School of Molecular and Life Sciences

Analysis and Characterisation of Interactions in Face-to-Face and Remote-Access Chemistry Laboratories

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Doctor of Philosophy

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Declaration

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.

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

Human Ethics The research presented and reported in this thesis was conducted in accordance with the National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number # RDSE-61-15

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Abstract

Laboratory classes have long been seen as a critical component in science and engineering learning and it is assumed that the laboratory experience enriches conceptual learning, as well as connecting theory and practical learning with the physical manipulation of equipment. The nature of laboratories has changed with the arrival of new technologies implemented in laboratory environments, especially computers and the Internet. This change has led to the development of simulated and remote laboratories to complement the more traditional face-to-face laboratory class. These advances offer significantly enhanced opportunities for STEM students.

Remotely operated laboratories allow distance learners to carry out experiments using real equipment at any time, from any place. Remote laboratories can also complement traditional laboratories or even replace some of them because they can provide students with individualised, flexible learning opportunities. However, research into different laboratory modes: face-to-face, simulated or remotely-operated have focused on technological feasibility, or comparison between learning outcomes, whereas little has been reported on student behaviours and learning experiences, particularly with respect to remote laboratories.

This thesis aims to fill this gap by delivering a deeper understanding of the learning process in both face-to-face and remote laboratories through the analysis of the various interactions of learners, and the satisfaction levels with the laboratory approach. How these interactions might influence students' learning outcomes was investigated by connecting the various interactions with meaningful learning, student engagement and the development of lifelong learning skills.

The conceptual framework of this thesis concluded that three main elements in an undergraduate chemistry laboratory – the students, the learning content and the learning environment – had intersecting influences. Systematic instruments designed to investigate interactions had taken into account all of the three elements, with the understanding of the students' perceptions as a key factor. Interviews and direct observations were carried out in some circumstances to generate deeper understandings.

This research comprises four studies pertaining to both first-year and second-year undergraduates, conducting analyses of face-to-face and remote laboratories that provide comparisons between experiences in laboratories, learning setting (modes of manipulation, face-to-face or remote), the characteristics of laboratory content, and variances of learning achievements. Study 1 was conducted to analyse the applicability of the instruments designed for this research and to test the preliminary data analysis methods. Study 2 was performed to modify the items in the instruments and to provide richer information from the instruments. After study 2, the post-lab survey was proved as a reliable and valid instrument to measure interactions and satisfaction in undergraduate laboratories. Study 3 was carried out to provide further information about the influences of the student experience on interactions and satisfaction. Study 4 was designed to understand the student interactions and their perceptions of remote laboratories, as well as to investigate how technologies influence student laboratory approaches.

The findings from this thesis identified various factors influencing students' interactions and satisfaction with the laboratory. The students' experiences of laboratories had impacts on their perceptions about interactions and satisfaction. The students behaved differently in different types of laboratories, with procedural interactions more prominent in procedural laboratories, and far fewer interactions in the remote laboratory. The laboratory manual plays a vital role in the progress of laboratory activities, especially the well-designed ones. There were significant positive correlations between the frequency of interactions and student satisfaction in face-to-face laboratories, and the frequency of student-instructor interactions and overall satisfaction in the remote laboratory. The findings provide information about the importance of interactions for the design of the laboratory curriculum and the format of the laboratory classes.

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List of Abbreviations

TA	Teaching Assistant
F2F	Face-to-Face
S-S	Student-Student
S-I	Student-Instructor
S-E	Student-Equipment
I-I	Indirect Interaction
MER	Model of Educational Reconstruction
IULC	the Interactions in Undergraduate Laboratory Classes
FA	Factor Analysis
EFA	Exploratory Factor Analysis
CFA	Confirmatory Factor Analysis
SLOP	the Segmented Laboratory Observation Protocol
SSR	S-S Lab-related Interactions
SIR	S-I Lab-related Interactions
SIU	S-I Lab-unrelated Interactions
SSU	S-S Lab-unrelated Interactions
UNE	University of New England
RQ	Research Question
CFI	Comparative Fit Index
TLI	Tucker–Lewis Index
RMSEA	the Root Mean Square Error of Approximation
SRMR	the Standardized Root-Mean-Squared Residual

List of Publications and Presentations Arising from This Thesis

Peer-reviewed journal articles

Wei, J., Mocerino, M., Treagust, D. F., Lucey, A. D., Zadnik, M. G., Lindsay, E. D., & Carter, D. J. (2018). Developing an understanding of undergraduate student interactions in chemistry laboratories. *Chemistry Education Research and Practice*, 19(4), 1186-1198. doi:10.1039/C8RP00104A

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Oral presentations

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

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Chapter Five includes the content of a submitted manuscript "Development and assessment of an instrument for analysing students' perceptions of interactions in undergraduate chemistry laboratories", has been accepted to *Research in Science Education* in 2020.

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CHAPTER 1: INTRODUCTION

Opportunities of time vouchsafed by Heaven are not equal to the advantages of situation afforded by the Earth, and the advantages of situation afforded by the Earth are not equal to the union arising from the accord of Men.

-Mencius, fourth-century B.C. Chinese Philosopher

1.0 Chapter Outline

This chapter provides a background to the thesis and a general introduction. Section 1.1 discusses the rationale of the thesis, including a description of the conflicting ideas of the usefulness of technology in laboratories; a possibility of solving them by analysing interactions; a brief review of previous studies leading to the necessity for conducting this research. Section 1.2 presents the theoretical framework and conceptual framework guiding the thesis. Section 1.3 introduces the four research goals regarding the conceptual framework, and Section 1.4 specifies the research questions to address the different foci of the research goals. Section 1.5 presents the strengths of this thesis by summarising the previous five sections. Section 1.6 overviews the general information of the four studies. Section 1.7 contains a description of the remaining eight chapters.

1.1 The Rationale of this Thesis

Laboratory learning has long been thought to be an important aspect of chemistry learning Elliott, Stewart, and Lagowski (2008). According to the latest available data, there are presently around 102,000 students enrolled in engineering and related technology degrees and 112,000 in natural and physical science degrees in Australia (DEET, 2014). With the increasing number of undergraduate students, the growing demands for laboratories, especially the need for more equipment, is a significant factor in providing more laboratory classes in most universities. One solution can be the use of simulated or remote laboratories as a supplement or replacement for the traditional laboratory type. The sharing between different universities of remote laboratories can allow for the full use of apparatus and therefore be economically sustainable (Orduna et al., 2015).

In *face-to-face (F2F) laboratories*, experiments are manipulated physically, meaning that the learners and the equipment, the instructors and other learners are in the same location. Data from the laboratory result from the conduct of the learners. Advocates of traditional laboratories argued that the traditional laboratories provide the student with real data and the opportunity to learn from their mistakes. However, others proposed that face-to-face laboratories are too costly, and the excessive amount of time and money spent on face-to-face laboratories did not match their educational outcomes (Elliott et al., 2008; Hodson, 1993).

Remote laboratories are characterised as mediated manipulation, meaning that there is a geographical separation between the learners and the equipment, sometimes also a separation from the other learners, and/or the instructors. Even though data are obtained from the students' manipulation of equipment, the work is mediated through computers and the Internet. In this way, remote laboratories can be an important and viable supplement for face-to-face laboratories and provide students with close-to-authentic experiences, especially for those laboratories that are unsafe or inconvenient to implement (Krbecek, Das, Schauer, Ozvoldova, & Lustig, 2018). Laboratory sharing between different universities can also compensate for other universities not all having expensive equipment (Botero, Selmer, Watson, Bansal, & Kraft, 2016; Richter, Boehringer, & Jeschke, 2011). With the increasing usage of remote operation in industries, training in the use of remote laboratories in universities is important preparation for future employment (Gomes & Bogosyan, 2009). Simulated laboratories are another form of augmented-technology science laboratory, in which the laboratory process is computer-simulated and not a physical laboratory activity. However, as this research only focuses on face-to-face and remote laboratories, simulated laboratories are not analysed to a great extent in this thesis, only accounting for a small part in the review chapter (Chapter 2).

The increasing use of technology presents a quandary for institutions of higher education. On the one hand, learning technologies have provided the possibility for instructors to teach a large number of geographically dispersed learners both in synchronous and asynchronous modes. On the other hand, a reliance on technology does cause a change in the learning environment, and experience, where the learners may undergo a reduction in unexpected situations and direct experience of uncertainty that in traditional laboratories scaffold learning.

Some researchers proposed that possible explanations for the contradictory opinions regarding the effectiveness of laboratories were due to the different research objectives associated with each type of laboratory (Elawady & Tolba, 2009). It is true that research goals are mostly directions and sometimes provide guidance for the laboratories. However, to more clearly understand students' learning in laboratories, it is not enough to take only the final outcomes into account, the learning process should also be considered.

A possible method to investigate aspects of the learning process is the analysis of the influences of social factors on learning. According to the theory of distributed cognition, learners' performance and learning effects are significantly influenced by the interactions between the learner and the learning environment (Cole & Engeström, 1993; Nakhleh, Polles, & Malina, 2002). *Interactions* are the mutual influence between two objects and two actions, while instructional interactions occur between the learner and the environment, in which the learners' behaviour is influenced by the educational objectives (Wagner, 1994).

There have been multiple studies on the characteristics and the influences of interactions in science laboratories. Some examples from face-to-face science laboratories are the implementation of Teaching Assistant (TA) observation protocols in a chemistry laboratory (Lund et al., 2015; Velasco et al., 2016), the exploratory study of interactions in different levels of inquiry laboratories (Xu & Talanquer, 2013), and the TA behaviours and student engagement levels in physics laboratories (Stang & Roll, 2014). While the above research studies have provided valuable information about the instructor and student interactions in science undergraduate laboratories, they focused on the analysis of instructor behaviours or the qualitative description of student behaviours. These studies provided limited detail about the interactions in face-to-face science laboratories from the viewpoint of students and results from quantitative data analyses. Hence the need for the current research to fill this research gap primarily using quantitative data sources.

In research relating to remote laboratories, most were concerned with the introduction and implementation of new technologies (Saxena & Satsangee, 2014); the comparison of learning outcomes in face-to-face and remote laboratories (Brinson, 2015; De Jong, Linn, & Zacharia, 2013); students' feelings of engagement, authenticity, and presence in the remote laboratories (Childers & Jones, 2017; Sauter, Uttal, Rapp, Downing, & Jona, 2013), and the selection of potential guidance in inquiry laboratories (Zacharia et al., 2015). In addition, although some studies have been about the learning processes or interactions in undergraduate laboratories, they were from the area of engineering, not from science (Luis de la Torre et al., 2013; Tirado-Morueta et al., 2018). To summarise, there is a scarcity of studies about the learning process that have included detailed descriptions, and data collection methods, of interactions in science undergraduate laboratories.

Accordingly, this thesis endeavours to address these gaps by analysing the interactions in face-to-face and remote science laboratories, in and across two Australian universities.

