet needed to have better instructions.

7.6.3.3.2 Suggestions for the remote-laboratory instruction sheet

Students' suggestions for improving the laboratory sheet in the remote-laboratory experiment were to some extent similar to the suggestions received for the face-to-face laboratory instruction sheet. As the two laboratory modes have different modes of performing the experiment, some of the suggestions reflected that difference. For instance, students suggested putting guidelines in the laboratory sheet for ways to download the files containing their data obtained during their experiment and also mentioning whether an external drive needed to be brought to the laboratory session.

Students in the remote laboratory also suggested that videos be used to illustrate the procedures related to laboratory work and also for the theoretical aspect of the experiment. Some suggested that in addition to the laboratory procedures, it would be good if there was a brief description of the phenomena or changes that were taking place in the equipment when instructions were given from the computer interface. They believed that this would give them foreknowledge about what they were expected to do and also whether they were noticing the right observables on the screen. There was also a suggestion regarding guidance for writing the report which they thought was missing.

7.6.3.4 Summary of findings regarding Research Question 6.3

The design of the laboratory-instruction sheet has been shown to be dependent upon both the mode in which the laboratory is undertaken and, for the face-to-face mode, the achievement of the student in terms of the marks obtained for the unit. In the former regard, remote-mode students appear to place less reliance on the instruction sheet than those students in the face-to-face laboratories. This difference may be because the remote laboratory students are prepared to access other sources of online information while the face-to-face students largely depend upon the instruction sheet and the expertise of the instructor who is effectively absent in remote-access work. With regard to the influence of student achievement on the needs of the instruction sheet, the main finding is that low-achieving students place greater reliance on the instruction sheet than high-achieving students. The most striking student suggestion for improving the laboratory instruction sheet in remote mode concerned the use of video (presumably hyperlinked from the sheet) for both procedural and conceptual aspects of the activity; this would be a natural extension of the activity-delivery platform. This suggestion could also be applied to face-to-face laboratories, that is, if students can read the laboratory instruction from an electronic device such as a tablet or computer, it could enhance students' interest and hence their work in the laboratory. A relevant work in this context is that of Patterson (2011).

7.7. Discussion of overall findings

The laboratory instruction sheet is generally viewed by students to provide all the basic information required for conducting the experiment, namely: a background or description of the concepts to be reinforced by the experiment, detailed procedural guidelines and the opportunity to validate the understanding of the laboratory work. This is true for students in both face-to-face and remote laboratories. The laboratory instruction sheet for the remote laboratory contains additional information regarding the establishment of the connection with the equipment which is remotely situated from the students. From the model of relationships between the interactions and the laboratory instruction sheet, shown in Figure 7.1, it can be ascertained that the basis for all interactions related to laboratory work is underpinned by the laboratory instruction sheet.

In the remote laboratory, students are bound to rely on the laboratory instruction sheet to perform their work due to the absence of the real-time support of instructors and laboratory partners. Satisfaction with the student-equipment interaction was reported by students to be higher among the remote laboratory groups from both institutions as compared with the face-to-face laboratory users. This is perhaps surprising given the absence of the element of physical touch and sense of the equipment and its behaviours as it is manipulated. However, the differences in satisfaction level scores were only marginal and thus the similarity in scores may be due to the fact that the laboratory experiment considered in this study was relatively simple (a bending beam) and therefore there was little difference in its observed behaviour between the two modes. A more complex piece of equipment, for example rotating machinery, may offer limited or restricted viewing of its behaviour in remote access mode as compared to its observation in the proximity of a face-to-face laboratory. Furthermore, the presence of an instructor/invigilator and other students in the remote laboratory set-up used in this study may have eased conduct of the laboratory task which led to better satisfaction.

As every interaction type makes its own distinct contribution to student learning and is guided by the laboratory sheet, effort needs to be made to preserve the learning that is gained from each interaction, at least to some extent. Design of the laboratory instruction sheet should be based on the interactions that are possible to synchronise in a particular laboratory mode. For instance, in the face-to-face laboratory, all interactions are synchronous so the laboratory instruction sheet can simply be modified to improve the quality of its contents. By contrast, in the remote laboratory, changes in the design of the laboratory sheet could address the missing interactions of the student with instructors and peers, who respectively provide support with the demonstration of the experiment and carrying out of the experiment. Clearly, the fact that the remote laboratory is enabled by the internet means that further online extensions to the traditional (document-based) laboratory briefing sheet could achieve this.

The design of effective laboratory-instruction sheets also seems to be dependent upon to the ability of the student undertaking the activity. The variation of such needs is more difficult to accommodate in a traditional document-based briefing sheet –

usually written in a linear mode of exposition - that would become unwieldy if to cover all possible student needs. By contrast, in remote-laboratory work, an online briefing sheet is better suited to a design that includes links to additional online materials (that may include video explanations) so that students can follow an exposition pathway suited to their particular needs and abilities.

The investigations reported in this chapter are based on small cohort of students who worked on remotely-accessed laboratory experiment. Remote-laboratory experiments are not widely available in Australian institutions, and those that do exist have fewer students who opt to work in this of mode of laboratory. Investigating the effectiveness of remote laboratories with small cohorts and then to later introduce them to a larger group has remained the focus of educators who foresee a greater advantage of this mode. This also remarked that the laboratory activity studied was mainly of the procedural type, typical in the first-year of an Engineering degree, which reinforced students' theoretical study of concepts as opposed to being an open-ended 'discovery' type of laboratory activity. Also, because this study only reports on the students' perceptions from first-year undergraduate engineering degrees, it would be valuable to compare the findings of this study with those of a future study on the perceptions of students from senior years of an undergraduate engineering degree.

7.8 Chapter Summary

The laboratory-instruction sheet has been shown to be an essential resource for laboratory work for both face-to-face and remote laboratories. The quality and depth of information in the laboratory instruction sheet can have an effect on the way in which students perceive the importance of their various interactions that occur in either laboratory mode. This perception further influences the students' satisfaction with the laboratory work performed as a result of the interaction with the equipment.

The results from the pre-laboratory survey revealed that before commencing the laboratory experiment, students in both laboratory modes considered the laboratory-instruction sheet to be the most important resource for undertaking the laboratory procedures. For face-to-face laboratory students, it plays a similar role as instructors for the clarification of the basic concepts related to laboratory activity. Students in remote as well as in face-to-face laboratories did not expect to make much use of the laboratory instruction sheet for the purpose of analysing their results.

After the conduct of the actual experiment, there remained similarities across the two laboratory modes in students' responses to the importance of the different interactions experienced in the laboratory. This study then focused on the relationship between laboratory instruction sheet and student-equipment interaction, the post-laboratory response analysis showing that there was substantial reliance upon the laboratory-instruction sheet by students in both laboratory modes when interacting with the equipment. The laboratory instruction sheet also significantly affected students' satisfaction of the student-equipment interaction in the face-to-face laboratory, while in the remote laboratory setup it made a significant contribution to providing students with the feel of performing a real experiment leading to comparatively greater satisfaction for student-equipment interaction.

Students' perception of the laboratory instruction sheet for the remote laboratory indicated that a well-designed laboratory instruction sheet has the potential to effectively replace an instructor or a laboratory partner in terms of successfully completing the activity. A qualitative investigation of students' views of the laboratory sheet suggested that students perceive some modifications in the laboratory instruction sheet in all its major areas in order to achieve better learning outcomes from the laboratory work.

The main findings of this study can be summarised as follows. The laboratory sheet:

1. Is perceived by students to be very important for procedural aspects of laboratory work but students undertaking remotely-operated laboratories find that actually operating the (remote) equipment can meet this need;
2. Is a contributing factor to student satisfaction in face-to-face laboratory work but less important for student satisfaction in remote-access laboratories, although it plays an important role in giving students the feel that they are conducting a 'real' experiment; and
3. Should meet different content requirements and emphases that depend upon the laboratory mode and perhaps should be tailored to, or at least recognise, different levels of student academic ability.

The overall outcome of the chapter is that the laboratory instruction sheet is comparatively less important for effective learning in remotely accessed laboratory work. This may be because students are less fearful of damaging equipment that is not physically co-located and therefore more likely to learn by ‘experimentation’ as opposed to following procedures. On the one hand, free experimentation is an ideal way to learn but on the other hand engineering students must, through the course of their studies, learn how to interpret, respect and adhere to operating procedures for equipment because graduate engineers do not play (experiment) with expensive and sometimes dangerous equipment in their post-university workplace.

This study has only considered the development of technical and analytical skills, based on theoretical concepts, through laboratory learning. The design of laboratory-instruction sheets for remote laboratories should also promote or preserve the learning outcomes of face-to-face laboratories that include the tacit development of personal and professional engineering skills that are most often inculcated through the student-student and student-instructor interactions. This aspect of laboratory learning remains a topic for future studies.

Interactions are useful only when they enhance students learning in the laboratory and support them in attaining essential personal and professional attributes. In the next chapter, the relative importance of various interactions in the students’ attainment of important laboratory learning outcomes, as stipulated by Engineers Australia, is presented.

Chapter 8

A Study of the Relative Importance of Student Interactions for the Attainment of Laboratory-Learning Outcomes

Statement of Contribution to Co-authored Published Conference Article

This Chapter is the content of a peer reviewed conference article "A relative importance of student interactions in obtaining laboratory learning outcomes", published in the *30th Annual Conference of Australasian Association of Engineering Education* in 2019.

I, Sulakshana Lal, as the primary author, conducted all the work of data collection and data analysis, including creating figures and tables, and writing and editing the manuscript.

I, as a Co-Author, endorsed that this level of contribution by the candidate indicated above is appropriate.

Anthony D. Lucey

Euan D. Lindsay

David F. Treagust

Mauro Mocerino

Marjan G. Zadnik

This chapter presents an investigation conducted to understand perceptions of the relative importance of interactions for their contribution to students' attainment of the laboratory learning outcomes mandated by accrediting bodies. The laboratory learning outcomes focused upon are those stipulated by Engineers Australia for students graduating with an accredited Bachelor of Engineering. The perceptions studied and compared are those of final-year students and academic instructors in a School of Civil and Mechanical Engineering.

Findings presented in this chapter have been published as a peer-reviewed conference-proceedings paper and a modified version of the published paper is presented in this chapter.

8.1 Background and aims

Engineering laboratories are currently conducted in various modes (Corter et al., 2011; Ma & Nickerson, 2006). Those which involve real physical equipment are face-to-face and remotely-operated laboratories. Face-to-face laboratories are the traditional and the most common mode for conducting laboratory experiments but may become impractical or too expensive to operate when the number of students is very large due to their lack of flexibility in terms of time availability and scheduling. In contrast, technology supported remotely-operated laboratories provide greater flexibility of time and space, can be less expensive to operate, and can potentially cater to larger student cohorts. The wider adoption and use of remotely-operated laboratories for educational purposes is currently limited possibly because of the difficulty of establishing a collaborative environment for students and instructors to interact during the laboratory work and also because of the physical separation between students and equipment. The present study therefore seeks to determine the relative importance of such interactions in traditional laboratory learning, as perceived by students and instructors, as a basis for the appropriate design of remote laboratories.

Previous studies have classified student interactions into three types: student-student (SS), student-instructor (SI), and student-equipment (SE) (Anderson, 2003; Miyazoe & Anderson, 2010). Recent studies (Lal et al., 2018; Wei et al., 2018) have added a fourth type termed indirect interaction (IndInt). This interaction occurs when a student learns or is assumed to learn from the observation or listening in to other students' interactions either between themselves or with an instructor in the laboratory. Each interaction has its own significance for students' learning in the laboratory (Lal et al., 2018).

In face-to-face laboratories, the physical presence of students and instructors along with physical access to the equipment used provides opportunities for all four interactions to take place. For instance, instructors' guidance and demonstration of laboratory work is a student-instructor interaction. Similarly, students working together in groups permit student-student interactions. Students' operation of equipment to collect data is a student-equipment interaction. Finally, inter-group discussions and observations or a student listening to other students' questions being answered by an instructor demonstrate the existence of indirect-interactions. However, these interactions may be modified or even entirely absent in remote laboratories.

Attempts to establish opportunities for all four interactions to take place in remotely-operated laboratories have yet to be reported.. However, some remote laboratories such as Netlab (Teng Nedic et al., 2016) have design features that allow students to collaborate during their laboratory work. Other external laboratories have incorporated features that allow instructors to guide and observe students during the conduct of their laboratory experiment. The primary focus so far in the design of remote laboratories has been on providing students with convenient access to real equipment (Lindsay & Good, 2005).

The present study serves to understand further the relationship between student interactions in laboratory learning and the attainment of Engineers Australia's (EA) ten laboratory-learning outcomes (Engineers Australia, 2019) in face-to-face laboratories from which recommendations for remotely-operated laboratory learning can be made. The study is centred on the views expressed by fourth-year undergraduate engineering students regarding graduate attribute competencies (Cicek Ingram et al., 2014; Cicek Labossiere et al., 2014) and also by their instructors. Final-year students were chosen because through their earlier study they would have developed a better understanding of the EA laboratory-learning outcomes that are expected of them and, to some extent, would have attained some or all of those outcomes.

8.2 Engineers Australia (EA) laboratory-learning outcomes

Engineering laboratories, irrespective of the mode, are deemed important for students because they inculcate the scientific method used for investigation, develop the practical skills required of engineers, reinforce theoretical concepts learned in lectures, and their conduct provides the opportunities to develop and practise essential personal and professional skills. Engineers Australia (2019) stipulates ten laboratory-learning outcomes for all students graduating with an accredited (at professional level) Bachelor of Engineering degree; these are presented in Table 8.1. In the sequential order presented by EA these learning outcomes (as LO1 to LO10) broadly represent the way that laboratory learning is designed to take place.