1.2 Theoretical Framework and Conceptual Framework

1.2.1 Theoretical Framework

The guiding theory for this thesis is distributed cognition, a cultural-historical conception work attributed to Alexei Leont'ev, Alexander Luria, and Lev Vygotsky (for details, please refer to Cole and Engeström, 1993). This theory depicts the structure of human activity and emphasizes that culture mediation plays an important role in the human mind and human action. In other words, human behaviour is influenced by the relationship between individuals and their cultural environment. To some extent, the theory of distributed cognition focuses on the influence of the cultural environment or the community on human behaviour. For example, Geertz (1973) wrote:

The "control mechanism" view of culture begins with the assumption that human thought is basically both social and public - that its natural habitat is the house yard, the marketplace, and the town square. Thinking consists not of "happenings in the head" (though happenings there and elsewhere are necessary for it to occur) but of traffic in what have been called, by G. H. Mead and others, significant symbols - words for the most part but also gestures, drawings, musical sounds, mechanical devices like clocks. (p. 45)

Research to investigate the applicability of distributed cognition in education has primarily involved studies about the connection between psychology and education. One study illustrated how learning to read was a process distributed among learners, instructors, and the environment (Cole & Engeström, 1993). Another example is a book-length study reporting research in biomedical engineering laboratories, in which the laboratories were considered as systems of distributed cognition (Osbeck, Nersessian, Malone, & Newstetter, 2010). In a review of this book, Giere (2011) reaffirmed that scientific cognition, especially problem-solving ability, was distributed and was developed in the process of interactions between humans and the instruments in laboratories. Encouraged by the previous work, the present thesis was designed to investigate the interactions that occurred in chemistry laboratories. Using distributed cognition as the guiding theory, the present research utilised and modified the conceptual framework based on the Model of Educational Reconstruction (MER) (Duit, Gropengießer, Kattmann, Komorek, & Parchmann, 2012; Komorek & Kattmann, 2008), the details of which follow.

1.2.2 Conceptual Framework

In the conceptual framework – the Model of Educational Reconstruction (MER) (Komorek & Kattmann, 2008) - three main elements were prominent, namely, the students' perceptions, the science content and the design of the learning environment. In the present work, this has been applied to undergraduate chemistry laboratories (see Figure 1.1). Two types of laboratories - face-to-face and remote - were involved and both first-year and second-year undergraduate laboratories were studied.

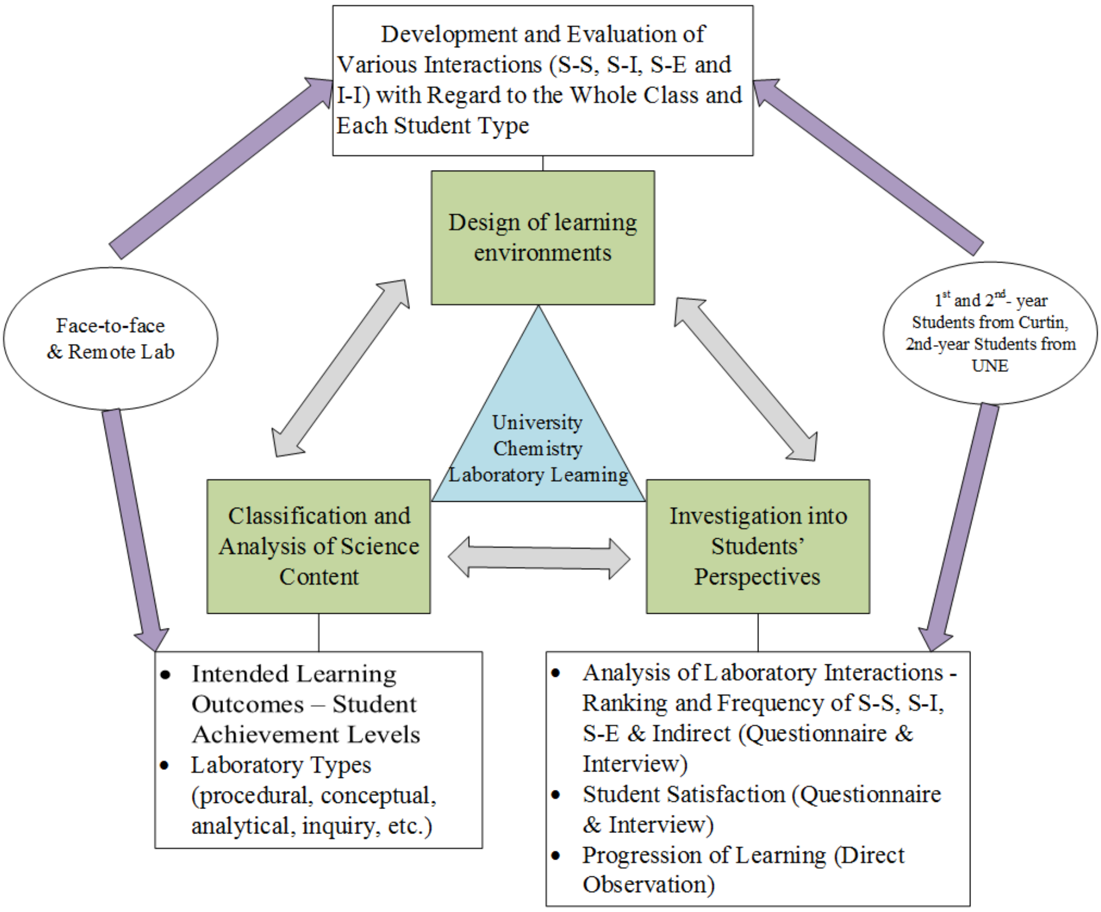

Figure 1.1 The conceptual framework for this thesis, derived from the Model of Educational Reconstruction (MER)

Note: S-S = Student-Student, S-I = Student-Instructor, S-E = Student-Equipment, and I-I = Indirect

One feature of this thesis is that the studies were carried out from the viewpoint of students and so the students' perspectives are considered as one of the main factors. From the theory of distributed cognition, knowledge is not something that goes on in an individual's mind but is developed by the process of interactions. Science content in each laboratory is thought to influence the learning process and is another factor of the conceptual framework. The learning environment comprises various components such as the learners, the instructors, the equipment, and the laboratory manual, each of which has an impact on learning. Thus, the learning environment is an integral part of this model. However, it should be emphasized that the students are 'active players' in the laboratory process, and their behaviours also influence how the science content is learned and the activities in the classroom environment. All three elements/factors mutually influence each other and have intersecting effects.

Specifically, in each element there are different matters to consider:

1) The students' perspectives being investigated included the frequency of the interactions, the importance of the interactions, and the satisfaction with the individual laboratory, measured by performing pre- and post-lab surveys, direct observations in the laboratory process and interviews after the completion of the laboratory activities.

2) The science content to be classified and analysed included the learning outcomes related to each type of laboratory signified by student achievement levels. Furthermore, the types of laboratories were classified and regarded as influencing factors.

3) The learning environment to be designed was portrayed in this thesis as the application of various interactions in chemistry laboratories. The interactions were classified as Student-Student (S-S), Student-Instructor (S-I), Student-Equipment (S-E) and Indirect Interactions (I-I) from the viewpoint of students in the classroom and were further analysed based on the student achievement levels.

The four types of interactions were based on previous findings (Moore, 1989; Sutton, 2001), among them:

- Student-Student (S-S) Interactions are about the interactions that occurred among students within or between groups;

- Student-Instructor (S-I) Interactions are about the interactions that happened between students and the instructor. In this thesis, instructors refer to the demonstrators in face-to-face laboratories. In the remote laboratory, because no demonstrators were included and the technician played part of the roles of an instructor, the instructor in the remote laboratory refers to the laboratory technician.

- Student-Equipment (S-E) Interactions are about the interactions when students manipulate equipment such as glassware, using chemicals, consulting the laboratory manual, or accessing the Internet in the laboratories. In this thesis, only interactions with laboratory manuals and the Internet are analysed because in chemistry laboratories the students are consistently manipulating glassware or using chemicals and it is hard to capture all of these interactions.

- Indirect/Vicarious interactions (I-I) are about the interactions through which students learn by observing others or listening to others' conversations.

In the development and implementation of the research methods, the theory and model played significant roles in the creation of the pre- and the post-lab surveys, the laboratory observation sheet and the design of interview questions. To be specific, in Study 1, the Model of Educational Reconstruction guided the initial foundation of the study and consistently provided guidance for the improvement of research methods, as illustrated in Chapter 4, Section 4.2. Furthermore, the theory of distributed cognition directed the design of the instrument - the Interactions in Undergraduate Laboratory Classes (IULC) - as illustrated in Chapter 5, Section 5.2.

1.3 Research Goals

In face-to-face laboratories, the overarching purpose of this research was to determine how the different kinds of interactions (Student-Student, Student-Instructor, Student-Equipment, and Indirect Interactions) that happen during chemistry laboratory activities contribute to overall affective and cognitive learning outcomes. In the remote laboratory, the purpose was to understand whether the change of learning interface (from face-to-face to remote) makes for a more inclusive and interesting science experience for the undergraduates. The goals for the research activities for each type of laboratory are now described:

For face-to-face laboratories:

1. Characterise the learning process in face-to-face chemistry laboratories by focusing on interactions and satisfaction from the viewpoint of students, using pre-designed instruments.

2. Study the relationship between interactions and the students' learning achievements, by examining the data from instruments and the laboratory marks and term graduation rates (pass or fail).

3. Investigate the relationship between interactions and satisfaction, by analysing data from instruments.

For the remote laboratory:

1. Characterise the learning process in remote chemistry laboratories by providing information about interactions for effective learning from the viewpoint of students, using pre-designed instruments and conducting on-site observations.

2. Investigate the satisfaction levels with regard to the remote laboratory by analysing items related to laboratory satisfaction based on students' self-reflection, by using pre-designed instruments and intensive interviews with focus groups.

1.4 Research Questions

Similarly, the research questions of this study are divided into two main categories based on the laboratory types, namely face-to-face and remote laboratories.

In face-to-face laboratories, the research questions (1.1 to 1.8) are:

Descriptive Research Questions: Importance and Frequency of Interactions

Research Question 1.1: What do undergraduate students consider to be important interactions before the conduct of the chemistry laboratories?

Research Question 1.2: What type and range of frequency of interactions do students engage in during chemistry laboratory work?

Research Question 1.3: What do undergraduate students consider to have been important interactions after the completion of the chemistry laboratories?

Correlational Research Questions Type 1: Interactions and Student Learning Outcomes

Research Question 1.4: How do the frequency of interactions and student learning outcomes correlate in chemistry laboratories?

Research Question 1.5: How do the frequency of interactions and laboratory types correlate in chemistry laboratories?

Research Question 1.6: How do the importance of interactions and laboratory types correlate in chemistry laboratories?

Correlational Research Questions Type 2: Interactions and Student Satisfaction

Research Question 1.7: How do the frequency of interactions and overall student satisfaction correlate in chemistry laboratories?

Research Question 1.8: How do the importance of interactions and overall student satisfaction correlate in chemistry laboratories?

In the remote laboratory, the research questions (2.1 to 2.5) are:

Descriptive Research Questions: Importance and Frequency of Interactions, and Student Satisfaction

Research Question 2.1: What do undergraduate students consider to be important interactions before the conduct of the chemistry laboratory?

Research Question 2.2: What type and range of frequency of interactions do students engage in during the chemistry laboratory?

Research Question 2.3: What do undergraduate students consider to have been important interactions after the completion of the chemistry laboratory?

Research Question 2.4: How do the undergraduates describe their satisfaction with the chemistry laboratory?

Correlational Research Question

Research Question 2.5: How do the frequency of interactions, student opinions, satisfaction variables and overall student satisfaction correlate in the chemistry laboratory?

1.5 Significance

This research is important because it studies the perceived learning process of students in chemistry undergraduate laboratories and attempts to explain the students' learning experiences from their perspectives. The findings may help instructors and curriculum designers develop more efficient laboratory courses, as well as help students' experience in the use of the curriculum materials more wisely. A broader outcome is for society to have better-trained scientists.

Studies of face-to-face chemistry laboratories have been concerned more about the ideas of the instructors and how the behaviours of the instructors impacted student learning, with less on the perceptions of the learners. This research will add to the body of research about interactions in face-to-face chemistry laboratories from the viewpoint of the learners.

Similarly, this research will add to the body of research about interactions in remote chemistry laboratories. In remote laboratories, very few studies focused on the learning process. This research will enrich the analysis of students' learning experience in remote laboratories by providing data from multiple sources.

In addition, this research adds to the body of knowledge on the relationship between interactions and learning outcomes, as well as the links between interactions and student satisfaction. The learning outcomes are assessed by the laboratory marks and the final examination results. In addition, the relationship between interactions and laboratory types are addressed herein. The students' perspectives on interactions are analysed based on their previous knowledge and learning experiences by comparing the year levels of enrolment.

1.6 Research Design

The research design went through multiple stages for both face-to-face and remote laboratories. The research design for the face-to-face laboratories was experimental and for the remote laboratory was mixed-methods (Bryman, 2015).

Considering that there were limited previous studies in the area of interactions in undergraduate chemistry laboratories, a pilot study was performed in both face-to-face and remote laboratories. In the face-to-face laboratories, the pilot study was conducted in both science and engineering laboratories, to test the applicability of the items used in the instruments. After the pilot study, Study 1 was conducted to further refine the survey forms and the laboratory observation sheets. After the analysis of Study 1, two studies were carried out in each of first-year (Study 2) and second-year (Study 3) undergraduate laboratories, to apply the research including a larger number of participants. For the research in remote laboratories, a pilot study was designed and explored with the basic knowledge gained from the face-to-face laboratories. After the pilot study, Study 4 was conducted in two Australian institutions where the students used a remote laboratory.

Four different studies of face-to-face and remote laboratories comprise the substance of the thesis. Details can be found in Section 3.4, Chapter 3. To generalise the findings from multiple cohorts, a deliberate selection of the participants included first-year and second-year undergraduates at Curtin University, and the second-year undergraduates at the University of New England. Study 1 was conducted in two classes of the first-year non-major chemistry laboratories (small-scale first-year non-major F2F), Study 2 was conducted in the whole unit of first-year non-major chemistry laboratories (large-scale first-year non-major F2F), and Study 3 was carried out in the second-year chemistry-major laboratories (second-year chemistry-major F2F). All of the first three studies were concerned about face-to-face chemistry laboratories, while Study 4 was about the study of the remote laboratory (second-year chemistry-major remote).

1.7 Structure of the Thesis

This thesis which examined student interactions and experiences in face-to-face and remote chemistry laboratories used mainly quantitative methods in face-to-face laboratories, and both quantitative and qualitative methods in the remote laboratory to gather information on the characteristics of these interactions and students' rating on the satisfaction of individual laboratories. Information was collected from different years of undergraduate students from two institutions. The detailed explanation between each chapter and its relationship with the research questions are shown in Table 1.1.

Table 1.1 The Detailed Information of Each Chapter

Chapter Number	Focus	Laboratory Mode	Data Source	Students' Level of Study	Chemistry Laboratory Names	Research Questions	Written As
1	Introduction	N/A	N/A	N/A	N/A	All of the RQs	Thesis
2	Literature review	N/A	N/A	N/A	N/A	N/A	Published at *Disciplinary and Interdisciplinary Science Education Research, 2019*
3	Methodology	N/A	N/A	N/A	N/A	All of the RQs	Thesis
4	Importance and frequency of interactions	Face-to-face	Study 1	First-year	Principles of measurement, Intermolecular forces - solubility in liquids, Identification of acetic acid in vinegar, Standardisation of HCl with a standard solution of Na_2CO_3	RQ 1.1, 1.2 and 1.4	Published at *Chemistry Education Research and Practice*
5	Improved design and validation of the instrument	Face-to-face	Study 2	First-year	Principles of measurement, Identification of common ions in solution Identification of acetic acid in vinegar, Standardisation of HCl with a standard solution of Na_2CO_3	RQ 1.2, 1.3 and 1.7	Accepted: *Research in Science Education, 2020*

To be continued

Table 1.1 The Detailed Information of Each Chapter (continued)

Chapter Number	Focus	Laboratory Mode	Data Source	Students' Level of Study	Chemistry Laboratory Names	Research Questions	Written As
6	Student-Equipment interactions	Face-to-face	Study 2 and 3	First-year and second-year	Study 3: Hydride reduction of camphor, Synthesis of bromoaniline from acetanilide, Stilbene Synthesis of an ester,	RQ 1.1, 1.2, 1.3, and 1.7	Thesis
7	Frequency, importance of interactions and satisfaction	Face-to-face	Study 2 and 3	First-year and second-year	As mentioned before	RQ 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7 and 1.8	Thesis
8	Remote laboratory interactions and satisfaction	Remote	Study 4	Second-year	The enthalpy of vaporisation of n-octane	RQ 2.1, 2.2, 2.3 and 2.4	Thesis
9	Overall conclusion	Face-to-face and remote	Study 2, 3 and 4	First-year and second-year	As mentioned before	All of the RQs	Thesis

The following summarises the key features of each chapter in this thesis.

Chapter 1 provides the general rationale and background for this thesis with the research questions and the significance of the research being presented and justified. The theoretical and conceptual frameworks are explained. The modified conceptual framework for this thesis is developed with respect to the relationship between characteristics of interactions and students' experiences. The research design including the four studies of this research is briefly illustrated. The purpose of this brief overview is to provide general guidance for the structure of this thesis. *Chapter 2* presents a literature review related to studies of interactions and student experience in face-to-face, simulated and remote laboratories. In addition, theoretical frameworks that can be used in the analysis of interactions and future studies are suggested. In *Chapter 3*, the research methodologies are presented firstly, the development of instruments used in this thesis is introduced and secondly, strategies undertaken to assess the validity and reliability of the methods are explained. A detailed introduction of the research methods used in the four studies is included. *Chapter 4* provides the first step of the study – the description of Study 1. Chapter 4 is a further statement of the research methods. The preliminary analysis serves as the foundation of this study and guides further modification in later chapters.

Chapter 5 presents an in-depth analysis of the reliability and validity of the data resulting from the instrument. In Chapter 5 both Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) are implemented to analyse the data. Both Chapter 4 and 5 enrich the research methodology of this study and are therefore connected with Chapter 3. *Chapter 6* investigates and discusses issues of interactions in Study 2 and Study 3, sorted by the five factors that resulted from the factor analysis. Chapter 6 focuses on addressing and discussing research questions regarding interactions in face-to-face laboratories. *Chapter 7* summarises the results of Student-Equipment interactions in face-to-face laboratories. Discussions about the applicability of the laboratory manual and the Internet are presented in the final part. *Chapter 8* provides a detailed analysis of Study 4, meaning the interactions and student satisfaction in remote laboratories. This chapter discusses and describes in-depth student behaviours and interactions from multi-aspect views. In the final section

(*Chapter 9*), a summary of this thesis, its findings, conclusions and recommendations are presented and discussed.

1.8 Chapter 1 Summary

This chapter has given an overview of this thesis, its goals and the relevant research questions. The purpose and need were identified to justify the significance of this research, and research designs were illustrated to support the research goals. Lastly, the structure of each chapter was listed to give a general view of the ideas developed in this thesis. Following this, a chapter of the literature review is presented to provide richer background information associated with interactions in undergraduate laboratories.

CHAPTER 2: LITERATURE REVIEW

The content of Chapter 2 has been published and the citation is given below:

Jianye Wei, David F. Treagust, Mauro Mocerino, Anthony D. Lucey, Marjan G. Zadnik, & Euan D. Lindsay (2019). Understanding interactions in face-to-face, technology-augmented science laboratories: A comparative literature review. *Disciplinary and Interdisciplinary Science Education Research,* 1, 14 Doi:10.1186/s43031-019-0015-8

2.0 Chapter Outline

This chapter comprises a review of literature pertaining to studies of interactions in undergraduate face-to-face and technology-augmented (simulated and remote) laboratories. Section 2.1 introduces the necessity of analysing learning process or student interactions in undergraduate laboratories. Section 2.2 briefly describes the methods used, and constraints applied, to undertake the literature review. Section 2.3 concerns interactions in face-to-face laboratories addressing two aspects namely, observation instruments and the functions of interactions. Section 2.4 examines the characteristics of interactions in technology-augmented laboratories. Section 2.5 proposes possible theoretical frameworks, as extensions of existing theories, for the analysis of interactions in undergraduate laboratories. Finally, Section 2.6 brings together and compares studies of face-to-face and technology-augmented laboratories, relating interactions and learning objectives, the importance of interactions, as well as the research methodologies.

2.1 Introduction

The laboratory is considered by many researchers to play an important role in science education (Hofstein & Lunetta, 2004; Johnstone & Al-Shuaili, 2001). With the increasing use of automation in higher education, two new forms of technology-augmented practical activities, simulated and remote laboratories, have been commonly used as alternatives or supplements for the traditional face-to-face laboratories (De Jong et al., 2013; Lindsay & Good, 2005). For each laboratory type, researchers have made investigations from multiple viewpoints, namely the new techniques or teaching strategies implemented in laboratories (Botero et al., 2016; Saxena & Satsangee, 2014), the description of learning objectives/outcomes for individual laboratories (Bright, Lindsay, Lowe, Murray, & Liu, 2008), and the comparison of traditional and technology-augmented laboratories (Brinson, 2015; Faulconer & Gruss, 2018; Ogot, Elliott, & Glumac, 2003). However, most of the comparison of the three modes of laboratories has focused on learning outcomes and less on the students' learning processes and interactions. Furthermore, even though some of the simulated and remote laboratories were initially developed to be conducted by distance learning, and interactions have been systematically discussed widely in distance education, there is currently no overview of the literature on interactions in discipline-specific journals. This review addresses the characterisation of studies of interactions in hands-on/face-to-face, simulated and remote science laboratories.

Interactions have long been seen as important entities in science education. According to the theory of distributed cognition, the interactions between the learner and the learning environment had significant influences on learners' performance and learning effects (Cole & Engeström, 1993; Nakhleh et al., 2002). In science laboratories, the learning environment comprises elements such as the learners themselves, other learners, instructors, laboratory manuals, the Internet, equipment and/or computers. Studies of interactions in face-to-face situations have a long history dating back to the early days of 1970s (Power, 1977), though no standard classification of interactions had been clearly identified at that time. A key problem was that most of the studies of interactions were analysed from the aspect of instructors, not from that of the learners (Wei et al., 2019). To address this problem, a review of extant literature showed that the classification of interactions which originated from research in distance education would be useful in this research. This is because in distance education, learners conduct the learning activities mostly by themselves, thus the identification of interactions was differentiated from the viewpoint of learners. To be specific, four types of interactions, namely Student-Student Interaction (S-S), Student-Instructor Interaction (S-I), Student-Equipment Interaction (S-E) and Indirect Interaction (I-I) are common in science laboratories (Moore, 1989; Sutton, 2001). In other words, learners' interactions occur with other students, the instructor, the equipment or vicariously (i.e. students listen in to interactions in which they are not direct participants).

Traditionally, science laboratory equipment was manipulated directly by the student, meaning that the learners are in the same location as other elements of the learning environment. However, remote laboratories have become more common, where computers and other technologies are playing important roles in the learning process. In remote laboratories, the learners manipulate real equipment and the data results from their manipulation. Nevertheless, the learner and the equipment, sometimes without the instructor and other learners, are physically separated from each other. Researchers have convincingly argued that information technology has dramatically changed laboratory education (Scanlon, Morris, di Paolo, & Cooper, 2002), although there may be disparities between the effectiveness of simulated and remote laboratories compared to traditional laboratories.