Table 8. 1: Engineers Australia (EA) laboratory learning outcomes

S.N.	**EA laboratory learning outcomes**
LO1	An appreciation of the scientific method, the need for rigour and a sound theoretical basis
LO2	A commitment to safe and sustainable practices
LO3	Skills in the selection and characterisation of engineering systems, devices, components and materials
LO4	Skills in the selection and application of appropriate engineering resources, tools and techniques
LO5	Skills in the development and application of models
LO6	Skills in the design and conduct of experiments and measurements
LO7	Proficiency in appropriate laboratory procedures, the use of test rigs, instrumentation and test equipment
LO8	Skills in recognising unsuccessful outcomes, diagnosis, fault finding and reengineering
LO9	Skills in perceiving possible sources of error, eliminating or compensating for them where possible, and quantifying their significance to the conclusions drawn
LO10	Skills in documenting results, analysing credibility of outcomes, critical reflection, developing robust conclusions, reporting outcomes

Accordingly, an engineering graduate must possess a good understanding of the underlying theoretical concepts and also a sound knowledge of the scientific methods that govern laboratory work (LO1). Reflecting the nature of engineering work, an engineering student, through experimental work, must develop an understanding of the specifications of engineering devices, materials and also know how to characterise engineering systems (LO3, LO4). Students should also attain experience in equipment use to capture data and undertake its analysis with critical reflection so as to identify errors and explain their sources (LO5, LO6, LO7, LO8 and LO9). Laboratory learning also includes the opportunity to develop the ability to create a standardised reporting for the engineering laboratory work performed (LO10). Students working in laboratories, throughout their engineering studies, are assessed for their attainment of the aforementioned competencies.

A typical way to evaluate students' attainment of the EA laboratory learning outcomes is through a laboratory report or artefacts designed and/or manufactured as part of the laboratory assignment. However, the contribution of student interactions in the actual conduct of the laboratory activity to the attainment of the learning outcomes is less often considered. This is then the focus of the present study.

There are advocates for establishing remote-laboratory environments for students and instructors to conduct laboratory learning at the same level of effectiveness as achieved in the face-to-face laboratory mode; the proposition is that the remotely-operated laboratory could provide opportunities for appropriate collaboration and the attainment of essential skills. However, the direct significance of collaboration among students and instructors and the ease of access of equipment for its operation, with the actual attainment of the stipulated laboratory learning outcomes have not been studied yet.

Studies of the overall graduate competencies for engineering students have been conducted by Male et al. (2009, 2011) but without specific consideration for engineering laboratories. The detailed discussion in Lindsay and Stumpers (2011) does address the design of remote laboratories to support students' attainment of Engineers Australia Stage One professional competencies. They show that remote laboratory deployment in combination with face-to-face laboratories can assist students in achieving all of the targeted learning outcomes. Various other comparisons have been conducted between face-to-face and remote laboratories for their effectiveness in students' attainment of learning outcomes (Lindsay & Good, 2005; Nickerson et al., 2007; Ogot et al., 2003). However, these studies of attainment of laboratory learning outcomes are mainly based on students' perception of the ease of conduct of laboratory experiment in the respective laboratory modes. The distinct contribution of the present study is to relate the attainment of laboratory-learning outcomes with the interactions that take place within the laboratory activity.

8.3 Research questions

In light of the foregoing discussion, the present study is framed by the following research question:

RQ 7: How do interactions contribute to students' attainment of the practical skills necessary to be a professional engineer?

This research question is studied from two perspectives. These are:

7.1 Which interactions, from the viewpoint of students and their instructors, are important for their contribution to the attainment of each of the ten EA laboratory learning outcomes?

7.2 How can the results from Research Question 7.1 be utilised to inform design for effective laboratory instructional practices in both face-to-face and remotely operated engineering laboratories?

8.4 Conceptual framework

The concept framework for the study is summarised by Figure 8.1. This shows how the four interactions that occur during laboratory work are linked to: the design of engineering laboratory work, students' attainment of EA laboratory-learning outcomes and students' graduation as a skilled engineer. Thus from left to right (arrows) in Figure 8.1, graduates of an EA accredited degree must have achieved the laboratory learning outcomes, the development of which is through active participation in the four interaction types that are promoted by the design of Engineering laboratory activities. The sequence from right to left (also arrowed) shows that engineering laboratory design incorporates the four types of interactions discussed above. These interactions then contribute to attainment of laboratory learning outcomes stipulated by Engineers Australia. Finally, students are awarded an engineering degree upon their attainment of those skills.

The structure depicted in Figure 8.1 equally applies to remotely-operated laboratories. Thus, understanding developed from the study of face-to-face laboratory work can support the future design of remotely-operated laboratories.

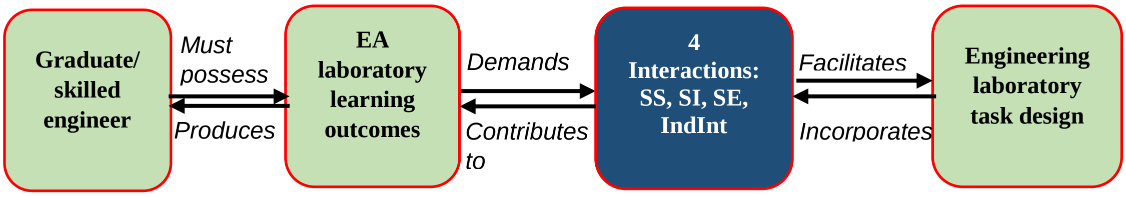


Figure 8.1: Interactions in engineering laboratory work contributing to the attainment of EA outcomes required to graduate as a skilled engineer. Note: SS=Student-Student interaction, SI= Student-Instructor interaction. SE=Student-Equipment interaction, and IndInt=Indirect interaction

8.5 Research methodology

A quantitative study (Creswell, 2014) was conducted to answer the research questions. An online survey questionnaire was designed and administered to all final-year (4^{th}-year) students of an accredited bachelor of engineering degree and, as a separate cohort, their academic instructors in the School of Civil and Mechanical Engineering at an Australian University. The questionnaire developed and used is shown in Appendix J. Respondents were asked to rank each of the four interaction types from most important (1) to the least important (4) on the basis of its contribution to attaining each of the ten EA learning outcomes. An extra column was added to the survey questionnaire and was named ‘Skip’. This was included in order to allow respondents to have the freedom of not answering rather than forcing them to randomly fill in the space with something that would not represent their actual perception.

A total of 26 final-year students (from a student cohort of approximately 300) responded to the survey; these Engineering students had undertaken all of their practical work in the face-to-face laboratory mode during their degree study. The students did not have exposure to, or experience of, remote-laboratory work. Similarly, 22 instructors (from an academic staff cohort of approximately 40), with teaching experience in face-to-face laboratory mode responded to the survey. It is recognised that the results discussed in this study arise from small number of respondents. Thus, the purpose of the investigation reported is to initiate an enquiry that has yet to receive sufficient attention in the Engineering-education community.

Despite the low number of respondents, the results of the study provide initial insights as to how each of students and instructors view the relative importance of student interactions in the laboratory in the context of attaining the overall set learning outcomes expected by the professional body at the completion of a student's degree

8.6 Results and discussion

8.6.1. Results of mapping of interactions to learning outcomes

Figures 8.2(a) and (b) show the average of the ranking of the four interaction types in their contribution to the attainment of the 10 learning outcomes drawn from the responses received from students and instructors respectively. The 10 learning outcomes (LO) in the figures are listed in the first column of the survey form in Appendix J. Each of the concentric rings represent a rank from 1 to 4, noting that 1 represents the greatest importance and 4 the least.

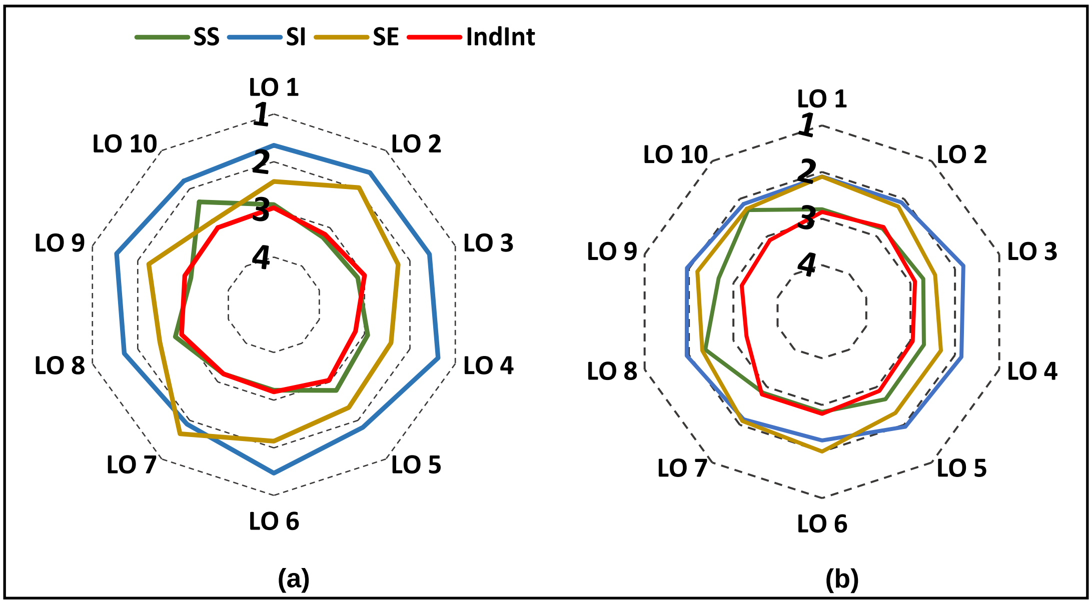


Figure 8.2: (a) Students' (N=26) perceptions and (b) Instructors' (N=22) perceptions of the relative importance of students' interactions in laboratory work towards attaining the EA laboratory-learning outcomes (LOs). Note: SS=Student-Student interaction, SI= Student-Instructor interaction. SE=Student-Equipment interaction, and IndInt=Indirect interaction.

Figure 8.2(a), shows that students report a marked importance for Student-Instructor interaction because for all learning outcomes the rank average was below 2 for Student-Instructor (SI) interaction. The second most important type of interaction was that of Student-Equipment (SE) interaction with an average rank that was mostly between rank 2 and 3, but peaked and averaged below 2 for the learning outcomes LO2 (safety) and LO7 (use of test rigs). The third most important type of interaction is that between students (SS). However, this interaction was deemed more important than student-equipment interaction for LO10 (reporting results, critical reflection and drawing conclusions) with an average between 2 and 3. Finally, students believe that of least importance are indirect interactions (IndInt) as all rank averages for this category are greater than 3. Nevertheless, for many learning outcomes their importance is reported to be at a similar level those of student-student interaction.

The average rankings plotted in Figure 8.2(b), received from instructors, show similarity with the students' views plotted in Figure 8.2(a). The outermost results boundary is again the Student-Instructor (SI) interaction, indicating it to be the most important type of interaction of all. The average rankings for SI interactions peaked more visibly for LO3 (characterising engineering systems) and LO4 (selecting tools and technologies) each with an average rank of less than 2. As with the students' perceptions, instructors also ranked themselves important for LO8 and LO9 (both relating to error analysis) with an average rank of 2. What is clearly different between Figures 8.2(a) and (b) is that the Instructors' average ranking of Student-Student (SS), Student-Instructor (SI) and Student-Equipment (SE) interactions all lie between 2 and 3 for all LOs with indirect interaction (IndInt) marginally lower. This indicates that instructors perceive all four types of interaction to be important contributors to the students' attainment of laboratory learning outcomes. A clear reflection of this is observed in the average ranking for LO10 (reporting results, critical reflection and drawing conclusions) where the average rankings for student-instructor, student-equipment, and student-student have almost identical average ranking of importance. Instructors ranked Student-Equipment slightly higher than the interaction with themselves for learning outcome LO6 (design and conduct of experiments) and at the same level as them for LO7 (proficiency in the use of procedures and equipment use). This might be expected given that instructors would expect the students to engage strongly with the equipment in order to gain command of its use.

8.6.2. Discussion

8.6.2.1. The relative importance of interactions in face-to-face laboratories

Figures 8.2(a) and 8.2(b) have shown that both students and instructors perceive Student-Instructor interaction to be the most valuable interaction in laboratory learning. However, the Student-Instructor interaction is perceived to be much more important by students than by their instructors. A clearer picture of the relative importance for interaction types expressed by students and instructors for attaining the 10 EA laboratory learning outcomes is seen in Figure 8.3.

Figure 8.3 emphasises the difference between student and instructor perceptions by plotting the difference in average ranking for each LO calculated by subtracting students' average ranking from instructors' average rank. It is important to note here that 'Rank 1' represents the most important interaction and 'Rank 4' represents the least important. This means that positive bars in Figure 8.3 indicate interactions that students perceived to be more valuable for the attainment of that LO while negative bars indicate the important ones from the instructors' perspective. Note that the sum of all bars within each LO result is zero.

For the purpose of the following discussion of Figure 8.3, the 10 laboratory learning outcomes, listed in Table 8.1, are grouped into five broad experimental categories, namely: {LO1, LO2} concern Engineering practice, {LO3, LO4} concern method selection and application, {LO5, LO6, LO7} concern equipment use, {LO8, LO9} concern error analysis, and {LO10} concerns reporting, reflection and concluding.

For {LO1, LO2} students ranked their interaction with instructors to be more important than did the actual instructors who indicated the importance of students' interaction with equipment to be more useful in gaining an appreciation of scientific method. Also noteworthy is that instructors perceive interactions with student peers inculcate safe and sustainable practices.

For attainment of the group {LO3, LO4} students believed that interactions with instructors and equipment provide better support whereas instructors again believed that students' interactions with other students, either directly or through indirect interactions, were more suited to this purpose.

In the attainment of group {LO5, LO6, LO7} student and instructors were in close agreement regarding the development and application of models (LO5) but reported very different views on the value of interactions regarding the design and conduct of experiments (LO 6) and matters related to laboratory procedures (LO 7). In these two los, students continue to look to their instructors for guidance whereas instructors believed that these were enabled by student interactions with their peers. Interestingly, students were more positive than instructors in asserting that their interactions with equipment enabled the development of proficiency in the use of equipment.

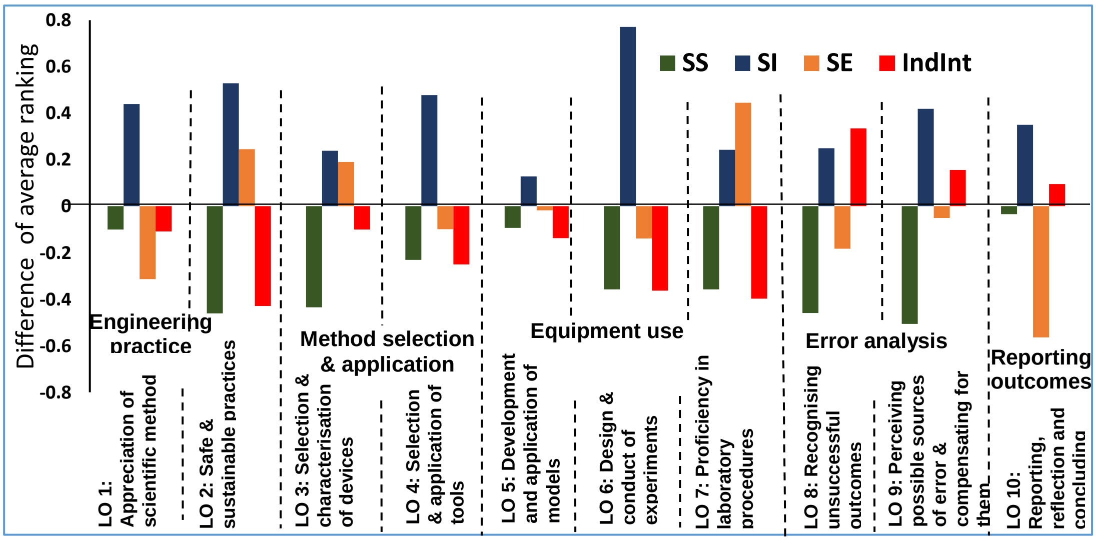


Figure 8.3: Difference of the average ranking observed in the students and instructors' response. Note 1: +ve difference represents students' ranking of interactions greater than instructors and –ve difference represents instructors' ranking of interactions greater than students. Note 2: SS=Student-Student interaction, SI= Student-Instructor interaction. SE=Student-Equipment interaction, and IndInt=Indirect interaction.

Skills required through the attainment of {LO8, LO9} yield different emphases between student perceptions and those of their instructors. For this group, students clearly place greater importance on student-instructor interactions and indirect interaction. For the former they seek guidance from instructors while the latter suggests that their error analysis benefits from seeing what other students are doing and the questions that they ask instructors as to the 'correctness' of their results. Again, instructors expected students to acquire skills in error recognition and analysis by discussions with their peers, most probably by comparison of results obtained.

Finally, for the development of skills in documenting results, analysing the credibility of outcomes, critical reflection, developing robust conclusions and reporting outcomes, {LO10}, students expected to be guided by instructors while instructors placed greater emphasis on these to be developed through, a little surprisingly, students' interactions with the equipment used. Students and instructors were in agreement over the role of peer interactions (both direct and indirect) in developing this LO.

The foregoing differences in student and instructor perceptions of the relative importance of interactions for attaining the laboratory learning outcomes suggest the need to re-consider the design of present face-to-face laboratory activities and other arrangements made for students to gain practical knowledge of engineering concepts. Overall, it seems that final-year students expect instructors to lead their attainment of learning outcomes while instructors currently expect that such students, at their relatively advanced stage of educational development, should have become more independent learners and/or be able to learn through peer interactions.

8.6.2.2. Potential implications for remote laboratories

For proponents of remote laboratories, the above results from face-to-face laboratories pose challenges for creating a remote laboratory design which can effectively allow students to interact with instructors and gain the equivalent of a hands-on experience of equipment at a similarly effective level.

In remotely-operated laboratories, student-equipment interaction is evident and probably the most focused-upon feature by designers of remote-laboratory systems. Recommendations for enhancing the design of remotely-operated laboratories generally come from the instructors themselves or academics researching engineering-education practice. However, the present findings for face-to-face laboratories suggest that it is crucial to take into account students' perceptions of the types of interaction that they believe allow them to learn effectively through laboratory activities.

For the effective integration of remotely-operated laboratories alongside existing face-to-face laboratories in a laboratory teaching and learning program, it is important that efforts are made to create similar environments. This means enabling the important interactions that lead to the attainment of a set of mandated laboratory-learning outcomes which apply to both face-to-face and remotely-operated laboratory learning.

8.7 Limitations

The findings reported in this study are from a small cohort of students and instructors who were from Civil, Mechanical, and Mechatronics Engineering, and is exclusively based on their experiences of face-to-face laboratories. The investigation for applicability of the results, reported in this chapter, to other disciplines and with larger number of student and instructor responses remains a focus. It would be additionally useful to conduct similar investigations for remotely-operated laboratories.

8.8 Conclusions

The present study of perceptions of the relative importance of student interactions for attaining the laboratory learning outcomes stipulated by Engineers Australia highlights some important matters that require careful consideration.

In answer to Research Question 7.1, a marked difference has been shown between student perceptions and those of their instructors for face-to-face laboratory learning. The main areas in which differences arise have been identified in terms of groups of laboratory learning outcomes. Overall though, final-year students value, or remain dependent upon, interactions with, or learning from, instructors and any opportunity for hands-on manipulation of equipment more than the opportunity to interact with their peers and/or to be able to learn from observation of others' work in the laboratory. This then suggests that while instructors believe that peer interactions (direct and indirect) are an equally important means of attaining laboratory learning outcomes, this is in fact not occurring to the extent for which the laboratory activities have been designed.

In answer to Research Question 7.2, the beneficial adoption of remotely-operated laboratories may rely upon the consideration and incorporation of the types of interaction prioritised by students, namely student-instructor and student-equipment interaction, or their replacement via technological innovations, as their most effective means of attaining the laboratory learning outcomes.

This matter is explored further in the following chapter that concludes the work of this thesis and specifically addresses the question of which types of interactions currently of value in face-to-face laboratories should be replicated in remotely-operated laboratories.

Chapter 9

Conclusions

This chapter summarises the findings obtained through the research reported in this thesis. The conclusions are presented in accordance with the theoretical framework (Figure 1.1; see page 18 of Chapter 1) based on the Model of Educational Reconstruction discussed in Chapter1. The design of the existing face-to-face and remotely-operated laboratories were studied in terms of the experimental arrangement and, the possibilities and extent to which students' interactions for conducting the laboratory work were possible. This study further conducted research on laboratory learning and teaching practices in both face-to-face and remotely-operated laboratories by administrating student surveys before and after laboratory sessions, video recording students and instructors engaged in laboratory work, and seeking students' opinions about their experiences in the laboratory. These investigations provided an understanding of students' expectations of the interactions from both students' and instructor's perspectives; these results are reported in Chapters 3 to 8. Summaries of findings are drawn from each chapter and then suitably woven together to identify interactions that are important and should be prioritised in the enhancement of the present face-to-face engineering laboratories and for transfer to the future design of remotely-operated engineering laboratories. These findings are inter-linked and combined to arrive at the overall conclusions of the study and for future recommendations.

9.1 Background and aims

The internet has impacted all walks of life. People are more technology dependent than ever before for doing even the smallest of things. As in other fields, innovators have attempted to redesign the educational sector through new technology. Indeed, delivering theoretical concepts through technological mediation has widely been accepted, as well as been adapted into mainstream education. However, the teaching of practical concepts and skills using technology mediation is still an area of current research. Although remotely-operated laboratories now exist, there remain difficulties for educators in their design so that learning experiences similar to the traditional approach of teaching practical courses can be provided.

The investigations described in Chapters 3 to 8 have contributed to the aims for this chapter. Through the summary of the results, this chapter provides answer to the final research question:

RQ 8: What interactions need to be prioritised for transfer from face-to-face to remotely-operated engineering laboratories?

9.2 Overall findings

This section addresses the Research Questions 1 to 7 (Chapter 1, Section 1.7, page 22) summarises their attendant findings, and combines them into the overall findings of the study. This thesis has investigated processes through which students' learning occurs in engineering laboratories by examining the interactions in both face-to-face and remotely-operated engineering laboratories. The purpose of the present chapter is to understand whether students learn in a similar manner in both laboratory modes and to examine whether or not the EA laboratory learning outcomes attained are equivalent. Attempts have been made to understand the important interactions in face-to-face laboratories that should be prioritised in the future design of remote laboratories so that the students obtain an equally valid laboratory learning experience.

Students from all four years of undergraduate engineering degree were invited to participate in the investigations of this thesis. This research design provides a perspective regarding the importance of interactions not just for the conduct of laboratory activities but also for the attainment of the expected laboratory learning outcomes as mandated by accrediting bodies.

In face-to-face laboratory work, a comparison between the expectations and frequency of occurrences of interactions that students from first- to third-year experienced during the conduct of their laboratory work was made in Chapter 3 (Research Question 1). There was also a comparison made between first- and third-year students to generate an understanding of the change in expectations and opinions about the importance of interactions between students in their first- and third-year of engineering degrees in Chapter 4 (Research Question 2). Further, responses from remotely-operated laboratories regarding their expectations, frequency of occurrences of interactions and perception of importance of interactions in Chapter 5 (Research Question 3 and Research Question 4) provided an understanding of the difference in the opinion about the importance of interactions between face-to-face and remotely-operated laboratory modes.

As reported in Chapter 3 (Research Question 1), students' expectations for various interactions did not align with their actual behaviour in the laboratory. Students at all levels interacted more with their peers more than with instructors during their conduct of a laboratory activity. Interactions between students and an instructor are important, as reported in Chapter 4 (Research Question 2). The opportunity for hands-on manipulation and the availability of a laboratory instruction sheet are considered important for laboratory learning. Indirect learning opportunities were also considered important by students at a higher level of their undergraduate engineering degree. Students' satisfaction with the four types of interactions aligned well with their perception of the importance of these interactions.

Opportunities for hands-on manipulation and the availability of the laboratory instruction sheet were important for learning in remote laboratories, as seen in Chapter 5 (Research Question 3 and Request Question 4), a finding similar to that for face-to-face laboratories. Students were also satisfied with the interactions that they reported to be important for learning in the remotely-operated laboratory. In addition, remote laboratories can provide a similar laboratory learning experience as face-to-face laboratories and are capable of enhancing students' interest in the subject matter.

The findings of Chapter 6 (Request Question 5) showed that students' experiences and responses identified the need to consider whether or not remote laboratories can provide the opportunity for first-year students to acquire all of the essential laboratory skills obtained through various interactions at their level. The responses further showed that consideration is needed for remote laboratories to be blended into regular engineering studies so that students are able to experience quality laboratory learning and are prepared for modern industry demands and a globally-connected workplace culture.

Chapter 7 (Research Question 6) showed that, for first-year students, the laboratory instruction sheet significantly influenced the occurrence of the four interactions among students, instructor, and equipment during their conduct of laboratory activities. The laboratory instruction sheet was perceived to be essential for learning the procedures to conduct the laboratory activity in face-to-face mode, while students undertaking remotely-operated laboratories found that actually operating the (remote) equipment could meet this need. The laboratory instruction sheet was also a contributing factor to students' satisfaction in face-to-face laboratory work but was less important for students' satisfaction in remotely-operated laboratories. Nevertheless, the laboratory instruction sheet was considered to play an important role in giving students the feeling that they are conducting a 'real' experiment. Consequently, the laboratory instruction sheet should be designed depending upon the content requirements and emphases based on different laboratory modes.

Chapter 8 (Research Question 7) investigated how interactions contributed to students' attainment of practical skills necessary to be a professional engineer. The findings revealed that final-year students expected their attainment of laboratory learning outcomes to be led by instructors while instructors expected students to become independent learners and/or be able to learn through peer interactions. It was further stated that if the design of remote laboratories were enhanced so that students could acquire the EA laboratory learning outcomes as in the face-to-face laboratories, then remote laboratories could be widely adopted in engineering studies.

9.3 Recommendations for prioritising interactions for transfer from face-to-face to remotely-operated laboratories

To answer Research Question 8, the following highlights the main recommendations for the future design of remotely-operated laboratories.

9.3.1 Student-student interaction

Student-student interaction is frequent and the most satisfying for students at most levels of an engineering degree, so it should be maintained in remote laboratories by creating ways for peer-to-peer learning.

Student-student interactions have been reported to be beneficial for students' learning skills in laboratories. This collaboration supports them in gaining confidence and assures them of the correctness of their laboratory work. In face-to-face laboratories, students work in groups due to its perceived importance for students' learning from laboratory activities and also because of the constraints of resources and time. Students were more comfortable interacting with each other for laboratory work. Instructors also reported the importance of this interaction and expected students to be independent learners as well as engaged in interactions with peers for attaining laboratory learning outcomes. Student-student interactions not only provided opportunities to collaborate for laboratory work but also to learn significantly from each other, thereby reinforcing their learning obtained in the laboratory.

In the remotely-operated laboratories, although students interacted most among themselves, there was no provision for students to collaborate synchronously with other students in conducting the laboratory work. However, some remote laboratories do allow students to collaborate through social media or video and audio conferencing tools incorporated in them.

The dominant nature of students' behaviour reported in both face-to-face and remote-operated laboratories evidenced in the research reported here emphasises that all remote laboratories designed in the future should create opportunities for students to collaborate during their laboratory work. This collaboration is further linked to students' better engagement in the laboratory and hence better performance.

9.3.2 Student-Instructor interaction

The student-instructor interaction is a highly valued interaction and should be retained in the design of remote laboratories by developing mechanisms that enable students to seek expert advice during the laboratory activity.

Interaction with instructors is important and satisfying for students at all levels of an engineering degree in both face-to-face and remotely-operated laboratory modes. In addition, the student-instructor interaction plays an important role in the students' attainment of laboratory learning outcomes.

A typical remote laboratory does not have provision for students to interact with instructors while they are conducting activities, as in the face-to-face laboratory. The remote laboratory reported in this study had two separate arrangements at two different institutions, one with the instructor in the laboratory and the other without the instructor. The first-year students who conducted laboratory work with and/or without the instructor's supervision at both institutions indicated the need for and importance of instructors while conducting laboratory work. This result further justifies the importance of an instructor's presence for remote laboratory work.

Instructors serve as a knowledge guide and ensure the appropriateness and correctness students' laboratory activities as well as providing a measure of their attainment of laboratory skills. Opportunities for students to seek expert guidance for the conduct of a laboratory activity is vital for their learning of appropriate and accurate laboratory skills. This situation implies that, as in face-to-face engineering laboratories, the future design of remote laboratories should have features that allow for student-instructor interactions. Some possible ways of establishing student-instructor interactions in remotely-operated laboratories can be by allowing audio and video conferencing between students and instructors during the conduct of the activity (Banky & Blicblau, 2019) and incorporating design features such as "Chatbot" software (Javare et al., 2021), or a 'Frequently asked questions' section.