There exist slight differences in the terminology of instructors due to the international sources. In Australia, 'demonstrator' was commonly used to refer to the positions of conducting teaching and learning in the laboratories. While in America, *the phrase "teaching assistants" (TAs), sometimes also referred to as "graduate teaching assistants" (GTA) is employed as a more generic term* (O'Toole et al., 2012). There might be another difference because of the nature of laboratories. For example, in some remote laboratories, no instructors were present with the learners and the role of teaching and learning was completed partly by other persons like the technicians. To summarise, in the process of literature search, both demonstrators and TAs/GTAs were presumed to be equivalent in face-to-face laboratories. While in the remote laboratory, any person who had been involved in the learning process, whether to be the demonstrator or the technician, was assumed to be the one who had been carrying out the role of demonstrators.

These disparities may be due to the change in learners' interactions with the learning environment. To address this issue, first, we summarise the findings from publications that fall into two fields: interactions in face-to-face science laboratories and interactions in remote science laboratories. We then review existent theories that have been used in the analysis of interactions, as well as presenting other theoretical frameworks that may be implemented for the analysis of interactions in the two types of science laboratories. Finally, we make conclusions and discuss implications for future work.

2.2 Scope of the Review Methods for this Literature Search

Three databases were used, namely, Google Scholar (2017), Scopus (2017) and Web of Science (2017), using the keywords: face-to-face, simulated laboratories, remote laboratories, interactions, interactive learning environment, computer-supported learning, and collaborative learning. However, most results were not about interactions in educational contexts. Nevertheless, there were some review papers about interactions in distance education or online classes (Ravenna, Foster, & Bishop, 2012; Tallent-Runnels et al., 2006) as well as about the comparison between hands-on, simulated and remote laboratories (Ma & Nickerson, 2006). There appeared to be no literature-review papers about interactions that occurred in science laboratories and hence the need for this review.

To ensure as many as possible relevant publications were included in the present review, strategies were implemented to expand the search criteria. Thus the database search was broadened to include journal websites and conference papers while citation and reference list searching were also conducted.

With this procedure, the initial collection of literature was reduced to 238 sources that included journal papers, conference papers, book chapters, and PhD dissertations. Further analysis such as reading abstracts showed that some of these results did not pertain to the stated aim of measuring interactions in the laboratory, especially in the field of remote laboratories where more publications focused on comparisons between the three modes (Ogot et al., 2003) or introducing the availability of some software or hardware (Botero et al., 2016; de la Torre, Guinaldo, Heradio, & Dormido, 2015; Orduna et al., 2015). Even in the technology-augmented laboratory publications, there were about triple the amount of engineering-related papers than science ones (Ma & Nickerson, 2006). Based on discussions with the other co-authors, 30 papers on interactions in face-to-face and technology-augmented laboratories were selected. Behaviours and interactions in the science laboratories were interchangeable and were used simultaneously in some research papers. In this paper, the authors treat those two terms as being the same.

2.3 Interactions in Face-to-face Science Laboratories

Research on interactions in face-to-face science laboratories appeared earlier than their counterpart studies in simulated and remote laboratories and continue broadening to studies with many new perceptions. Observers have created and are updating a wide variety of observation instruments to capture both the instructor's and learners' interactions. Techniques used to identify and collect these interactions have changed from only paper-and-pencil and audiotape recordings to more advanced computer-assisted means. Such tools have been used to investigate the connection between learners' behaviours and their learning outcomes. Thus, researchers have analysed the content, nature, and functions of interactions, to identify not just their frequency but also to identify the influences of frequency on learning. Consequently, both quantitative, qualitative and mixed methods in data collection and data analysis processes have been used. In brief, researchers have described what the interactions were and how they worked. Below we overview the tools developed to this end and the functions of the interactions that were measured.

2.3.1 Variations of Measurement Tools in Face-to-face Science Laboratories

As illustrated by the following authors, the designs of observation tools were motivated by the desire to assess learning or instructional effects in some reformed curricula such as by inquiry (Hilosky, Sutman, & Schmuckler, 1998; Sadler, Puig, & Trutschel, 2011; Stang & Roll, 2014; West, Paul, Webb, & Potter, 2013). These authors chose observation as the main method of data collection because observation could provide direct and reliable data to record and describe students' and instructor's behaviours (Lund et al., 2015). Most of these observations provided information about the frequency of interactions and whether or not the interactions were verbal and/or non-verbal. Consequently, the results were quantitative rather than qualitative. A summary of these studies is presented in Table 2.1.

Table 2.1 The Name and Category of Observation Tools, Types of Interaction and Main Findings

Observational Tools Included	AAAS Category	Interactions	Main Findings	References
Science Laboratory Interaction Categories (SLIC)- Student	Segmented	Verbal and nonverbal	Most time was spent on transferring information	(Kyle, Penick, & Shymansky, 1979)
N/A	N/A	Verbal	Most of the laboratory interactions were about laboratory procedures	(Lehman, 1990)
A Modified-Revised version of the Science Teacher Behaviour Inventory (MR-STBI)	Segmented	Verbal and nonverbal	Instructor behaviours are different in U.S. and German institutions of higher education	(Hilosky et al., 1998)
Computerized Real-time Instructor Observation Tool (RIOT)	Continuous	Verbal and nonverbal	S-I interaction varied in both small group and whole class observations.	(West et al., 2013)
Teaching Assistant Inquiry Observation Protocol (TA-IOP)	Holistic	Verbal and nonverbal	Peer reflection can help TAs' teaching in inquiry laboratories.	(Miller, Brickman, & Oliver, 2014)
TA Observation Form (TA behaviours) On-off task form (student engagement)	Segmented	Verbal	S-I interactions could possibly predict student engagement	(Stang & Roll, 2014)
Laboratory Observation Protocol for the Undergraduate STEM (LOPUS)	Segmented	Verbal and non-verbal	Students' behaviours were independent of the instructor's style. The nature of interactions is related to laboratory activities.	(Velasco et al., 2016)

All the observation instruments in the aforementioned papers/studies can be allocated to three categories described by the American Association for the Advancement of Science (2013): holistic, segmented or continuous. With holistic instruments, the observer documents the instructor's and learners' behaviours altogether and rates them according to pre-defined criteria. With the segmented instrument, the observer records the instructor and students' performance at short intervals, normally every few minutes. The only continuous protocol, developed by West et al. (2013), requires the whole observation to be conducted without any break.

Some earlier studies focused on the frequency of student interactions in science laboratories. For instance, Kyle et al. (1979) compared the frequency of a wide range of interactions in both introductory and advanced laboratories in five college science disciplines. The occurrence of the interaction of each student was identified using the Science Laboratory Interaction Categories (SLIC) that listed ten main student activities. The authors further compared the frequency of interactions according to the level of laboratories (introductory or advanced) and the five science subjects. Their study focused on undergraduate behaviours in science laboratories and the results mostly comprised a description of the frequency of interactions. This research by Kyle et al. (1979) showed that students spent a large amount of time in reading and writing, more than that for experimenting. The students also listened a lot, both to instructors and their peers, and the authors concluded that these listening activities were more about information transmission and less about question-answering or problem-solving. No significant differences were found for the ten detailed interactions, except for the amount of time spent on reading and writing, existing within and among the laboratory levels and science disciplines.

In addition to the foregoing type of observation in whole classes that documented both verbal and nonverbal interactions, some researchers were more interested in the frequency of verbal interactions. For example, Lehman (1990) divided the various verbal interactions into 13 types: five S-S interactions, four student-initiated Student-Instructor interactions, and four instructor-initiated Student-Instructor interactions, and documented the length of students' verbal interactions according to these categories. The findings showed that students interacted a lot with their classmates, referred to laboratory equipment or read laboratory manuals. As for S-S interactions, the style of laboratories had an impact on them, and more time was spent on procedures in unfamiliar laboratories, whereas more time was spent on data collection in familiar ones. By contrast, only 11% of the whole interactions were related to Student-Instructor interactions. It needs to be noted that although Lehman did not define his observation instrument according to the American Association for the Advancement of Science categories; it was inferred to belong to the structured observations category.

The two studies (Kyle et al., 1979; Lehman, 1990) discussed above were both concerned with the frequency of interactions from the students' perspective. In other words, the observers concentrated more on how student behaviours influenced their learning. They only captured the instructor's behaviours when he/she was interacting with the students. By contrast, in many other types of studies, the researchers focused on how to improve instructional capacity by designing the observations to document the teachers' interactions with their students (Cohen & Ball, 1999). One example is the study made by Hilosky et al. (1998) when the observations were based on the Modified-Revised Science Teacher Behaviour Inventory (MR-STBI) in both general and introductory chemistry laboratories, in one German and sixteen American higher education institutions. A further interview with each instructor clarified why some interactions were more or less important. The results by combining the MR-STBI and the interviews illustrated that the design of the laboratories did not consider highlighting higher-order thinking. Another research direction by Lang, Wong, and Fraser (2005) combined S-I interactions with laboratory classroom environment to improve teaching in gifted secondary-school students in Singapore. In addition to the Questionnaire on Teacher Interaction (QTI) to describe interpersonal behaviours between teacher and students, they also used the 30-item Questionnaire on Chemistry-Related Attitude (QOCRA) to gather students' attitudes about laboratory classroom, and the Chemistry Laboratory Environment Inventory (CLEI) to obtain information about laboratory environments. To compare results from gifted and non-gifted classes, and by correlating results from the three questionnaires, they proposed that S-I interactions played important roles in gifted students' attitudes towards chemistry. Moreover, they suggested that teachers should create a more open-minded learning environment for gifted students.

The relationship between interactions and student engagement has been the focus of many researchers' interests. In two studies (Sadler et al., 2011; Stang & Roll, 2014), student engagement was considered an important factor in describing or correlating with interactions. Sadler et al. (2011) developed a tool - Laboratory Instructional Practices Inventory (LIPI) - to assess laboratory instruction in transformative courses. They included two main ideas: levels of student engagement and the content of student discourse. This observation tool was designed for instructors or laboratory coordinators to improve the quality of laboratory learning according to students' perceived learning processes. Another group (Stang & Roll, 2014) included student engagement level as a research element in an attempt to find the relationship between teaching style, student engagement, and student learning. The Teaching Assistant (TA) observation form was designed to collect three main instructor interactions. The modified on-off task form from Ocumpaugh (2015) was used to record whether the students were engaged or not. In addition, pre- and post-lab multiple questions were used to compare the learning achievements. Results showed that only the frequency of teacher-initiated S-I interactions positively influenced engagement while the rate of student-initiated S-I interactions and the length of interactions has no effect on engagement. On the other hand, students' engagement and their learning were mutually influential. In summary, the authors suggested that instructors should interact with their students more actively and frequently to increase student engagement and thereby improve student learning outcomes.

Driven by technological breakthroughs and their applications in education, the stages in data collection and data analysis of laboratory interactions varied from microphone and audio-tape to more computerised or online tools. West et al. (2013) introduced a computerised Real-time Instructor Observation Tool (RIOT) to analyse S-I verbal interactions. In this research, data analysis, especially in a quantitative way, was more efficient in the computer-based approach. The Internet also improved efficiency in communication and information exchange between different institutions. Based on the theory developed by Cohen and Ball (1999) that interactions between students, instructor, and materials each influence instructional capacities, Velasco et al. (2016) developed an observation instrument - the Laboratory Observation Protocol for the Undergraduate STEM (LOPUS) - to investigate the TAs' instructional practices. It was found that students' behaviours were independent of TAs' instructional characteristics, and the TA initiated fewer verbal conversations than did the students. It was also reported that TAs behaved similarly in all laboratories, whereas the nature of S-I verbal interactions varied according to the types of laboratories.

In contrast to the studies described above, Miller et al. (2014) developed a peer assessment tool for one TA to assess the other TAs' teaching using the Teaching

Assistant Inquiry Observation Protocol (TA-IOP). Both novice and experienced TAs observed other instructors' laboratories in different periods of the whole semester. The new TAs learned a great deal from their peers and made changes in their own teaching. The researchers also recorded the frequency of student and instructor interactions using this holistic observation instrument.