9.3.3 Student-equipment interaction

The present design of remote laboratories already focuses on enhancing technical specifications to provide students with better screen resolution, better internet connectivity, and better live feed of the equipment. This level of technology reflects the value of student-equipment interaction realised for the remote laboratories and this effort has been instrumental in providing students with the feeling of operating real equipment, similar to face-to-face laboratories.

The student-equipment interaction is important for the conduct of both face-to-face and remotely-operated laboratories. In a well-designed remote laboratory, this interaction should have an efficiently designed web interface for manipulation of the apparatus, comprehensive views of the equipment and its parts during operation. Also, the laboratory instruction sheet is an important resource for face-to-face laboratories and remote laboratories; for the latter, it provides students with the feeling of conducting a real physical experiment. Therefore, the laboratory instruction sheet for remote laboratories should be carefully designed so that it contains sufficient information about the specification of the equipment and its set-up, ways to establish and connect with the apparatus and, finally, on the steps to collect and analyse the data.

9.3.4 Indirect interaction

Students engage in indirect learning obtained from the interactions that occur between other students and also those that occur between other students and instructors. This interaction is useful when direct interaction opportunities are not possible or students are hesitant to interact directly with other students and instructors during the conduct of laboratory activities.

Indirect interaction is possible in face-to-face laboratories but remains a challenge in the design of remote laboratories. Considering the change in students' behaviour as they progress through the years of their program from first- to fourth-year of an engineering degree, it is deemed important to provide students with indirect interaction opportunities in remotely-operated laboratories along with the direct interaction opportunities among students. One approach is to create libraries of students' exchange of messages with one another and/or with the instructors during the conduct of laboratory activities. Such a library could allow students working in a remote laboratory to benefit from the indirect interactions of other students and instructors.

9.3.5 Blended learning approach

The present research does not suggest replacement of all the existing face-to-face laboratories for engineering students. Instead rather a blended approach is envisioned to be beneficial for students' complete learning of personal and professional skills. This approach is needed in order to prepare engineering students for future industry demands where remote operation of engineering work is rising.

9.4 Limitations

The research questions investigated in this study gave rise to many limitations in the findings reported in this thesis. Important limitations that became apparent during the research are as follows:

This thesis only reports the findings from one first-year mechanical engineering remote laboratory only. It was difficult to access and survey students performing remote laboratory activities in second-, third- or fourth-year engineering courses in Civil, Mechanical or Mechatronics Engineering. To provide appropriate recommendations for the improved design of remotely-operated laboratories, the perspectives of students in higher years of engineering as well as from other disciplines of engineering would have added significant value to the recommendations made in this thesis.

The remote laboratory selected for study was set-up in the premises of University of Technology Sydney and the students who were surveyed performed experiments on this set up were situated at institutions in Victoria and Western Australia. This constrained the time of study and also the type of data that could be obtained. As the classes in remote laboratory at the institution in Victoria did not run every semester, the results obtained from the remote laboratory could not be repeated. Also the student numbers were quite low (N=26, Chapter 5) so it is difficult to judge the value of the results reported for the remote laboratory as applicable to a larger population. Unfortunately, during the course of this study the remote laboratory at UTS was ultimately shut down by the host institution which limited all opportunities to conduct any further research in this remote laboratory.

Due to the nature of the research questions targeted for investigation and also the design of the engineering classes for each year in engineering courses, it was difficult to repeat a set of investigations. The first-year results report perspectives of students from multiple disciplines of engineering. From second-year onwards, the results reported are from students pursuing Mechanical type units. Consequently, it is unclear at this stage if the findings presented in this thesis can be representative of responses of students from other engineering disciplines.

Students' responses reported from third-year students is only half of the total number of students in that cohort. For the fourth-year cohort in the face-to-face laboratory (N=22, Chapter 8), the student number is not representative of the total population in that cohort. So the perceptions reported by the final-year students do not necessarily reflect the opinions of the whole cohort.

Many survey responses were not completely filled or properly filled, due to which the number of responses reported does not reflect the perspectives of the overall cohort in all years of engineering.

Finally, the results reported in this thesis are based on an Australian context and Australian accrediting body, Engineers Australia, for reporting laboratory learning outcomes.

9.5 Further Research

The limitations reported in Section 9.4, highlight opportunities for conducting further research in the areas investigated in this thesis. These opportunities may help to ascertain the wider applicability of the results presented in this thesis. Some research that can be conducted as extensions or developments from the present work are as follows.

This thesis reports findings only from accredited university undergraduate four-year engineering degrees. It would be valuable to check whether the present findings apply to three-year Bachelor of Technology degrees and two-year Associate Degrees in Engineering, the former delivered through universities while the latter is usually delivered by TAFE providers.

Remote laboratories in other disciplines and for higher years should be studied to learn from both students and instructors' opinions about the need and importance of establishing interaction opportunities. Collaboration among institutions can allow more students' and instructors' participation in the investigation which would provide strength and authenticity to the findings obtained.

There has been a significant change made in the learning and teaching processes for remote laboratories at many universities during the COVID-19 pandemic. It would be worth studying the effect of these on the adjustments made for students to collaborate in their laboratory work and instructors to provide their guidance during the conduct of remote laboratory experiments. This will provide an added perspective on the importance of incorporating student interactions in remote laboratories for increasing its wide adoption by universities.

A study of the variation in expectation and opinion about the importance of interactions based on gender would determine if there was any effect of gender on the way students collaborate among themselves and with instructors. Such responses may further pave the way to design a laboratory activity that provides equal learning opportunities obtained through the various interaction categories.

As students in a higher level of an engineering degree tend to behave as independent learners, interviews could be conducted with them to understand the applicability of remote laboratories at that stage. This research should be carried out with students from multiple disciplines of engineering.

In addition to studying multiple disciplines of engineering, it will be advantageous to extend the above study for other types of engineering laboratories, such as problem-based or open-ended laboratories conducted in both face-to-face and remotely-operated laboratory modes. These results would further help in understanding the applicability of the present findings for recommendations on the transfer of important interactions from face-to-face to remotely-operated laboratories.

Interviews with instructors from across the full range of Engineering disciplines, those who are involved in class-based teaching as well as laboratory teaching, should be conducted. It would be advantageous if instructors involved in teaching in both face-to-face and remotely-operated laboratory modes could be invited to the study.

A study of the effects of the four interactions in the teaching process from the viewpoint of instructors in both laboratory modes should be conducted. Such a study will provide understanding for instructors of the importance of interactions in the laboratory and also how interactions could be considered while designing teaching practices in both laboratory modes. This will also allow for more awareness about remote laboratories for instructors who are only experienced in face-to-face laboratory teaching. Likewise instructors in remote laboratories can partner with face-to-face laboratory instructors to design effective teaching practices in remote laboratories. The effects of instructors' ability, in terms of laboratory knowledge on the students' attainment of laboratory learning outcomes should be investigated. This is important because the contributions by student-instructor interactions on students' learning outcomes can be significantly affected by the experience and knowledge of instructors regarding the underlying theory and familiarity with the equipment used in the laboratory activity.

Laboratory instruction sheets will always play an important role in the students' conduct of laboratory activities, irrespective of the laboratory mode. It would be beneficial to study and compare the design of laboratory-instruction sheets for later year engineering units in both face-to-face and remotely-operated laboratories. This will be particularly important in cases where moving face-to-face laboratories to remotely-operated laboratory modes is considered necessary and beneficial for students' learning.

Face-to-face laboratories have several advantages that are worth incorporating in the design of remotely-operated laboratories. In a similar manner, there are some aspects of remotely-operated laboratories which can be considered for enhancing face-to-face laboratories. Providing students with live video or recorded videos of the laboratory activity can allow students to gain experience of operating equipment and learning the laboratory procedures before entering the laboratory premises. These recorded laboratory activities can enhance students' engagement as well as performance in their conduct of a face-to-face laboratory activity.

Finally, a study similar to the present study reported in this thesis should be conducted to establish, extend and confirm the reliability of the survey instruments used in the study and to confirm the applicability of the results.

9.6 Conclusion

The research conducted for understanding the processes through which learning occurs in both face-to-face and remotely-operated engineering laboratories can contribute to the existing literature in the area. The findings reported in this thesis are important in many ways as indexed by the following:

1. Results reported for student-student, student-instructor, student-equipment and indirect-interactions have allowed for a better understanding of students' learning processes in both face-to-face and remotely-operated laboratories.
2. Students' expectations of interactions, occurrences of interactions and perceptions of the importance of interactions in face-to-face and remotely-operated laboratories have revealed aspects of laboratory-learning approaches that could beneficially be modified. For instance, students expect to learn most from instructors as well as express the importance of interacting with instructors in the laboratory but interact with peers and equipment more than instructors during the conduct of the laboratory activity.
3. Lack of important interactions such as direct student-student and student-instructor interactions in remote laboratories, that are possible in face-to-face laboratories, suggests reasons that might have affected the wide adoption of

remote laboratories. These interactions need to be transferred in the future design of remote laboratories as these interactions play an important role in the students' learning process in laboratory work.

4. As the study for remote laboratories reported in this thesis was conducted in collaboration with two institutions, it is possible to claim that remote laboratory resources can be shared thus reducing the cost required to provide laboratory access to students. Also students at varying locations can work on the same equipment several times.
5. Students' enrolment number is not a concern for remote-laboratory setting. Therefore, the work reported in this thesis contributes to enhancing the design of current face-to-face and the future design of remotely-operated engineering laboratories in terms of student interactions for improved learning and teaching practice in engineering laboratory education.

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Appendices

Appendix A: Ethics approval granted for the overarching project

MEMORANDUM

Curtin University

To:	Prof David Treagust
	SMEC
CC:	
From:	Dr Catherine Gangell, Manager Research Integrity
Subject	Ethics approval
	Approval number: RDSE-61-15
Date:	19-Oct-15

Office of Research and Development
Human Research Ethics Office

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for your application submitted to the Human Research Ethics Office for the project: 5633

The online future of Science and Engineering education: The essential elements of laboratory-based learning for remote-access implementation.

Your application has been approved through the low risk ethics approvals process at Curtin University.

Please note the following conditions of approval:

1. Approval is granted for a period of four years from **19-Oct-15** to **19-Oct-19**
2. Research must be conducted as stated in the approved protocol.
3. Any amendments to the approved protocol must be approved by the Ethics Office.
4. An annual progress report must be submitted to the Ethics Office annually, on the anniversary of approval.
5. All adverse events must be reported to the Ethics Office.
6. A completion report must be submitted to the Ethics Office on completion of the project.
7. Data must be stored in accordance with WAUSDA and Curtin University policy.
8. The Ethics Office may conduct a randomly identified audit of a proportion of research projects approved by the HREC.

Should you have any queries about the consideration of your project please contact the Ethics Support Officer for your faculty, or the Ethics Office at hrec@curtin.edu.au or on 9266 2784. All human research ethics forms and guidelines are available on the ethics website.

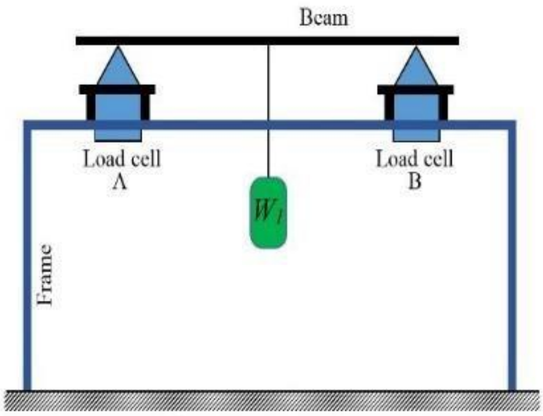
Yours sincerely,

p.p.
Dr Catherine Gangell
Manager, Research Integrity

Appendix B: Design of laboratory activity in the undergraduate face-to-face engineering laboratories

B.1 First-year Face-to-Face laboratory activity

The main objective of first-year face-to-face laboratory activities is to allow students to investigate the effect of loading on the bending of a beam. For conducting the laboratory activity, approximately 12 students in groups of three performed the activities under the guidance of an instructor. In the first-year face-to-face laboratory, shown in Figure D.1 (a), students personally set up the beam by supporting it on two load cells. The students manually increase the load applied on the beam and the reaction forces are indicated at the supporting load cells. The arrangement is then used to confirm the equilibrium condition of the beam. This laboratory activity involved two sets of an investigation where the loads were applied at two different positions. A schematic diagram of the experimental setup is shown in Figure D.1 (b).



(a) (b)

Figure B.1: Face-to-face laboratory set up (a) Apparatus for simply supported beam experiment (b) Schematic diagram of the face-to-face laboratory

In the face-to-face laboratory, there is no fixed time allotted for data collection. The students were free to manage their laboratory time within the 90-minute session.

B.2 Second-year face-to-face laboratory activities

The experimental arrangement for the second-year face-to-face laboratory is provided in Lal et al. (2017) shown as associated research conducted in Appendix K.

B.3 Third-year face-to-face laboratory activities

Third-year students performed laboratory activities from Applied Fluid Mechanics to calculate the drag on a cylinder when subjected to a fluid flow. The experimental set up is shown in Figure D.2. The main objectives of this activity were to measure the pressure distribution around a cylinder using pressure tapping and compare it with the predicted distribution from potential flow theory, and then to determine the pressure drag coefficient of a cylinder.

Figure B.2: Third-year Applied Fluid Mechanics laboratory

Appendix C: Pre-laboratory survey questionnaires

C.1. Pre-laboratory survey for first and second-year students

Below is a list of 13 possible interactions that may happen during this laboratory class.

Please **<u>choose ONLY 5 of them</u>** that you think are most important and **<u>rank the ones you choose</u>** from 1-5 (where #1 is the most important).

Example interaction		Rank
Talking to another student you learn	..... About the procedures/lab equipment	
	..... How to analyse your results	
	..... About the basic science theory behind the lab	
Talking to a lab demonstrator you learn	..... About the procedures/lab equipment	
	..... How to analyse your results	
	..... About the basic science theory behind the lab	
During the prelab you learn	..... About the procedures/lab equipment	
	..... How to analyse your results	
	..... About the basic science theory behind the lab	
Reading the laboratory manual/notes you learn	..... About the procedures/lab equipment	
	..... How to analyse your results	
	..... About the basic science theory behind the lab	
You learn about the basic science theory behind the lab by using the internet on a smart device		

C.2. Pre-laboratory survey for third-year students

Below is a list of 13 possible interactions that may happen during this laboratory class.