Although none of the above observation tools was able to capture all of the instructor's or learners' interactions, these observation tools could provide a general view of the students' and instructors' interactions in the laboratory classroom for researchers and instructors to understand and anticipate what is happening and what may happen in a science laboratory. In some studies, correlations between the frequency and time spent on different kinds of tasks and student engagement were presented (Sadler et al., 2011; Stang & Roll, 2014) while others compared inquiry learning and instructor behaviours (Hilosky et al., 1998). However, all of the former information was too general to describe the link between interactions among participants and their learning outcomes. A detailed analysis of various interactions with further differentiation and their educational influences is needed to answer this question. This gives rise to the second aspect of interaction studies: the function of interactions.

2.3.2 Functions of Interactions in Face-to-face Science Laboratories

Studies of interactions are not just about their frequencies but also focus on the analysis of the nature and functions of the interactions. Compared with the previous type of studies that were concerned with describing the interactions that happened in the classroom, the second type of studies emphasized the relationship between interactions and learning outcomes. Accordingly, researchers have tried to correlate results from surveys with students' learning achievements while others examined the way that learning environments influenced learning, mainly by investigating the content of conversations. Although observations were still being used by researchers as one of the main methods to examine the functions of interactions, the researchers in these studies did more than just record the frequency of learners' and instructors' interactions. A summary of these studies is presented in Table 2.2.

Table 2.2 Summary of Tools/Methods, Types of Interactions and the Major Findings of Interactions

Tools/Methods	Interactions	Main Findings	References
Practical Tests Assessment Inventory (PTAI) adopted from Tamir, Nussinovitz, and Friedler (1982)	Comparative, cooperative, and individualised S-S interactions	Competitive interactions were proved to be more potent than cooperative and individualised approaches.	(Okebukola, 1984)
Questionnaire on Teacher Interaction (QTI)	S-I interactions	Teacher behaviours are more strongly related to student learning outcomes than curriculum content.	(Wubbels, 1993)
Bloome's multiple levels of interactions	Verbal and non-verbal	This naturalistic study shows that S-I interactions illustrate different features in different stages of the laboratory.	(Roychoudhury & Roth, 1996)
The self-developed method through constant comparison	Verbal	Students interact less in inquiry laboratories than non-inquiry approaches.	(Krystyniak & Heikkinen, 2007)
Ethnographic and mixed-method comparison of verbal discourse	Verbal and nonverbal	A comparison between the three groups indicated that to effectively develop conceptual understanding, friendly and relatively critical group atmosphere was required.	(Oliveira & Sadler, 2008)
Interviews, observations, and video documentation	Verbal and nonverbal	The S-I interaction was helpful in guiding students' activities.	(Högström, Ottander, & Benckert, 2010)
Sociocultural discourse analysis	Verbal and nonverbal	Students favoured proposing ideas than asking questions in a higher level of an inquiry laboratories	(Xu & Talanquer, 2013)
Tuckman's stage model	Verbal and nonverbal	Instructors can take some methods to realise the students' behaviour and foster their peer interactions.	(Gresser, 2006)
Eighteen-category items of teacher/student interactions selected and modified after Ogunniyi and Ramorogo (1994)	Verbal and non-verbal	Human-machine interaction in CBI learning environments: learners need to reallocate cognitive gains and effort and examine possible sources of error.	(Kiboss, 1997)

A widely-used multiple-choice questionnaire - the Questionnaire on Teacher Interaction (QTI) (Wubbels, 1993) was designed to identify the interpersonal relationships of the learners and teachers. The teacher behaviour was divided into four dimensions: dominance, cooperation, submission, and opposition and the four dimensions were further divided into eight equal sessions to resemble teacher behaviours. The results showed a close relationship between teacher interpersonal behaviour and students' learning outcomes: the positive relationships were leadership, friendly and understanding; while the negative relationships were uncertain, dissatisfied and admonishing. Contradictory results for student achievement and attitudes in sectors Dominance-Opposition and Submission-Cooperation meant that there seemed to be a conflict for the teachers in being strict and at the same time giving students responsibility. Similarly, the connection between the curriculum and students' learning outcomes were not strong.

Other researchers have used qualitative content analysis, instead of multiple-choice instruments, to describe and inspect the nature and functions of interactions. In one example of this genre of research, using a naturalistic method in one inquiry-based laboratory, Roychoudhury and Roth (1996) investigated how collaborative work influenced students' learning experiences in the science laboratory and consequently their effects on learning in three representative groups. The authors videotaped each group's activities and transcribed the recordings into analysable data, then interpreted the interactions with group members and between the groups and teachers according to Bloome's cultural framework of multiple levels of interactions (Bloome, 1989). Bloome's theory about status difference within group members was affirmed. Three types of interactions within group members were identified: (1) symmetric interactions: the role of group members were equal, no one dominated the discourse for a prolonged time and members shifted their duties naturally; (2) asymmetric interactions: only one member discussed with the teacher and other group members only asked occasionally, which happened more in the process of conceptualisation; and (3) shifting asymmetric interaction: this kind of interaction had both components of symmetric and asymmetric interactions, the dominant people varied from one student to another within a notable time period. However, although more frequently interacting with others meant higher levels of participation of some students, the research did not definitely show that these students had higher levels of academic achievements. In the laboratory data collection stage, all group members had equal involvement. For the S-I interactions, there were two types in different stages of the laboratories: discussion about conceptualization in the planning and data interpretation stages; and an advisory role of the teacher in the data collection stage. Overall, from the observations of overt participation in the discourse, no relationship between interactional patterns and academic achievement of group members was identified. However, the researchers proposed that the teacher's intervention had an impact on students' learning and that teachers should promote passive members' involvement.

In another study, Krystyniak and Heikkinen (2007) differentiated categories of interactions based on the constant comparison method (Glaser, 1965) and documented the transcribed verbal interactions of each group into various parts, conducted both in Independent Chemistry Project (ICP) and non-ICP chemistry laboratories. By comparison, it was found that ICP could help students focus more on concept development and less on procedural steps. Högström et al. (2010) connected S-I and S-S interactions with learning experiences using one explanatory method that analysed the verbal and nonverbal behaviours of the students and the teacher. Three components – safety and risks, procedures and equipment, and chemical concepts - were the main forms of S-I interactions; the first two topics were prominent in S-S interactions. The authors also pointed out that S-I interactions were useful in promoting learner's thinking and acting. Flaherty, O'Dwyer, Mannix-McNamara, and Leahy (2017) also employed the constant comparison method to evaluate the impact of Teaching as a Laboratory Graduate Teaching Assistant Program (TCL-GTA) in S-I psychomotor and cognitive verbal interactions. After coding and comparing the S-I discourses in each of the three stages of the chemistry laboratories, the authors found that implementation of the TCL-GTA program had increased the frequency of both psychomotor and cognitive verbal interactions. In other words, the level of conversations related to concepts also developed with the process.

Besides qualitative methods, mixed-method studies were also common in categorising the functions of interactions. As an example, Xu and Talanquer (2013) collected data in one method of running records (Evertson & Green, 1986; Poulsen et al., 1995) whereby the researchers recorded the behaviours of one group closely in each laboratory, at the same time trying not to interfere in their activities. As in Roychoudhury and Roth (1996)'s work, they focused on analysing the characteristics of group verbal and nonverbal interactions but used only one sociocultural discourse analysis method (Kumpulainen & Mutanen, 1999) to describe the effect of level of inquiry on interactions comprising three categories: language function, cognitive processing, and social processing. Results showed that changes in levels of inquiry in the science laboratory could be one factor but not a determining factor on learners' higher level of cognitive processing.

Oliveira and Sadler (2008) examined collaborative learning in three representative groups using a combination of ethnographic and mixed-method discourse analysis. According to their description of elaboration within groups and dealing with conflicts, as well as the conversation analysis, different characteristics were found in these three groups although the instructional direction was almost the same. For Group 1, most of the peer interactions were in the form of non-elaborated conceptions, while unsolicited self-elaboration occurred sporadically such that the whole process tended to lead to vagueness. For Group 2, group members interacted with each other with gradual elaboration, which led to well-articulated conceptual constructs. For Group 3, there was a confrontational atmosphere and minimal convergence. This study also gave suggestions on how to combine social culture and social cognition together to promote science learning. The results from Oliveira and Sadler (2008) illustrated that although collaborative actions were efficient in developing concepts, some factors might hinder these results, such as students' preferences, group culture and timely instruction from teachers. By contrast, Gresser (2006) was concerned more with the relationship between group sharing of the epistemological framework and constructive work, as well as the social patterns inside the group activity. After observing several case studies, groups with a good understanding of the laboratory activity arrangements led to more efficient results; groups with a less common understanding of the target were directed by the dominant person, acting more like an individual and without cooperation.

Overall, in face-to-face laboratories, the main forms of interactions of interest to researchers were the verbal interactions rather than the nonverbal ones. However, compared with the critical review of interactions in the science classroom by Power (1977), current studies have stayed the same in many aspects. The two approaches proposed by Power, namely using observation as the main data collection method, and the influences of the interactions, are still prominent nowadays.

2.4 Interactions in Technology-augmented (Simulated and Remote) Science Laboratories

The appearance of technology-augmented laboratories was closely related to technology innovations, as they would not have been possible without the support of advanced technology. However, although technology underpins the development of technology-augmented laboratories, technology is only the interface, not the ultimate goal. It is the interaction and engagement between the learner and the technology, not the technology itself that imposes function on the learning outcomes (DiSessa, 2001). The notion that the use of technology-augmented laboratories is to improve learning or as a way to supplement traditional laboratories is central to their development and use. As to interactions that occur in technology-augmented laboratories, on the one hand, they were transformed in terms of technology improvement; on the other hand, this transformation aimed to serve the need to improve learning, especially in students' conceptual understanding.

2.4.1 Interactions in Simulated Laboratories

Two opposite opinions about the effectiveness of simulated laboratories have existed for a long period. Advocates of simulated laboratories believe that they are necessary and valuable. Simulated laboratories can be regarded as developing concepts by showing invisible concepts via computers (Meir, Perry, Stal, Maruca, & Klopfer, 2005), making the transfer of abstract learning easier (Goldstone & Son, 2005), supporting students in solving complex and real tasks in a developmental way (Osin & Lesgold, 1996), and providing multiple opportunities to correct mistakes for students (Hodson, 1991). In their review article, Rutten, Van Joolingen, and Van der Veen (2012) illustrated that computer simulations could help enhance instructions, especially in the area of laboratory learning. By contrast, detractors argue that simulated laboratories lack the combination of reality and the virtual world because the laboratory process is simulated, not a real process. Due to this lack of authenticity, students may lose interest, as well as the opportunity of learning by trial-and-error from true data (Grant, 1995).

The reason for these differences of opinion may be due to the misunderstandings about simulated laboratories. The simulated laboratory is a program that can be divided into two types, conceptual and operational (De Jong & Van Joolingen, 1998). However, if the simulated laboratories were merely regarded as a process of recreating the laboratory process through computer software or a rigid process of imitating science laboratories, their actual and potential functions were highly underestimated. Just as conversion from algorithms to interactions in human-computer interface technology signify the interdisciplinary connections to philosophy in computer science (Wegner, 1997), the learning process that occurs in simulated laboratories needs to be understood in terms of interaction. We, therefore, start our analysis by searching the various terms that were introduced and used for interactions in the computer-simulated environment. Dourish (2001) gave four forms of human-computer interactions: electrical, symbolic, textual and graphical, in terms of user interfaces' development and the human skills anticipated to achieve. Since the first two interactions were concerned with the early human-computer interactions and are not used so much today, we only discuss textual and graphical interactions here. Textual interactions were based on language and text, making the 'interactive loops' – the repeated instruction and response between learner and computer system - possible. In graphical interactions, texts were replaced by icons and this replacement changed the interactions from linearly arranged information (one-dimensional) to widely spread-out information (two-dimensional). The improvement of graphical interaction led to the development of direct manipulation - a currently predominant interface form. Direct manipulation means that users can interact with the objects directly, with them being explicitly represented. To incorporate computers more into our daily lives and our daily experiences, tangible computing and social computing, are being implemented in new forms.