Please **choose ONLY 5 of them** that you think are most important and **rank the ones you choose** from 1-5 (where #1 is the most important).

Example interaction		Rank
Talking to other student you learn	..... About the procedures/lab equipment	
	..... How to analyse and interpret your results	
	..... About the basic theory behind the lab	
Talking to a lab instructor you learn	..... About the procedures/lab equipment	
	..... How to analyse and interpret your results	
	..... About the basic theory behind the lab	
Operating the equipment you learn	..... How to perform the experiment	
	..... To find possible errors in the experimental results	
	..... About theoretical concepts that govern the experimental phenomena	
Reading the laboratory manual/notes you learn	..... About the procedures/lab equipment	
	..... How to analyse and interpret your results	
	..... About the basic theory behind the lab	
You learn about the basic theory behind the lab by using the internet on a smart device		

Appendix D: Post-laboratory survey questionnaires

D.1. Post-laboratory survey for first and second-year students (Occurrences)

Reflecting on the laboratory class you just completed:

1. (*Student-Student Interactions*) Did you talk to another student about ...	**Never**	**A few times**	**Many Times**
The procedures, protocols or lab equipment?	①	②	③
The basic science concepts behind the lab?	①	②	③
Analysing your results?	①	②	③
Discipline topics not directly related to the lab?	①	②	③
Topics not related to the lab?	①	②	③
Were there any other interactions? If so, please comment on the nature and frequency (please use back for more space):			

2. (*Student-Teacher Interactions*) Did you ask the teacher about ...	**Never**	**A few times**	**Many Times**
The procedures, protocols or lab equipment?	①	②	③
The basic science concepts behind the lab?	①	②	③
Analysing your results?	①	②	③
Discipline topics not directly related to the lab?	①	②	③
Topics not related to the lab?	①	②	③
Were there any other interactions? If so, please comment on the nature and frequency (please use back for more space):			

3. (*Student-Equipment Interactions*) Did you ...	**Never**	**A few times**	**Many Times**
Read the lab manual/instructions associated with this lab?	①	②	③
Use the Internet for technical assistance, data analysis or for concepts behind this lab?	①	②	③
Were there any other interactions? If so, please comment on the nature and frequency (please use back for more space):			

4. (*Indirect Interactions*) Did you learn by observing someone else's interactions in the lab, such as ...	**Never**	**A few times**	**Many Times**
Observing another students experimental setup or behaviour	①	②	③
Listening to a student/group of students asking another student for help/advice	①	②	③
Listening to a student/group of students asking a teacher for help/advice	①	②	③

D.2. Post-laboratory survey for third-year students

A. Please pick five of the most important interactions observed below in Table

1.	2.	3.	4.	5.

B. Reflecting on the laboratory class you just completed:

1. (*Student-Student Interactions*) Did you talk to another student about ...	**Never**	**Rarely**	**Occasionally**	**Frequently**	**Very frequently**
1.1 the procedures, protocols or lab equipment?	①	②	③	④	⑤
1.2 the basic theory concepts behind the lab?	①	②	③	④	⑤
1.3 analysing and interpreting your results?	①	②	③	④	⑤
1.4 engineering topics not directly related to the lab?	①	②	③	④	⑤
1.5 general topics not related to the lab?	①	②	③	④	⑤
Were you happy with the student-student interactions?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩				

2. (*Student-Instructor Interactions*) Did you ask the instructor about ...	**Never**	**Rarely**	**Occasionally**	**Frequently**	**Very frequently**
2.1 the procedures, protocols or lab equipment?	①	②	③	④	⑤
2.2 the basic theory concepts behind the lab?	①	②	③	④	⑤
2.3 analysing and interpreting your results?	①	②	③	④	⑤
2.4 engineering topics not directly related to the lab?	①	②	③	④	⑤
2.5 general topics not related to the lab?	①	②	③	④	⑤
How satisfied are you with the student-instructor interactions?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩				

3. (*Student-Equipment Interactions*) Did you ...	**Never**	**Rarely**	**Occasionally**	**Frequently**	**Very frequently**
3.1 read the lab manual/instructions associated with this lab?	①	②	③	④	⑤
3.2 use the Internet for laboratory related tasks?	①	②	③	④	⑤
3.3 Operate the equipment for collecting the data	①	②	③	④	⑤
How satisfied are you with the student-equipment interactions?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩				

4. (*Indirect Interactions*) Did you learn in the lab by ...	**Never**	**Rarely**	**Occasionally**	**Frequently**	**Very frequently**
4.1 observing other students' experimental setup or behaviour	①	②	③	④	⑤
4.2 listening to other students asking for help/advice	①	②	③	④	⑤
4.3 listening to other students asking an instructor for help/advice	①	②	③	④	⑤
Were the indirect interactions useful to you?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩				

Appendix E: Observation protocols for using GORP tool

Type of Interactions	Student Code	Abbreviated Definition
Student-Student	SSP	Student-student talking about laboratory procedures, protocols and equipment etc.
	SST	Student-student discipline science concepts
	SSR	Student-student analysing their results
	SSU	Student-student talking about topics unrelated to the laboratory
Student-Instructor	LP	Students listening to the instructor lecturing about procedures
	LT	Students listening to the instructor lecturing about the theory behind the lab
	Rtw	Students listening to the instructor doing Real-time writing on board, doc cam, etc.
	SIP	Student-initiated talks with the instructor about procedures
	SIT	Student-initiated talks with the instructor about the theory
	SIR	Student-initiated talks with the instructor about result analysis
	STU	Student-teacher unrelated topics
	TIP	Teacher-initiated talks about procedures
	TIT	Teacher-initiated talks about a theory
	TIR	Teacher-initiated talks about results analysis
	TIG	Teacher talks about general topics
Student-Equipment	SLM	Students are reading the lab manual
	SA	Students manipulate apparatus
Indirect-interaction	SOBT	Students observing others' behaviours
	SLSS	Students listening to other students' conversations
	SLST	Students listening to another student talking to the instructor

Appendix F: Post-laboratory survey for first-year face-to-face laboratory (Perception of importance of interactions)

Reflecting on the laboratory class you just completed:
Significance: 1=Insignificant; 10=Extremely significant

1. (*Student-Student Interactions*) **How significant was talking to another student about…**	
1.1 the procedures, protocols or lab equipment?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
1.2 the basic theoretical concepts behind the lab?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
1.3 analysing and interpreting your results?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
1.4 engineering topics not directly related to the lab?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
1.5 general topics not related to the lab?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
What was your level of satisfaction with the above interactions?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

2. (*Student-Instructor Interactions*) **How significant was talking to instructor about...**	
2.1 the procedures, protocols or lab equipment?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
2.2 the basic theoretical concepts behind the lab?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
2.3 analysing and interpreting your results?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
2.4 engineering topics not directly related to the lab?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
2.5 general topics not related to the lab?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
What was your level of satisfaction with the above interactions?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

3. (*Student-Equipment Interactions*) **At what level of significance, did you...**	
3.1 read the lab manual/instructions associated with this lab?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
3.2 use the Internet for laboratory related tasks	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
3.3 operate the equipment for collecting the data	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
What was your level of satisfaction with the above interactions?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

4. (*Indirect Interactions*) **How significant was your learning by.....**	
4.1 observing other students' experimental setup or behaviour	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
4.2 listening to other students asking for help/advice	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
4.3 listening to other students asking an instructor for help/advice	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
What was your level of satisfaction with the above interactions?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

Appendix G: Post-laboratory survey questionnaire for remote-laboratory (Perception of importance of interactions)

1. (*Student-Student Interactions*) **How significant was talking to another student about…**										
the procedures, protocols or laboratory equipment?	1	2	3	4	5	6	7	8	9	10
the basic theoretical concepts behind the laboratory?	1	2	3	4	5	6	7	8	9	10
analysing and interpreting your results?	1	2	3	4	5	6	7	8	9	10
engineering topics not directly related to the laboratory?	1	2	3	4	5	6	7	8	9	10
general topics not related to the laboratory?	1	2	3	4	5	6	7	8	9	10
What was your level of satisfaction with the above interactions?	1	2	3	4	5	6	7	8	9	10

2. (*Student-Equipment Interactions*) **At what level of significance, did you...**										
use laboratory manual/instructions for conducting the experiment?	1	2	3	4	5	6	7	8	9	10
use the Internet for laboratory related tasks	1	2	3	4	5	6	7	8	9	10
feel you were operating a real equipment for collecting the data	1	2	3	4	5	6	7	8	9	10
feel difficulty in operating equipment via internet	1	2	3	4	5	6	7	8	9	10
What was your level of satisfaction with the above interactions?	1	2	3	4	5	6	7	8	9	10

3. (*Indirect Interactions*) **How significant was your learning by…..**										
observing other students' operation of the remote laboratory	1	2	3	4	5	6	7	8	9	10
listening to other students discussion	1	2	3	4	5	6	7	8	9	10
listening to other students asking an instructor for help/advice	1	2	3	4	5	6	7	8	9	10
What was your level of satisfaction with the above interactions?	1	2	3	4	5	6	7	8	9	10

4. Student Satisfaction	**Strongly disagree**	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
Working in remote laboratory is as equally effective as the other physical face to face laboratory?	1	2	3	4	5
I would like to do another laboratory experiment via internet	1	2	3	4	5
This laboratory has increased my interest in the subject matter	1	2	3	4	5
I am satisfied with the overall conduct of this laboratory	1	2	3	4	5

Would you like to provide any feedback for this remotely controlled laboratory?

Appendix H: Laboratory-activity description and brief overview of the instruction sheets used in Chapter 7

H.1 Overview of the laboratory activity

For both laboratory modes, the objective of the activity undertaken by students was to determine the relationship between the deflections of a simple beam of fixed dimensions and the downward force (load) applied to its mid-point and to confirm that the sum of the reactions at the support locations of the beam equalled the load applied. Students varied the applied load and measured the deflection of the beam at its mid-point while also recording the reaction forces at the support points. Further details of the experiment conducted in each mode are provided in Lal et al. (2018).

H.2 Conduct of the laboratory activity

H.2.1 Face-to-face laboratory mode

Students worked together in groups of three or four students using the equipment that had already been set up. After giving a safety briefing, a graduate teaching assistant instructed students on experimental procedures by giving a demonstration of the equipment's operation and the data-acquisition process; thereafter the students conducted their investigation during which they physically interacted with the equipment, for example, to change the load. The instructor remained available throughout the one-hour session to assist and answer questions from students. At the end of the session, students submitted a (group) report comprising their data, calculations, and analysis of their results.

H.2.2 Remotely-operated laboratory mode

Students worked together in pairs and accessed the equipment located at the University of Technology Sydney (UTS) using a PC via the internet (from Perth or Melbourne). At the start of the session, the instructor explained how to open the link to the remote equipment and the features of the graphical user interface (GUI) followed by an overview of the actual experimental procedure. The instructor then remained in the room, available for consultation, throughout the one-hour session. After the completion of the experiment, students were required to prepare laboratory report for submission one week later.

H.3 Summary (in order of presentation) of contents of the laboratory-instruction sheets

H.3.1 Face-to-face laboratory mode

1. Outline of the thoeretical concepts to be studied through the conduct of experiment
2. Basic definitions of the terms that form basis for the theoretical concepts
3. Schematic diagram to illustrate the experimental arrangement
4. Detailed step-by-step procedures to perform the experiment
5. Tables to assist students with collecting the required data from the experiment
6. Questions to guide students through the analysis of their the results after calculation
7. Marking rubric for the activity for both the instractor to grade the report and for students to understand the basis of the score they receive for their work

H.3.2 Remotely-operated laboratory

1. Aim of the experiment and the theoretical concepts to be studied
2. Schematic diagram of the experimental arrangement and a photograph of the remote equipment
3. An illustration of the web interface (GUI) that the students use to manipulate the equipment
4. Detailed procedures on connecting with the remotely set-up equipment
5. The necessary operational steps to collect the data
6. Tables and equation for data collection and its analysis
7. Analysis questions for students to consider so as to arrive at overall findings for the experiment

Appendix I - Laboratory Sheet survey

Please think about the laboratory 1a and 1b that you did today in the Unit MCEN 1000 and answer as best you can the following:	**Strongly disagree**	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
Reading the lab briefing sheet is an	①	②	③	④	⑤
I often referred to the lab briefing	①	②	③	④	⑤
I often referred to the lab briefing	①	②	③	④	⑤
The lab briefing sheet contained	①	②	③	④	⑤
The present lab briefing sheet is	①	②	③	④	⑤
I was satisfied with the contents	①	②	③	④	⑤

What improvements would you like to suggest in regards to

1. Theoretical concepts included in the briefing sheet

2. Instructions for laboratory procedures

3. Data collection and analysis of results

Please provide any other suggestions for improving the lab briefing sheet for a better lab experience.

Appendix J: Survey questionnaire for mapping interactions to EA laboratory learning outcomes

Reflecting on the overall laboratory experiences in your undergraduate engineering laboratories, for each of the 10 competencies, please rank (from 1 highest to 4 lowest) the importance of the interaction type to develop the competency described in column 1 of the table below.

EA laboratory learning outcomes	Interaction type			
	Student-Student Interaction (learning through discussions with other students)	**Student-Instructor Interaction** (learning through discussions with laboratory instructors)	**Student-Equipment Interaction** (learning through operation of equipment and from lab sheet instructions)	**Indirect Interaction** (learning through observation of or listening to other students and instructors interaction in the laboratory)
LO1. An appreciation of the scientific method, the need for rigour and a sound theoretical basis;				
LO2. A commitment to safe and sustainable practices;				
LO3. Skills in the selection and characterisation of engineering systems, devices, components and materials;				
LO4. Skills in the selection and application of appropriate engineering resources, tools and techniques;				
LO5. Skills in the development and application of models;				
LO6. Skills in the design and conduct of experiments and measurements;				
LO7. Proficiency in appropriate laboratory procedures; the use of test rigs, instrumentation and test equipment;				
LO8. Skills in recognising unsuccessful outcomes, diagnosis, fault finding and reengineering;				
LO9. Skills in perceiving possible sources of error, eliminating or compensating for them where possible, and quantifying their significance to the conclusions drawn;				
LO10. Skills in documenting results, Analysing credibility of outcomes, critical reflection, developing robust conclusions, reporting outcomes				

Appendix K: Associated research conducted

An alternative approach to student assessment for engineering-laboratory learning

Statement of Contribution to Co-authored Published Journal Article

This Chapter is the content of a peer reviewed journal article "An alternative approach to student assessment for engineering-laboratory learning", published in the *Australasian Journal of Engineering Education* in 2017.

I, Sulakshana Lal, as the primary author, conducted all the work of data collection and data analysis, including creating figures and tables, and writing and editing the manuscript.

I, as a Co-Author, endorsed that this level of contribution by the candidate indicated above is appropriate.

Anthony D. Lucey

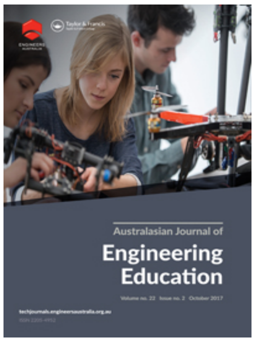
Euan D. Lindsay

Priyantha R. Sarukkalige

Mauro Mocerino

David F. Treagust

Marjan G. Zadnik



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An alternative approach to student assessment for engineering–laboratory learning

Sulakshana Lal[a], Anthony D. Lucey[a], Euan D. Lindsay[b], Priyantha R. Sarukkalige[a], Mauro Mocerino[d], David F. Treagust[c] and Marjan G. Zadnik[d]

[a]School of Civil and Mechanical Engineering, Curtin University, Perth, Australia; [b]Faculty of Engineering, Charles Sturt University, Bathurst, NSW, Australia; [c]School of Education, Curtin University, Perth, Australia; [d]School of Science, Curtin University, Perth, Australia

ABSTRACT
Assessment of students' performance in laboratory activities evaluates students' achievements and weaknesses in practical work. This is vital from both student and institutional perspectives. Practical skills assessment methods evaluate students on three major components: the ability to collect data and perform calculations, to analyse the cause of failures in the process, and finally students' active engagement and participation in the practical work. A conventional, report-based, assessment method combined with an alternative method, termed in-class assessment, were developed and used for second-year Fluid Mechanics laboratory work. In this article, we describe these two approaches and present the results of a quantitative investigation of students' responses. Students expressed similar experience and satisfaction levels for each of the assessment methods that measured the attainment of different but essential personal and professional skills stipulated by the professional body for students graduating with an engineering degree. These skills include the development of research skills, conceptual understanding, application of techniques, preparing a report, team working abilities and the communication skills needed to interact with peers and demonstrators effectively. This article shows that the use of in-class assessment can serve as a useful complement to conventional report-based assessment methods ensuring optimal laboratory learning for students across engineering knowledge and skills areas.

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KEYWORDS
Engineering laboratories; assessment method; in-class assessment; report-based assessment; laboratory skills

1. Introduction

Laboratory work is an integral component of engineering education (Feisel & Rosa, 2005; Ma and Nickerson 2006; Saniie et al. 2015) and hence the engineering curriculum (Lindsay and Good 2005). Engineering laboratories not only focus on clarifying concepts conveyed through theoretical models but they also permit the development of the overall personal attributes essential for professional practice in students' future engineering careers (Feisel and Rosa 2005). Engineers Australia accreditation guidelines (2008) also express the requirement for institutions to set up proper experimental arrangements so as to meet the expected outcomes from laboratory learning. There are 10 distinct learning outcomes from laboratory work specified in the accreditation guideline that highlight aspects such as instrumentation, models, experiment, data analysis, design and creativity (Couteur 2009; Engineers Australia 2008; Feisel and Rosa 2005; Hofstein and Lunetta 1982).

Essential practical skills in a laboratory can be attained in a systematic order. According to Kolb's Cycle, the laboratory learning process mainly involves the grasping of knowledge before experimentation and transformation of that knowledge during experimentation in the laboratory (Abdulwahed and Nagy 2009). They assert that knowledge acquisition in the laboratory takes place when attempts are made to develop concrete knowledge of a topic on the basis of abstract concepts underpinning that knowledge acquired prior to commencing the practical work. This process can be viewed as two basic steps. First, students develop a tentative idea of what they are about to learn and observe in the laboratory as well as what is expected from them during the work they perform, typically through the laboratory briefing sheets provided to the students. Second, demonstrations by the laboratory instructor, conducting the experiment themselves, and, finally, assessment of the work performed and knowledge gained, all help students to transform and realise the concepts that they assimilated before performing the actual laboratory. Learning through laboratory work is effective when both the above two steps occur together. One of the ways to ensure this is by implementing appropriate methods of assessment for laboratory learning.

CONTACT Sulakshana Lal s.lal2@postgrad.curtin.edu.au

Present-day engineering laboratory activities are mature in their design. They provide opportunities to students ranging from performing an experiment in groups in a laboratory to designing a model independently, with different skills to be acquired in each step of the laboratory activity (Feisel and Rosa 2005). Ascertaining students' skills attainment in the learning process is as important as designing the instructions for learning. Evaluation of the students' attainments of practical skills and performance in the laboratory occurs mainly in two stages: during the laboratory session and after the laboratory session. Assessments which are carried out during the laboratory session are called assessment for learning and those carried out at the end of laboratory sessions are called assessment of learning (Hunt, Koenders, and Gynnild 2012; Wiliam 2011). Both these modes have their own advantages and disadvantages. They are also sometimes referred as formative and summative assessments, respectively, although the purpose and context of their use can vary. Generally, formative assessments help identify areas of student improvement through teaching and learning practices in the laboratory while summative assessments merely inform the instructor of the level of student performance in the laboratory (Wiliam 2011).

Gregory & Morón-García (2009) found that report-based assessments are popular at undergraduate level studies allowing students to learn time management and workload management skills. These practices are not found to consider students' perspectives, their experiences and attitudes as part of the implementation process. The use of such assessment methods are solely determined by convenience to the educational institution in terms of ease of applicability and resource friendliness. However, educational research and discussion among academics have led to reform in this practice over the years (Boude and Dochy 2010; Evans 2013).

Assessment in any context not only assesses whether students' learning is aligned with the expected learning outcomes but also whether the instructional design of the laboratory actually serves the attainment of the learning outcome. Assessments are also important for monitoring students' progress and development (Bone 2010; Caspersen, Smeby, and Olaf Aamodt 2017; Ross, Brown, and Torabi 2017; Williams 2014) as well as making the teaching and learning process a motivating journey for both student and teacher. Students are strongly driven by assessment and the feedback that they receive on their assessment task (Nicol and MacFarlane-Dick 2006; Torrance 2007). Students are able to acknowledge their shortcomings and then work on the right areas for improvement and their development (Olds and Miller 1998). The assessment also helps students to determine the right approach to laboratory learning (Jones 2005; Olds and Miller 1998). As a consequence, there is much active debate over why and how students' learning should be assessed (Guskey 2003; McColskey and O'Sullivan 2012; Olds and Miller 1998; Ross, Brown, and Torabi 2017; Sadler 2005; Stassen, Doherty, and Poe 2001; Williams 2014). Theoretical assessments are purely content-based and do not cover areas such as personal and professional development. By contrast, the assessment of practical work (Derek 1992; Hofstein and Lunetta 1982; Olds and Miller 1998) can include all aspects of learning such as content knowledge, team-building and collaborative skills, analytical skills, communication skills and error analysis to name a few (Caspersen, Smeby, and Olaf Aamodt 2017; Ramírez et al. 2014). Accordingly, laboratory learning and its assessment offer much greater scope for inculcating and reinforcing the attributes required of engineering graduates.

In this article, we offer a model for the design of laboratory class assessment and then apply this to the practical work programme of a second-year engineering unit. The effectiveness of the assessment regime is then studied through the lens of student experience and its ability to account for the diverse range of engineering skills that students are able to develop through laboratory learning.

2. Model for designing a laboratory class assessment method

In order to understand how the design of a laboratory assessment method is relevant to the laboratory learning environment, we used and modified the Model of Educational Reconstruction (MER) (Duit et al. 2012), which emphasises the following essential aspects required for an effective teaching and learning process:

- Clarification of the subject matter and analysing the educational significance of the chosen subject matter;
- Accounting for both teachers' and student's perspectives including students' prior knowledge of the subject, their attitudes, skills and interests in the subject matter; and
- Combining the above two aspects to design and evaluate a learning environment that is appropriate for teaching and learning to take place.

In the present study, we focus on assessment method and its significance for students' learning in the laboratory, rather than clarifying the subject matter and analysing the significance of that subject matter. Based on the Model of Educational Reconstruction, the design of an assessment method can, in general, be depicted schematically in Figure 1. There are three important components involved in the design of an assessment method for a laboratory class that we describe as follows.

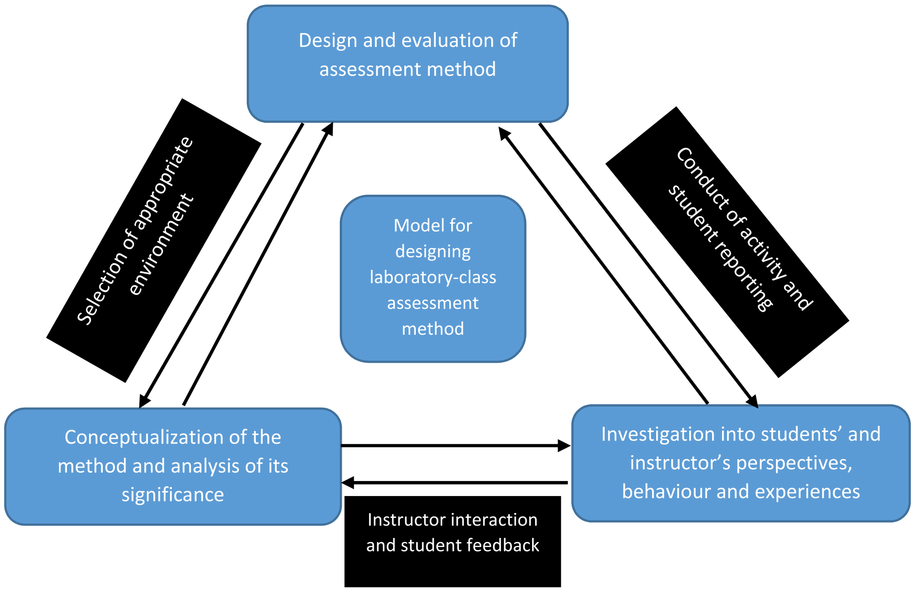

Figure 1. Model for designing a laboratory class assessment method.

2.1. Conceptualisation

The design is generally initiated by the faculty, who develop certain specific grounds and criteria for assessing students' learning from the laboratory experiments. This is an important step as the courses at the institutions require compliance with the guidelines provided by accrediting bodies, such as Engineers Australia in the context of Australian Universities. Assessment, therefore, plays a significant role in ensuring that students learn and acquire a set of skills prescribed by the accrediting body. Olds and Miller (1998) propose the consideration of few basic questions before designing or developing an assessment method; these are 'What are the program objectives?' and 'What should students know and be able to do when they complete the program'. Based upon the answers to these questions, along with a clear analysis of the significance of its implementation in laboratory education, the faculty proposes a certain conceptual framework to design an assessment method for the evaluation of laboratory work.

2.2. Design and evaluation

A clear concept of the design for an assessment method, with possible correct and appropriate alternatives, leads to designing the actual assessment method. This process is accompanied by the evaluation of the design in terms of validity and reliability measures. An important step in this process is the selection of appropriate environments for implementing the proposed assessment method.

The assessment method designed should reflect the nature of the task and type of laboratory being assessed. The learning outcomes measured by the assessment method should also align with the competencies required by the accrediting body to ensure that the students are acquiring the right skills for their future professional careers. This is then followed by the actual implementation of the assessment tool in the laboratory classes, through rigorous instructor interactions in the laboratory, and allowing students to conduct experiments in the laboratory, based on the concept that underpins the assessment method.

2.3. Investigation of students' experiences and perceptions

In order to obtain information regarding the effectiveness of the assessment method, it is necessary to investigate students' perspectives, their behaviour during the assessment and finally their experience of the assessment method used in the laboratory. This can be carried out in numerous ways. The most commonly used methods are qualitative and quantitative surveys. This provides two important types of information. First, the benefits and drawbacks of using the assessment method in the laboratory skills assessment can be identified, and second, the satisfaction level of students undergoing the assessment is measured. The former information leads to the redesign or improvement of the assessment tool while the latter provides feedback on students' ability and motivation to construct their knowledge of the topics explored in the laboratory activity. Refinements of the tool to address both types of feedback may modify the original concept and thus enhancements to the assessment design occur through an iterative process.

2.4. Further design factors

It is also remarked that any assessment tool designed using this model must align assessment with the learning outcomes of the laboratory. A further design constraint is that the assessment method should be simple and convenient to use within the specified time limit of the intended laboratory. Laboratory instructors' ease of adoption of the method and their ability to implement the method within the specified time period allocated to the laboratory activity should also be considered during the design process.

3. Research questions

To illustrate the application of the foregoing process, the remainder of this article describes, as an example, the design of assessment methods for a second-year engineering laboratory programme, in doing so presenting students' experience and satisfaction when assessed using two different modes of assessment within the programme.

The study, therefore, serves to answer the following questions.

(1) How should students be assessed in the engineering laboratories so as to measure the essential practical skills attainment as required by Engineers Australia for graduate engineers?
(2) Does the mode of assessment affect students' activities in the laboratory and the marks they are awarded?
(3) How does the assessment method affect students' satisfaction with their laboratory work?

4. Design of assessment comprising in-class and report-based methods for an engineering laboratory programme

Herein, we first describe separately the mechanisms of the two different methods, namely in-class and report-based, used in the assessment of laboratory learning and offer review comments based upon observations of their implementation. Thereafter, we show how these combine to create the overall assessment of the laboratory programme of the second-year engineering course in Fluid Mechanics at Curtin University, Australia, taken by students in the sub-disciplines of Chemical, Civil, Mechanical, Mining and Petroleum Engineering. Students observed were a multicultural cohort with male predominance. Both the laboratory sessions were instructed and assessed by 5 sessional staff members and there were 10 laboratory sessions per week run by these five sessional staff. The main activities in the fluids laboratory include operating equipment such as that shown in Figure 2, using instrumentation to collect data, processing data to obtain the overall results and the interpretation of these results.