Interaction with computers includes not only the interplay with physical devices such as keyboards, screens, mouse, or virtual devices, but also concerns the relationship between computers, the environments and our lives (Dourish, 2001). From this perspective, interactions in computer simulations (Table 2.3) can be thought of as having ranged from direct interaction or graphical interaction to embodied interaction (Dourish, 2001). From these processes, it can be seen that new types of interactions become possible with the appearance of new technologies.

Table 2.3 Development of Interactions in Simulated Laboratories

Interaction mode	Technology used	Functions of computers	Communication Methods	Characteristics	Examples
Direct interaction	Mouses and computer-screens	Theoretical process imitation of the microscopic phenomena	Text, images and animations on screen, hypertext	Interactions happened in one 'focus' – the cursor. The sequential organization of interaction	(Evans, Yaron, & Leinhardt, 2008; Hodson, 1991)
Participatory simulation	Small computers such as Thinking Tags	Computers as a transition from the real world to the virtual world.	Voice, gesture, and expression	Personal experience was connected with the learning process	(Colella, 2000)
Embodied interaction	Virtual Reality or Augmented Reality	Tangible experience	Head-mounted displays, data glove, AR glasses etc.	Computing was embedded in the environments	(Cheng and Tsai, 2013; Dourish, 2004; Lindgren, Tscholl, Wang, & Johnson, 2016)

Direct interaction used to be the most common interaction in simulated laboratories. It always happens as a way of graphical interaction, meaning that the user only interacts with visual materials through computer peripherals. Like graphical interactions, direct interactions were common, as the main method to communicate with a computer was through the mouse. The learner manipulates an object or a symbol in a virtual environment. In simulated laboratories, students can try the laboratory multiple times, learning from their own mistakes which were helpful in enhancing deep learning and thinking. However, students may lose interest in this simple two-dimensional interactive way.

Participatory simulation is the transitional step between direct interaction and embodied interaction, which means that the learners themselves are the symbols in the virtual world, and their behaviours affect the outcomes of the learning systems. In other words, the relationship between personal experience and inquiry skills and scientific understanding is combined altogether. In one example, Colella (2000) used a small computer – Thinking Tags – to transfer players into the micro world. In the micro world, rules and regulations were connected with the real-world actions to create a role-playing experience for the players. The micro world could afford a good transition from non-formal operations in the real world to formal descriptions and investigations of those investigations in the macro world (Dourish, 2004, p.471). Learners were directly engaged in the learning environment by using voice, gesture, and expression, instead of text and images on-screen to communicate and interact with each other. The unobtrusive nature of the Tags gave participants a rich experience that engaged them in the process. Colella (2000) suggested that computers could foster learning. Compared with other simulated laboratories, participatory simulation improved the learners' engagement levels (Wilensky & Stroup, 2002).

Embodied interaction can be thought of as one attempt to combine two popular areas in Human-Computer Interaction: tangible computing and social computing. In the embodied interaction process, the participants are involved in the process, entailing a first-person learning experience (Dourish, 2004). Arising from the phenomenological perspective, embodied interaction places emphasis on the influence of experiences on minds. Lindgren, Tscholl, Wang, and Johnson (2016) compared the learning effects of two groups of simulation game - embodied interaction and desktop - on students' concept development, attitudes toward simulation, presence, and engagement. In the embodied interaction simulation, the participants engaged in the process completely, entailing a first-person learning experience while in the desktop simulation, the experience came from birds-eye perception.

While embodied interaction emphasizes the full involvement of learners and their emergent influences on the laboratories; participatory simulated activities highlight the fact that all learners influence each other and the transfer from the micro world to the physical world. Embodied interaction and participatory simulation are concepts defined from different views, so it is not necessary to differentiate them. However, they have one feature in common, requiring the learner to be actively involved in the activities and this fosters their engagement. They can be combined together in some studies, as they are both designed for improving meaningful learning. For example, Oh, So, and Gaydos (2017) created an Augmented Reality (AR) environment to develop a conceptual understanding of the refraction of light. They adopted the idea of embodied interaction when designing the instrument and found that bodily movement has positive effects on their concept development. Similarly, Virtual Reality (VR) technology provides the possibility for learners to interact with the learning process and it was shown that the learners' interest and engagement had been improved when assisted by VR (Cheng & Tsai, 2013; Hsieh et al., 2013).

Operational and conceptual models were common in computer simulations (De Jong & Van Joolingen, 1998). Operational simulated models, also called experiential learning or task control systems, are being used predominantly in the business world (Munro, Fehling, & Towne, 1985), while the conceptual models, pertaining to the simulated principles, concepts, and facts, are prominent in science laboratories. A large number of publications have endeavoured to address issues in terms of conceptual development (Hodson, 1991; Meir et al., 2005; Scanlon et al., 2002; Winberg & Berg, 2007). However, simulations were not always effective in achieving the presumed goals of teaching the associated concepts (Berry & Broadbent, 1984). The reason may be that most of the relevant studies were focused on the comparison between simulated laboratories with other laboratory modes, less on the learning process, or to illustrate the importance and suggest some strategies for efficient instructional scaffolding in simulated learning. Duit and Treagust (2003) indicated that for conceptual change to occur the pre-instructional conceptual structures of the learners have to be fundamentally restructured in order to allow understanding of the intended knowledge. Therefore, it is necessary to investigate the learning process (interactions) to understand the restructuring process in greater detail.

2.4.2 Interactions in Remote Laboratories

In remote laboratories there is a physical and psychological separation between learners and equipment; thus, it is necessary to use technology-supported learning interfaces to diminish this separation, creating decreased satisfaction levels (Lindsay, Naidu, & Good, 2007). For example, although most students in this study believed that they had conducted a real laboratory and the data were authentic, they still preferred a hands-on laboratory. They also proposed that they were not feeling personally engaged in the laboratory because of the separation from the apparatus (Lowe, Newcombe, & Stumpers, 2012).

A 'real' remote laboratory requires that the learners manipulate the equipment individually and no instructors or other on-site peers are with them at that time. Learners can only receive immediate help from embedded help formats or online search engines; information from sources such as online discussion groups or feedback from instructors are sometimes available but are not simultaneous. These differences mean that support from technology is indispensable. Therefore, some studies are concerned with improving technology to enrich students' learning experience and learning outcomes. On the other hand, some researchers are interested in whether or not to use a 'false' remote, meaning to retain some elements such as online help from instructors or conduct group work during the laboratory process instead of individual work. Although some researchers believe that not as many interactions were required in remote laboratories (Scheucher, Bayley, Gütl, & Harward, 2009), the present review endeavours to examine whether the change of interactions influences students' learning.

Studies of remote laboratories fall into three main types: (i) introduction to developed hardware or software applied in remote laboratories, (ii) comparison of learning outcomes in the two laboratory modes (face-to-face and remote), and (iii) the creation of effective collaboration and communicational learning environment. Although none of the three categories directly describes the influences of interactions on learning, or even uses the term 'interaction', analyses were completed to explore the three elements in a learning environment, student, instructor, and material, as well as their connections with learning. Accordingly, the interactions implicitly covered in the literature were divided into three categories: Student-Student, Student-Instructor, and Student-Equipment, to explore their influences on students' learning. Thus, in Table 2.4 current knowledge of how the interactions between a student and the other elements have changed in remote laboratories and how these changes have influenced learning were summarized. The other elements influencing learning might be instructors, other learners, laboratory materials such as a laboratory manual or equipment, or technology. These interactions are then described in the following subsections.

Table 2.4 Interactions and Major Findings in Remote Laboratories

Sample	Type of Interactions	Major Findings	References
Secondary	N/A	Remote labs should be integrated with the curriculum design.	(Lowe et al., 2012)
Secondary	S-S, S-I interaction via video and text chat	A combination of the simulated and remote laboratory had provided more rich collaboration between learners, as well as between learner and instructors.	(Scheucher et al., 2009)
Undergraduate	S-S, S-I, S-E interactions	The frequency of S-S and S-I interactions had decreased	(Cooper & Ferreira, 2009)
Undergraduate	S-S and S-I interactions	The Collaborative Support system increased student engagement and the number of completed assignments.	(Luis de la Torre et al., 2013)
Undergraduate	S-I Interactions	Students were more engaged in remote laboratories watching the real live video.	(Sauter et al., 2013)
Undergraduate	S-S, S-I and S-E interactions	The Cooperative Weblab increased higher student engagement levels.	(Le Roux et al., 2009)
Undergraduate	S-S Interactions	Students preferred three members in a group.	(Botero et al., 2016)

Student-Student Interactions in remote laboratories

The S-S Interactions in remote laboratories occur between one student and other students, as happens within groups or individually, with or without the presence of an instructor (Moore, 1989). These interactions may be synchronous or asynchronous, in the form of e-mails, blackboard communication, or web ‘chatting’.

Such a remote laboratory comparison was made by Böhne, Faltin, and Wagner (2007) when allocating student pairs into two types: in one type the two students were in different rooms and could only contact each other online, while in the other type the students were in the same room and could see and talk to each other. A tele-tutor was in the laboratory process simultaneously for each kind of group. Results showed that if all the influencing factors were combined together, only initial knowledge was strongly correlated with task success, while group setting did not. However, if initial knowledge was eliminated from the factors, group setting would significantly correlate with task effectiveness. Another group's findings, from a student questionnaire, revealed that the students favoured working in three as a group in remote laboratories (Botero et al., 2016).

Other research focused on creating online platforms to increase cooperation between learners. For example, by developing the Cooperative Weblab in chemical engineering, Le Roux et al. (2009) showed that this platform increased teamwork skills and promoted higher interactions among learners because of working with unfamiliar colleagues and the embedded open-ended questions. Another example (Luis de la Torre et al., 2013) introduced a collaborative approach where other people can be invited by the learners/instructors in the virtual and remote laboratory sessions and interact with each other and share the learning process simultaneously. Students showed an increased level of engagement and the number of completed laboratory assignments also improved with the help of this collaborative approach.

Interestingly, one study (Corter, Esche, Chassapis, Ma, & Nickerson, 2011) proposed that in face-to-face laboratories, the data-collection mode in groups showed an improved positive relationship with the learning outcomes, while in the remote laboratory mode, the individual data-collection condition had more advantages than the group data collection condition. This finding may imply that in remote laboratories, the S-S interactions did not play as many important roles in the learning process as in the face-to-face ones. Although their study was made in the discipline of engineering, the findings can provide some directions for studies in science remote laboratories.

Student-Instructor Interactions in remote laboratories

It is widely thought that instructors play important roles in face-to-face chemistry laboratories (Herrington & Nakhleh, 2003) and that their behaviours have positive impacts on students' learning results (Stang & Roll, 2014). Compared with the S-I interactions in physical laboratories, sometimes there are no instructors when the students are conducting the remote laboratories because it is hard to provide 24/7 services in remote laboratories. Even though some groups had instructors involved, the instructors were not physically together with the students. Some research studies with remote-access laboratory examples where there were supervisors or teaching assistants in the room or via tele-tutorial support over the Internet (Böhne, Rütters, &

Wagner, 2004) may provide some hints about whether the absence of instructors influences students' learning. Böhne et al. (2004) used synchronous tele-tutorial methods such as desktop sharing, video or audio talking between instructor and learners in a remote setting. They also designed two forms of directed learning - instructor-directed and self-directed learning. In instructor-directed learning, the students received a large amount of help from the instructor and had to report to the instructor on the progress at the end of each task. In self-directed learning, the students only received hints from the instructor about where to find the information. To summarise their findings, the asynchronous human instructor was necessary to tackle some specific problems in remote laboratories, being available to help students online instead of being physically with them. These instructors did not participate a great deal in the learning process but provided help only when needed. The form of online help could be audio chat and desktop sharing whereas social cues like a gesture or facial images could not be used in this process.