4.1. *In-class assessment method*

The in-class assessment concept has been designed to assess students' performance within the laboratory session focusing on aspects such as data capture, its synthesis and the ability to draw inferences through a discussion of questions that follow the completion of the experimental investigation. There are three sets of experiments in this laboratory session, namely: (1) Stability of floating bodies; (2) Investigation of Bernoulli's equation in a closed water circuit; and (3) Discharge (Flow rate) measurement using different devices. The equipment used for experiments 1 and 2 is illustrated in Figure 2 below.

The score from the in-class assessment contributes 30% of the total laboratory programme marks for the unit. In the two-hour laboratory session, there are typically 12 students who are divided into 3 groups with a maximum of 4 students in each group. Since the assessment is purely on the basis of the students' laboratory performance and their understanding developed in the laboratory, students do not need to learn

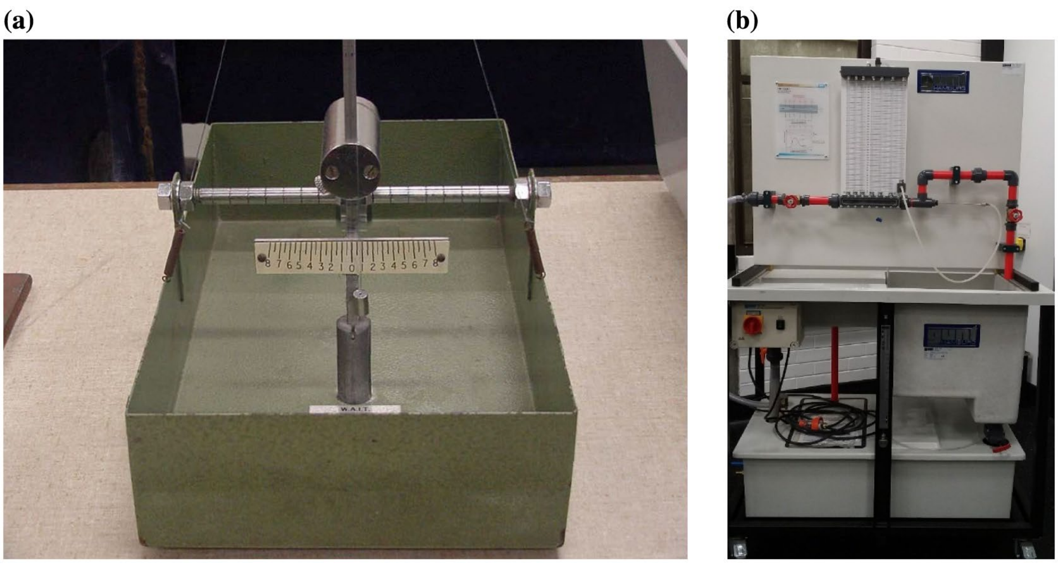

Figure 2. Types of equipment used by students in the laboratory work for: (a) Stability of floating bodies, and (b) Investigation of Bernoulli's equation in a closed water circuit.

any underlying theory prior to perform the experiments. Students receive a live demonstration of the experiments from their instructor for approximately 35 min and also obtain the first set of data from the demonstration itself. Thus, students not only learn how to perform the experiment but also get a glimpse of the nature of the data-sets expected from each of the three experiments. They then spend their own 'discovery' time totaling about one hour for the experiments to obtain a complete set of data for each. With the data in hand, students utilise a further 30 min undertaking calculations (data synthesis) and analyse the discussion questions posed in the laboratory briefing sheet; the latter generates rigorous consultation and discussion amongst the group members. In general, the concept of the in-class assessment is simple to understand and implement for both students and instructors in any laboratory. An example of the in-class assessment tool for just one of the three experiments is presented in Appendix 1.

During the session, the instructors also perform calculations on the data obtained by each group using an Excel spreadsheet which is later used to evaluate the accuracy of the students' calculations. Each group has to submit just one completed laboratory sheet with calculations and discussions for the three experiments. The instructor finally scores the students' performance on the grounds of accuracy and their understanding or inferences drawn from the phenomena that each experiment illustrates. Each member of the group receives the same score, reflecting the need for cohesive teamwork. This means each student in a particular group is adjudged to have performed in an identical way unless there is clear evidence of non-participation or inactive participation as observed by the instructor. Students have the freedom to distribute tasks among the group members and also the opportunity to share their knowledge and experience. Finally, the group receives their assessment mark and any oral feedback on their work at the end of the laboratory session. Not only does this provide immediate feedback to students but it also obviates post-laboratory marking work for the instructor which is beneficial for the institution in terms of human and financial resource costs.

The design of the in-class assessment method is effective in terms of focus upon its objectives, namely the inculcation of student skills in the engineering sequence of: conduct of experimental procedure, data capture, data synthesis and inference of concepts. However, there are some visible drawbacks which should inform the iterative process of improvement, most notably due to the pressures of the time limit and the number of activities planned within the session. While working under tight time constraints is a feature of professional engineering work, the quality of students' learning process can be compromised. For example, the time constraint in the present design denied students the opportunity to review their data and/or recalculate in the case of outliers or errors. The time constraint may also put instructors under pressure to complete the assessment thereby diminishing their role as teachers. It is clear that when implementing this method of assessment, careful planning should be used to determine what can feasibly be achieved within a time-constrained laboratory activity.

4.2. Report-based (conventional) assessment method

For the second session of the laboratory programme of the Fluid Mechanics course, a conventional assessment method is used. In the second laboratory students study flow through pipes, the objective being to understand laminar and turbulent flow regimes following the exposition of these concepts in the lecture series. Working in groups (again, typically four students), students perform the experiment and collect data after receiving a thorough demonstration from the instructor. At the end of the experimentation phase, the instructor explains how to prepare the laboratory report which each student has to submit individually within two weeks of completing the laboratory activity. This session is also designed within a two-hour time period. In this method of assessment, students and demonstrators do not interact with each other during the assessment process. Students' marks are purely based on the quality and content of the laboratory report that they prepare. However, a marking rubric, based on the development of the Engineers Australia Stage 1 competencies (Engineers Australia 2011), is provided. These competencies include the ability to write scientific reports, interpret data logically and correctly, use of theory to understand experimentally observed phenomena and apply written and diagrammatic communication skills. The mark for this laboratory contributes 70% of the total laboratory programme marks for the course.

In this method of assessment, like that of the in-class method, students know the criteria upon which they are being assessed. However, in the case of report-based assessment, students are less likely to make mistakes as they have post-session access to help during the period in which they prepare their report. There is also greater opportunity to reflect upon and review the work in their report, although they cannot revisit the experiment. Because assessment occurs after the laboratory session, the pressure to conduct data synthesis is reduced and students ostensibly get more time to spend on the practical aspects as compared with the first laboratory session that used in-class assessment. Nevertheless, a disadvantage of report-based assessment is that the mark given by the instructor often reflects the amount of effort put into preparing the report but not how students performed or actively learned from the practical work they performed. Additionally, authenticity checks for authorship can be difficult to carry out. Finally, although professional and team-working development skills are part of the laboratory learning objectives, they are difficult to measure through the conventional report-based assessment method (Hunt, Koenders, and Gynnild 2012).

4.3. Design objectives behind the in-class and report-based assessment methods

The in-class assessment method requires each student to have become familiarised with the equipment and its instrumentation process after the completion of the practical work. We remark that it does not measure students' level of adaptation of strict procedural instruction. The most clearly measured aspect of student learning is their ability to collect and record data accurately as captured in the group's laboratory briefing sheet. Marks assigned to each section in the laboratory sheet encourage students to critique their own collected data. Students generally tend to verify their data through comparison with those of other groups in the laboratory; this form of verification (reproducibility) is valid and promotes communication skills applied to the discussion of engineering work. The in-class assessment method also compels students to learn how to synthesise data by following a set of instructions given by the instructor together with those already provided in the laboratory briefing sheet. The discussion questions at the end of laboratory briefing sheet assess their ability to identify and interpret trends in collected data and synthesised results. This also assesses their ability to identify or infer the physical phenomena and their causes from observations made during experimentation and through the data collected during the process. This practice assists students in developing the ability to apply knowledge learned during the laboratory work to a different but related application in future.

Since the in-class assessment is a group assessment, each section of the laboratory sheet demands group collaboration. Students' discussions within their group generally focus on calculations (data synthesis) and answering the discussion questions (inferences drawn) so as to come to a consensus and complete the work within the specified time limit. This process develops the ability of students to communicate with team members and optimise the group's workflow to meet a deadline. During the assessment process, students are asked to elaborate on their calculations and discussion in front of the instructor (Ross, Brown, and Torabi 2017). This assesses students' ability to communicate the results obtained from the experimental work.

While the in-class assessment method measures the ability to use appropriate techniques in an engineering laboratory, the much more commonly used report-based individual assessment method measures compliance against a different group of Engineers Australia Stage 1 competencies for a professional engineer (Engineers Australia 2011). Report-based assessment mainly focuses on aspects such as development and research, conceptual understanding and use of techniques applied in preparing the report and, only implicitly, communication ability when working in groups and interacting with peers and instructors effectively. Accordingly, the combination of the two assessment methods can serve to measure most of the major personal, professional and technical skills required by Engineers Australia (Engineers Australia 2008) for students graduating with an engineering degree.

Appendix 2 tabulates the 10 EA learning objectives along with the corresponding assessment methods assessing those objectives.

5. Investigation of students' experience and satisfaction

5.1. Research method and participants

The quantitative research method is applied by means of a survey questionnaire (Creswell 2013). Closed-ended questions are included to ascertain students' participation and engagement at various levels in the two Fluid Mechanics laboratory sessions described in Section 4. The data were collected in Semester 1 2017. Students received the survey form after completing the second laboratory session in which the conventional report-based assessment was used, noting that the in-class assessment method was used in the first laboratory session. The survey forms were completed only at the end of the second laboratory because the questions are mostly couched in the form of a comparison of various aspects of the two laboratory sessions. The survey questions covered such aspects as preparation, active participation or teamwork both during the practical work and for completing the task or assessment. A total of 10 polar type questions were posed. A further focus of the questionnaire was on student satisfaction measured on a scale of 1 to 10, where 1 represents 'Not satisfied' and 10 represents 'Extremely satisfied' (see Appendix 3 for the sample of the survey form). A total of 263 students responded to the survey conducted over a period of five weeks of laboratory sessions. Students' laboratory marks in the two laboratory sessions were also considered in order to study the effect of the assessment methods on student learning.

5.2. Results and discussion

Out of 263 students, 259 students responded to all of the questions in the survey form. The results are presented in Table 1 that quantifies both positive and negative responses for the overall class as percentages of the total cohort survey (hence the absence of some responses, noted above, means that in a number of cases these do not sum to 100%).

Table 1. Students' recorded responses (as %) to the questionnaire.

		Overall students' response				
		Yes		No		
Areas of assessment	Basic laboratory activities	In-class	Report-based	In-class	Report-based	*z*-value
Preparation	Read laboratory instruction	85	74	15	23	−1.39
	Read relevant lecture materials	70	63	29	32	−0.23
Active participation/team work	Talk to peers/demonstrator	98	93	2	2	−1.96
	Control equipment yourself	92	70	7	25	−4.11*
	Record readings yourself	95	91	3	5	−0.16
	Find measurement errors	56	58	43	37	−2.84*
	Repeat task/measurements	52	56	47	40	−2.91*
Completion of task/assessment	Complete calculations in laboratory	84	68	15	26	−1.60
	Discussion for activity/report	86	85	11	8	−2.72*
	Sufficient time for the task	69	89	29	5	−7.38*

*p-value < 0.05.

It is evident from Table 1 that most of the students responded positively to the questions asked in the survey. This can be considered, as a whole, an encouraging response towards both of the assessment methods used for laboratory work assessment. Students reported that they are well prepared for the activities and seem to participate actively in the laboratory work. However, many students (above 40%) reported that they were not provided with suitable opportunities to find reasons for errors in their measurements and/or repeat tasks or measurements in the laboratory in both modes of assessment. These two aspects are important for students learning from laboratory work. These negative responses reflect inadequacies in both assessment methods suggesting the need for design improvements. Students' responses also reveal that they perceive that they have successfully attained some important skills, required by Engineers Australia, such as communication for task completion and group collaboration; both assessment methods exhibit significant social interaction (Lowe et al. 2009; Park et al. 2017) and active engagement in the laboratory.

A Wilcoxon signed rank test was performed to test the significant difference in responses for each item in the survey and the z-value obtained for each item has been added to Table 1 above with a * beside those which were statistically significant with p-value < 0.05. The test results show that differences in the response for controlling the equipment ($z = -4.11$), finding measurement errors ($z = -2.82$), repeating task or measurement ($z = -2.91$), discussing the activity or report preparation ($z = -2.72$) and finally sufficient time for task ($z = -7.38$) were statistically significant. Further features of the results in Table 1 are discussed below.

In order to compare students' preparedness and active engagement encouraged by the two assessment methods, only the positive response data from Table 1 are plotted in Figure 3 below; this form of visualisation (of the same data) has its emphasis upon student engagement in the overall laboratory activity process.

While the two forms of assessment yield broadly similar bar-chart profiles, we note the following differences. Figure 3 shows that students report that they are slightly better prepared for the laboratory session when

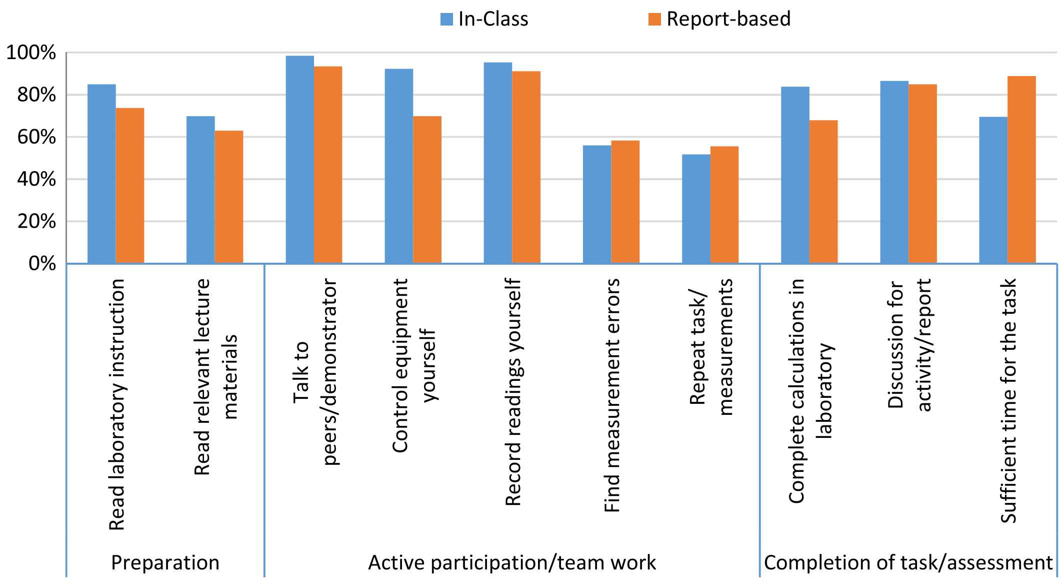

Figure 3. Comparison of students' preparedness and engagement in the two assessment methods.

the in-class assessment is used. The in-class assessment method also provided significantly better opportunities for students to control equipment individually and take the necessary data readings. By contrast, the opportunity to detect errors in measurements and repeat tasks and/or measurement was slightly better when the post-session report-based assessment was used wherein students also found that they had significantly more time to complete the laboratory task. Critically, many students reported that they did not have sufficient time to complete their tasks when the in-class assessment method was used for the first laboratory. Features observed in Figure 3 are in agreement with the statistical results obtained in Table 1.

As shown in Figure 4, students' satisfaction levels for both types of assessment method are similar. However, students seem to be slightly more satisfied with the conventional report-based assessment. The most common rating given for the assessment methods was 8 in both modes of assessment, 26% for in-class and 30% for report-based assessment methods. The average satisfaction levels found for in-class and report-based assessment are 7.71 (SD = 2.01) and 8.37 (SD = 1.3), respectively. It should be noted that a very small proportion of students was dissatisfied with the conventional method of assessment and about 11%, appeared to be dissatisfied with the in-class assessment method.

Overall, most students reported their satisfaction with both modes of laboratory learning assessment. This may be due to the fact that both assessment methods allow students to perform across all aspects of the laboratory activities at an almost similar level of familiarity. Gray & Diloreto, (2016) have indicated that student satisfaction is strongly influenced by the time given for task completion. The over-riding factor for dissatisfaction with the in-class assessment method also seems to be the time allotted for conducting the laboratory activities and their assessment. This is reflected by some students' comments communicated through the open-ended feedback section of the survey form, examples of which are:

Time was really less to do calculations and explanations,

Not enough time in the first lab to complete the in-class assessment,

Lab 1 provided very limited time to complete calculations and questions

The average laboratory marks obtained by students through in-class and report-based assessment methods were 89.0% (SD = 9.9%) and 73.6 (SD = 16.9%), respectively. Students' attainment of higher marks in the in-class assessment can probably be attributed to the fact that students worked and were assessed in groups for in-class assessment while there was a significant individual effort in the report-based assessment. The higher standard deviation arising from the report-based assessment method also reveals a greater variation in scores among students because students were assessed on an individual basis. Thus, for example, there were students who scored full marks in the laboratory with in-class assessment and scored as low as 24% in the report-based assessment. What can be deduced from this data is that the in-class assessment does not disadvantage students in terms of the marks that they receive. It is to be noted that there is a possibility that face-to-face marking could yield higher scores because of personal dynamics at work in the student–instructor interactions. However, observations indicated that even students who performed less well accepted the scores without dispute. Therefore, instructors seemed to be unafraid of marking objectively.

5.3. Observations

Informal observations of student behaviour during the first laboratory session that utilised in-class assessment suggested that some students compromised their learning experiences. In particular, students sometimes divided their tasks among the four group members with, for example, two students in the group focused solely on data collection while the other two students involved themselves in the calculations. Thus, the overarching objective of the group was to complete the tasks within

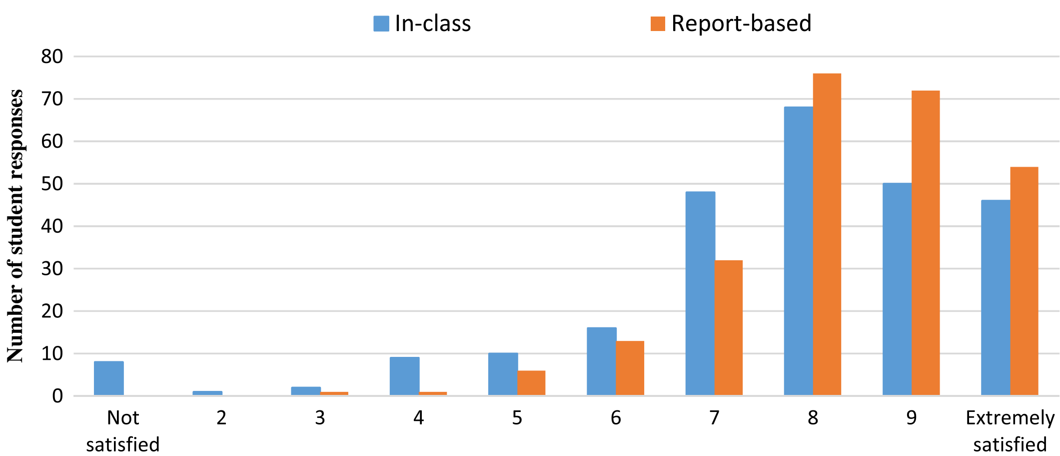

Figure 4. Students' satisfaction for in-class assessment and conventional report-based assessment.

the given time limit as opposed to learning how to perform an experiment and explore their understanding of the phenomena illustrated by the experiment. This behaviour, while optimising team work for task completion, was not an intended outcome of the design of the in-class assessment method. Similar instances were not observed in the second laboratory session in which time constraints were far less pronounced.

5.4. Overall findings and implications

Both the in-class and the conventional report-based methods assess students' performance in laboratory work and promote the development of essential skills expected of students when undertaking practical work. The marking rubrics for the two assessment methods clearly differ but each aligns with a subset of the Engineers Australia attributes of engineering graduates. Given that the student survey results show similarities in students' experience and their satisfaction level, the use of in-class and report-based assessment methods within the overall laboratory programme complement each other. Accordingly, their combined application in engineering laboratory learning is able to foster the development of a wider range of personal, professional and technical skills through laboratory learning as compared with the use of just (the currently predominant) report-based assessment method.

Notwithstanding the above recommendation, the addition of in-class assessment methods requires careful thought regarding the scope and scale of activities that can be realistically completed and assessed within a time-bound laboratory session. In the example of the present study, reducing the number of experiments in the first laboratory session could probably give more time for students to reflect upon and analyse the procedures and results obtained. Removing the excessive pressure (as identified through the student experience) to complete the activities would also provide increased opportunities for every student in a group to participate in each aspect of the activity. This would have the additional advantage of making the single mark awarded reflect more accurately the laboratory learning of each of the group's members.

6. Conclusions

The Model of Educational Reconstruction has been adapted and used to formulate a conceptual framework for the design of assessment for laboratory learning. This framework has then been used to design the assessment regime for the laboratory programme of a second-year Engineering Fluid Mechanics course at Curtin University. The novel feature of the resulting design is that it adds an in-class assessment method to the commonly used report-based assessment method across the sequential laboratory sessions undertaken by students. The in-class assessment of the first session is complementary to that of the report-based assessment in that its focus is upon promoting and rewarding the development of skills required in the actual conduct of practical work in a team work setting. These are critical skills for graduate engineers who will inevitably find themselves working on, operating or supervising practical processes in their careers. In contrast, a conventional assessment that requires an individual report to be submitted after carrying out the laboratory has a bias towards the application or reinforcement of concepts already taught in lectures and upon a student's report writing skills. A further difference is that in-class assessment provides immediate, and most often formative, feedback to students, whereas report-based assessment tends to be summative in practice.

The combined in-class and report-based components have been implemented in the laboratory programme and the resulting student experience quantitatively studied using a survey tool. The results of this investigation suggest that students prepare better when the in-class assessment is applied and that their interactions with equipment in the laboratory are greater. By contrast, when the report-based assessment is used students tend to focus more on obtaining a results data-set that they will analyse after the laboratory session. The survey results also indicate that there is very little difference in students' stated satisfaction levels between the two methods. Consideration of class marks awarded through the two methods reveals that instructors awarded higher scores using in-class assessment with a lower variance. This is probably due to the fact that the in-class mark was for group work whereas the report-based assessment was at an individual student level although students carried out the experimentation in groups. The most significant negative feedback on the use of in-class assessment arose from the fact that many students were pressured by the time constraint in which to complete their work and have it assessed. Clearly, careful consideration needs to be given so as to form realistic expectations of what can be accomplished within the session.

Overall, the findings of the present article suggest that the assessment of laboratory learning addresses a more comprehensive set of student attainments and fosters the development of a broader set engineering graduate attributes when a combination of in-class and report-based methods are used and that this is a practical approach from both institutional and student perspectives.

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Notes on contributors

Sulakshana Lal is a second-year doctoral student in Engineering Education at Curtin University in Perth, Western Australia.

Anthony D Lucey is a John Curtin Distinguished Professor, Dean of Engineering and Head of the School of Civil and Mechanical Engineering at Curtin University.

David F Treagust is also a John Curtin Distinguished Professor in the School of Education at Curtin University.

Euan Lindsay is the Foundation Professor of Engineering at Charles Sturt University in Bathurst, NSW.

Ranjan Sarukkalige is a senior lecturer in the Department of Civil Engineering and postgraduate coordinator in Civil Engineering at Curtin University.

Mauro Mocerino is an Australian Learning and Teaching Fellow and Coordinator of Chemistry post-graduate course-work at Curtin University.

Marjan Zadnik is assistant professor from the Department of Physics and Astronomy in the School of Science at Curtin University.

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Appendix 1. Sample of assessment form used for in-class assessment

Experimental Results and Calculations

Dimensions	(mm)	Mass	(gram)
Length	357mm	Movable mass (W_j)	200g
Breadth	205mm	Mass of assembled pontoon (W_p)	4200g

Distance of moveable mass from centre (x)	Angle of heel C.G1 =…….mm		Angle of heel C.G2 =…….mm		Metacentric height W_j . x $GN =$	
Distance (mm)	8_{degree}	8_{radian}	8_{degree}	8_{radian}	C.G1	C.G2
RIGHT (+ve)						
0						
10						
30						
60						
LEFT (-ve)						
20						
40						

[6 marks]

Discussion:

1. Does the position of the metacentre depend on the position of Centre of Gravity?

[1 mark]

2. Does the metacentric height vary with angle of heel?

[1 mark]

3. Active engagement, participation and team work

[2 mark]

(Total 10 marks will be offered for experiment # 1)

Appendix 2. Mapping of 10 EA learning objectives with the two assessment methods

10 Learning objectives from EA accreditation guidelines	13 learning objectives from Feisal & Rosa (2005)*	Assessments methods satisfying the learning objectives
1. An appreciation of the scientific method, the need for rigour and a sound theoretical basis	Models	In-class assessment and report-based assessment
2. A commitment to safe and sustainable practices	Ethics in the laboratory	
3. Skills in the selection and characterisation of engineering systems, devices, components and materials	Instrumentation	
4. Skills in the selection and application of appropriate engineering resources tools and techniques	Psychomotor	
5. Skills in the development and application of models	Models	
6. Skills in the design and conduct of experiments and measurements	Design	In-class assessment
7. Proficiency in appropriate laboratory procedures; the use of test rigs, instrumentation and test equipment	Experiment	In-class assessment
8. Skills in recognising unsuccessful outcomes, diagnosis, fault finding and re-engineering	Learn from failure	In-class assessment and report-based assessment
9. Skills in perceiving possible sources of error, eliminating or compensating for them where possible, and quantifying their significance to the conclusions drawn	Data analysis	In-class assessment and report-based assessment
10. Skills in documenting results, analysing credibility of outcomes, critical reflection, developing robust conclusions, reporting outcomes.	Data analysis, communication	In-class assessment and report-based assessment

*teamwork, sensory awareness, creativity are covered in the professional competencies standard mentioned in Engineers' Australia, (2008) document.

Appendix 3. Survey questionnaire form

ENGR2000 – Fluid Mechanics laboratory –2017 - Semester 1

Comparison of in-class assessment lab (Lab # 1) and post-class assessment lab (Lab # 2)

Lab group:…………………… Date of the lab………………………………………

Reflecting on the laboratory classes you have completed (lab # 1 – In-class assessment and present lab (lab #2) – report-based assessment), please put your view/comments/thoughts on the following aspects for both labs

1. To register a response completely, **fill the bubble ● with a blue or black ballpoint pen**.
2. If you make an error, cross out the unwanted response ✕ and completely fill the circle to your corresponding wanted response.
3. Do not make any other stray marks on the page.

	Lab # 1		Lab # 2	
(Preparation): Before you attend the lab, did you				
Read the laboratory instruction sheet/notes	⊖	●	⊖	●
Read the relevant lecture materials	⊖	●	⊖	●
(Active participation/Team work): Did you,				
Talk to group members/demonstrator	⊖	●	⊖	●
Control the equipment/experimental rigs yourself	⊖	●	⊖	●
Record the measurements/readings yourself	⊖	●	⊖	●
Find any measurement errors	⊖	●	⊖	●
Repeat any task/measurements	⊖	●	⊖	●
(Completion of task/Assessment): Did you,				
Complete the calculations within the class time	⊖	●	⊖	●
Discuss the activity/report content with your	⊖	●	⊖	●
Have sufficient time for the task set	⊖	●	⊖	●

To what extent were you satisfied with the <u>method of assessment</u> (Not the outcome/marks)

Please indicate your response (1- not satisfied, 10- extremely satisfied)

In-class (Lab #1)

1 2 3 4 5 6 7 8 9)

Post-class (Lab # 2)

1 2 3 4 5 6 7 8 9)

<u>Please provide any other feedback on the assessment process:</u>