Cooper and Ferreira (2009) introduced a framework to evaluate the pedagogical effectiveness of remote laboratories. The results showed that S-S and S-I interactions had decreased after the implementation of remote laboratories. One possible explanation was that the learners had no need for interaction with peers or instructors because they had unlimited access to the remote equipment.

Student-Equipment Interactions in remote laboratories

Even though some researchers proposed that an interface or equipment 'merely acts as a confounding intermediary' between learner, instructor, and content (Hillman, Willis, & Gunawardena, 1994), other researchers argued that the machine or monitor was an important communicating medium for learners, which could be helpful in "the mentoring, instruction, tutoring and assessment of students" (Henry, 2000). Remote laboratories have some unique functional features which cannot be provided by face-to-face laboratories (Cooper & Ferreira, 2009); for example, students can work from a library of instrument panels, receive an abundance of information instantly from the help function, or have embedded formative assessment to receive instant feedback.

Researchers have studied the impact of S-E interactions in remote laboratories on learning. Sauter et al. (2013) made a cross-comparison of four laboratories based on two influencing factors: the lab type (remote or simulation) and the representations (photo or videos). The remote users were more satisfied with the benefit from computers of reducing human error. The users who had watched the live video showing the process of data collection felt more engaged and were better at explaining some content knowledge compared with those who only viewed a picture. This phenomenon illustrated that the design of the interface that connects the learner and the equipment heavily influences the learners' experience and learning outcomes. In another example (Lowe et al., 2012), students reported that there was a decrease in interpersonal and social interactions during remote laboratory experiments. However, they still valued the reliability of the data collected in the laboratory activity and believed that they had developed positive conceptual learning and skills.

2.4.3 Overall Evaluation of Remote-laboratory Interactions

Overall, in remote laboratories, there may be fewer interpersonal interactions than in face-to-face science laboratories depending on the situation. For example, in some remote laboratories, the learners work in groups, with or without an instructor, while in other examples, learners conduct the experiment independently without any pre-designed interpersonal information exchange. It is thought that the decrease in interpersonal interactions may be compromised by S-E interactions provided by advanced technologies. However, current research is not rich enough to provide sufficient support to validate this assertion.

Researchers working in the area of Computer-Supported Inquiry Learning (CoSIL) have made valuable contributions on the development of tools in guiding online inquiry laboratory process (De Jong, 2006; Quintana et al., 2004). In the review paper, Zacharia et al. (2015) provided evidence of the relationship between suitable guidance in the inquiry process and student learning in a CoSIL environment and recommended personalised guidance. Although the studies of CoSIL are not necessarily related to this review, it is still believed there are overlaps and that their findings and work can potentially direct the design and study of interactions in remote laboratories. Detailed information can be found in the aforementioned papers.

2.5 Theoretical Frameworks for Interactions in Laboratories

The investigations of interactions in science-laboratory classrooms over the past decades have provided valuable information about laboratory learning. However, some of their usefulness is limited by the lack of operationalizing a learning theory in the specific context of a science laboratory. Theories that some researchers have proposed that may be used in the analysis of interactions in science laboratories are discussed in this section.

Roychoudhury and Roth (1996) implemented Bloome (1989) and Bowers and Flinders (1990)'s cultural framework ascertaining that classroom culture sheds light on knowledge construction in science laboratories. The culture framework proposes that each classroom has a unique culture that develops over time and influences the interactions among the persons involved. Based on the work of Roychoudhury and Roth (1996), the cultural framework was deemed appropriate to analyse the nature of interactions within individual groups and among group and instructors.

Kumpulainen and Mutanen (1999) illustrated a sociocultural analytical framework that included three dimensions: functional analysis, cognitive processing, and social processing. This analytical discourse theory also emphasized that culture played important roles in knowledge construction and attempted to underpin patterns of peer group interactions. The framework has been widely used in collaborative learning research (Mercer, Littleton, & Wegerif, 2004; Xu & Talanquer, 2013) in different learning contexts.

Similar to previous frameworks which emphasize the importance of the environment on learning, Komorek and Kattmann (2008) developed the Model of Educational Reconstruction (MER), referring to the interconnection of science content, students' perspectives and learning environment. Wei et al. (2018) applied this model to a study of interactions in science laboratories based on MER. The key finding was that students' perceptions, course content, and learning environments interrelate with each other and have mutual influences.

The earlier three models were implemented in face-to-face science laboratories. For remote laboratories, there is only one example that attempted to involve theory and this was for engineering laboratories. Tirado-Morueta et al. (2018)

adopted Kolb (1984)'s theory of experimental learning to assess learning and the design of remote laboratories. They illustrated that learning happened through interactions/interactivity between students and other people, or the equipment. During these interactions, learning occurs in the four phases according to Kolb's theory. The group then implemented Kolb's theory in the design of practical remote laboratories and assessed students' perspectives. However, this study is from engineering laboratories, even though the possibility of it being implemented in remote science laboratories is high, more evidence is needed to demonstrate its generality.

Theories developed for conventional laboratories could be applied or adapted to guide studies in remote laboratories. Distributed cognition was recommended as one possibility for the following reasons (Nakhleh et al., 2002). Technologies play important roles in remote laboratories in the information exchange for students. Therefore, students' interactions with other mediators, such as other learners, instructors, equipment and computer have significant influences on their learning process and learning outcomes. The distributed cognition theory arises from the consideration of knowledge being developed in the interactions with environments, not rooted in individuals (Cole & Engeström, 1993). Cole and Engeström added a new element of time to show the dynamics of interactions between learners and technology, based on the mediational triangle presented by Vygotsky (1978). In this assumption, technology is not a passive mediator to transact information but influences the learner and knowledge foundation. The application of this idea was reinforced by Garcia (2002) who implemented several simultaneous interactions using the interface technology in remote laboratories, By contrast, the model of Cole and Engeström, did not permit simultaneous interactions because it only applied to one student dealing with one tool and one curriculum, and therefore did not exploit the different opportunities offered by the remote-laboratory mode.

To sum up, there is limited literature on the implementation of theories in studies of interactions, especially in remote laboratories. However, it is necessary to apply relevant theories to studies on interactions. Theoretical frameworks are able to connect the researcher to existing knowledge, and guide researchers to explain, not just to describe, the observations and identify the key variables influencing a phenomenon. To combine existent theories into studies of remote laboratories has proven to be effective by Tirado-Morueta et al. (2018)'s work in the engineering area. It is therefore recommended that in science remote laboratories, theories are combined with the studies of interactions.

2.6 Discussion and Conclusions

2.6.1 On Interactions

Although studies about interactions have different characteristics and different emphases, it is necessary to learn from each other to improve learning. Some face-to-face science laboratories are being mediated by computers today, and the students are having S-E interactions when carrying out experiments. The development in simulated science laboratories to engage students in the simulation as participants may also benefit learners in face-to-face and remote laboratories. Even though the students are using real equipment in remote laboratories, as in face-to-face laboratories, there are fewer studies about interactions in remote laboratories as compared with face-to-face counterparts. There is a significant lack of systemic observation instruments and relevant theories in remote laboratories. The current methods for studying interactions already used in face-to-face laboratories may be converted to study remote laboratories. It is also suggested that studies in distance education be referred to for researchers of remote laboratories because they have two similar characteristics: a physical separation between learners and other people, and technology being used to reduce this separation.

2.6.2 On Learning Objectives and Interactions

Face-to-face, simulated and remote laboratories can serve different learning objectives. For example, Ma and Nickerson (2006) proposed that face-to-face laboratories put an emphasis on teaching design skills, while simulated and remote laboratories were effective in teaching concepts. In analysing the characteristics and functions of interactions in science laboratories, one should also consider the learning objectives, and laboratory types, not just the form of changes of interactions due to the variance of technology.

2.6.3 On Cooperation

Because of the physical distance between learner and equipment in remote laboratories, some students felt that they were not intimately involved in the laboratory process (Lowe et al., 2012). This problem may be overcome by adopting ideas from simulated laboratories - increasing learners' feelings of presence with the help of advanced technologies. However, it is not easy to achieve, especially in science laboratories, as this requires science remote laboratory designers, to also have high-level computer skills. In this way, different institutions or people from various areas can work together to solve this problem.

2.6.4 On Overlooked Interactions

In face-to-face laboratories, Student-Equipment Interactions and Indirect Interactions have mainly been neglected as compared with the two types of interpersonal interactions (S-S and S-I). Except for one article which adds new perspectives to the existing literature-Wei et al. (2018), the content of which is presented in Chapter 4 of this thesis-no studies in science laboratories were found including the types of interaction. It is suggested for curriculum designers that instructors be aware of this.

In remote laboratories, S-E is the most prominent type of interaction. The interaction between student and interface can be regarded as the difference between technicians and professionals, the technician doing what he or she was trained to manipulate while the professionals were always thinking about what and why they were doing the task this way and not in a different way (Biggs, 2011). In remote laboratories, because of being provided more freedom and time, students sometimes can be independent thinkers and learners. They can also control their speed of learning and think at a more complex level. On the other hand, since the remote laboratory is expected to be used worldwide, sometimes the language that the students will interact with may be included as one kind of learner-interface interaction. However, while English may be the dominant language in global online education, students' English proficiency may be a limiting factor.

2.6.5 On Quantitative or Qualitative Methods

Qualitative methods are believed to be beneficial for gaining deep insights of learning and teaching in the classroom and hence provide opportunities to understand the learning-related behaviours and/or motivations arising from the interactions (Cole, Becker, & Stanford, 2014; Gee & Green, 1998). However, qualitative studies have been constrained to limited numbers of participants and the results are consequently hard to generalise. From this aspect, quantitative methods have their advantages in their characteristics of easy-to-conduct and yield a broader view. The commonly used process-product paradigm has enriched people's knowledge in student and instructor's performance and the relationship between them with an individual's learning achievements (Fraser, Giddings, & McRobbie, 1992). It seems that the best way is to combine qualitative and quantitative method, for example, to collect data quantitatively and explain the results qualitatively (Hofstein, Levy Nahum, & Shore, 2001; Tobin & Fraser, 1998). However, the research goals and research questions are the most important aspects to be considered. Thus, whether to use quantitative or qualitative methods is not the central question. What matters is the identification of the problems to be addressed because the methods are just the tools used to support their solution.

After the critical review of Power (1977) pertaining to interactions in science classrooms, the general principles of methodologies have not changed much in face-to-face science laboratories. On the one hand, instruments/surveys, direct observations were conducted to capture and describe the interactions that occurred in the classroom. On the other hand, educationalists tried to understand the nature of verbal and nonverbal interactions that took place among and between students, instructors, and equipment. As for simulated and remote laboratories, systematic approaches to studying interactions in laboratory practices were not well-developed. The classroom is a complex environment where it is hard to record every occurrence and the influences of the phenomenon. The problems that Power proposed in 1977 such as theories and models are not sufficient to indicate that much progress has been accomplished.

2.7 Chapter 2 Summary

This chapter has illustrated the studies related to the interactions in face-to-face, simulated and remote laboratories. This review summarises the methods used for the analysis of interactions and make comparisons on interactions and learning outcomes. Possible theoretical frameworks were presented to guide further studies. Following this chapter, Chapter 3, 4 and 5 are all about the research methods used for this thesis. Chapter 3 is an overview introduction to the methodology; Chapter 4 is the detailed information about the first-stage development of the methods used in this thesis; Chapter 5 is the description of the instrument developed for measuring interactions in face-to-face laboratories.

CHAPTER 3: RESEARCH METHODOLOGY

3.0 Chapter Outline

This chapter and the following two chapters (Chapter 4 and 5) describe the methodologies implemented in this thesis. This chapter provides a general overview of the methodologies used in the four studies, including some detailed information pertaining to these methodologies in each study. Section 3.1 introduces the general quantitative and qualitative data collection methods. Section 3.2 introduces methods for ensuring the reliability and validity in the four studies, and the data analysis procedures. Section 3.3 describes the ethical considerations of this study. Section 3.4 examines the relationships between each study and the objectives of this research, with the detailed research questions listed.

3.1 Research Methods

Using a descriptive quantitative research method (Ranjit, 2014), quantitative data were used as the main method to address the research questions in face-to-face laboratories (see Section 1.4, Chapter 1). Using the concurrent convergent mixed-method methodology in the remote laboratories, both quantitative and qualitative methods were merged together to provide a triangular analysis to the research question in the remote laboratory (see Section 1.4, Chapter 1) (Creswell & Creswell, 2018; McMillan, 2012). Quantitative data collection included in this research were pre- and post-lab surveys and a structured laboratory observation sheet (Bernard & Bernard, 2012). Qualitative data collection included interviews and audio recordings. Quantitative results were used to address all of the research questions, the frequency, importance of interactions, the relationship between interactions and laboratory types, and with satisfaction, from a generalised viewpoint. Qualitative results provided a detailed description with regard to specific issues to address RQ 2.4, to provide detailed information about student satisfaction in the remote laboratory.

3.1.1 Surveys

Surveys in Face-to-Face laboratories Surveys have advantages as a data collection method. They are easy to distribute to a large number of participants and have no interviewer bias (Bryman, 2015). Since the project aimed to collect many students' perceptions in a limited timeframe, surveys were the ideal method to meet this project's goals. In this study, a pre-lab survey was administered just once before the beginning of the first lab class programme, whereas a post-lab survey was administered after each laboratory class, resulting in a total of 118 different post-lab surveys.

The design of the pre- and the post-lab survey instrument was based on the conceptual framework of this thesis and four types of interactions were included. There had been a gradual development of the pre- and post-lab survey instruments. Firstly, in the pilot study, a preliminary form was designed, and modifications were carried out after its trial use. The first version of the pre- and the post-lab survey was created from these modifications, and these forms were used in Study 1. Details of Study 1, the first version of survey forms and the first-step data analysis are introduced in Section 4.4.3, Chapter 4. After the implementation and the analysis of Study 1, new concerns were raised about the information provided by the first version of survey forms. Therefore, further developments were conducted to enrich the data collected, which resulted in the second version of the survey forms. Among the surveys, the pre-lab survey was conducted to gather students' expectations before the commencement of the laboratory, while the post-lab survey focused on the role of collecting information about the students' perceptions about the laboratory process. The results of the post-lab survey form were investigated further through statistical methods, and relevant suggestions about its applicability for teaching, learning and research are presented in Section 5.4 and 5.5, Chapter 5. Therefore, the second version of the post-lab survey was considered a valid instrument and it then was named as the 'Interactions in Undergraduate Laboratory Classes (IULC)' and used in Study 2 and Study 3. Details of the improvement of the IULC from the first version to the second version are presented in Section 5.2.1, Chapter 5. The two versions of the pre- and post-lab survey are included in Appendix A.

Surveys in the remote laboratory the pre- and post-lab survey forms in the remote laboratory are slightly different from the face-to-face counterparts, being changed to meet the characteristics of remote laboratories. Details are provided in Section 8.4, Chapter 8.

3.1.2 Laboratory Observation

Considering the fact that this project focused on interactions, and that interactions can be measured by observations (Yezierski, 2014), laboratory observations were used as another data collection method to validate the results from the survey forms in face-to-face laboratories and to provide another type of resource in the remote laboratory.

In this thesis, laboratory observations were aimed at measuring the frequency of interactions that happened in science and engineering laboratory classes. The observation protocol was based on observation tool – the Laboratory Instructional Practices Inventory (LIPI) developed by Sadler et al. (2011) and was informed by research on the collection of interactions between teaching assistants and students (Stang & Roll, 2014). Modifications were made to meet the needs of the observed students instead of the instructors. The laboratory observation sheet used in this thesis was named as the Segmented Laboratory Observation Protocol for Undergraduate STEM (SLOP). Observations were made in all laboratory sessions in Study 1 and in the pilot study and the focus groups of the remote laboratories.

Initially, the author and another group member observed several laboratory groups together and Inter-observer reliability (IOR) was assessed. The agreement was 0.91 and the author was deemed to be suitable to observe classes using the pre-designed observation forms. Please see Section 4.4.2, Chapter 4 for details.

The (SLOP) was developed through two versions, from version 1 (see Figure 3.1) to version 2 (see Figure 3.2) to suit the needs of the remote laboratory. Version 1 is paper-and-pencil based form and version 2 is a web-based form, developed from the platform of GORP, created at UC Davis (see: https://gorp.ucdavis.edu/protocols, SLOP).

To use Version 1, the laboratory observation sheet was printed out and interactions were recorded whenever one interaction was noticed by the observer. After the observation, the paper sheet was scanned to retain an electronic record and the results were typed into Excel spreadsheet manually to make further analysis. Version 1 of the laboratory observation was used in Study 1 and the results from it were used to compare with the data from the post-lab survey, to cross-validate the results. Details of the comparison between the results of the post-lab survey and laboratory observation sheet are given in Section 4.5.2, Chapter 4.

With Students	Prelab Lecture	Activity 1		
... lab procedures, protocols or equipment				
... analyse their results				
... discipline science concepts				
... topics unrelated to the lab				
Duration Time				
With Teachers/Demonstrators	Prelab Lecture	Activity 1		
... lab procedures, protocols or equipment		S.I.:	D.I.:	S.I.:
... analyse their results		S.I.:	D.I.:	S.I.:
... discipline science concepts		S.I.:	D.I.:	S.I.:
... topics unrelated to the lab				
Duration Time				
Indirect/Eavesdropping	Prelab Lecture	Activity 1		
... another student asking a student				
... another student asking a teacher				
Duration Time				

Figure 3.1 Portion of a screenshot of Version 1 of SLOP (Paper and pencil based form)

Note: S.I.: Student-Initiated; D.I.: Demonstrator Initiated

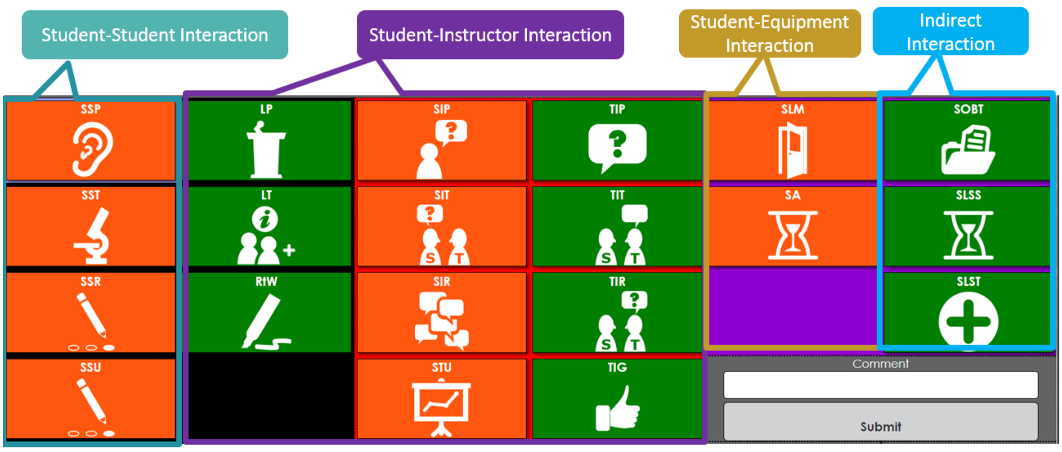

Figure 3.2 Version 2 of SLOP (Retrieved from https://gorp.ucdavis.edu/protocols***)***

Table 3.1 Student Interactions and Definitions in SLOP

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	The teacher talks about general topics
Student-Equipment	SLM	Students are reading the lab manual
	SA	Students manipulate apparatus
Indirect	SOBT	Students observing others' behaviours
	SLSS	Students listening to other students' conversations
	SLST	Students listening to another student talking to the instructor

Note: Url: https://www.dropbox.com/s/87i4wvr5tr94c1e/SLOP_supplement.pdf?dl=0

Version 2 of the laboratory observation sheet was designed to provide richer information for the remote laboratory observations. Since there were insufficient previous studies about detailed student behaviours in the remote laboratories, the laboratory observation sheet was assumed to provide information about student activities in the remote laboratory from the viewpoint of the observers. The laboratory observation sheet and the student surveys provided rich data to investigate student behaviours in the remote laboratory with the focus groups.

To use Version 2, the observer initially created an account, then a new observation could be started by choosing the SLOP protocol. The observer only needed to touch the screen when she/he noticed that a new interaction had occurred, and the data were automatically saved in the platform. A detailed explanation of each abbreviated code for student interactions and definitions in the SLOP is given in Table 3.1. The results and a simplified analysis can be downloaded directly into the computer by accessing the account. If necessary, further analysis can be easily conducted based on the initial Excel spreadsheet. Compared to Version 1, richer information can be collected due to efficiency and easy-to-use technology. Specifically, in Version 1, only S-S, S-I and I-I interactions were included, while in Version 2, S-E interactions were also contained. In the same way as used in the face-to-face laboratories, results from the laboratory observation sheet validated the results from the post-lab survey.

3.1.3 Interviews

Interviews were conducted in Study 4 to provide a deeper understanding of the students' experiences and to obtain their perceptions of the laboratories. In Study 4, interviews were used to conduct case studies in some of the remote laboratories. Interviews can provide views on the understanding of interactions that occurred in the laboratory classroom from another aspect and provide a powerful tool when combined with other data sources (Herrington & Daubenmire, 2014). The results from the interviews were used to address how-type questions and interview questions were designed to investigate the students' experiences. Interviews were conducted with three groups of students with two students in each group, to obtain a deeper understanding of student behaviours on the remote laboratory. No systematic designs were performed on the items in the interview platform, the interviewer only asked general questions to evoke perceptions from the students.

3.2 Reliability and Validity

Concerns about the reliability of surveys and laboratory observations are common in the area of educational research. To address this problem and other issues, various techniques were applied in the development of survey instruments. As mentioned in Section 1.6, Chapter 1, and Section 3.1, Chapter 3 in the research in both face-to-face and remote laboratories, a pilot study was conducted first to test the applicability of the pre- and post-lab surveys and the laboratory observation sheet.

3.2.1 Validity and Reliability in Face-to-Face Laboratories

In face-to-face laboratories, three methods were used to test the validity and reliability of the items in the survey forms, namely a pilot study, the laboratory observation sheet, and statistical analysis methods. As discussed in the following paragraphs, the pilot study was designed to test whether the designed items were suitable for undergraduate science laboratories before their usage in Study 1. In Study 1, results from the observation sheet were used as another source to validate the results from those from post-lab surveys. Factor Analysis for validity and Scale Analysis for reliability were used in Study 2.

A pilot study was conducted in face-to-face laboratories in 2015 (see Section 4.4.4, Chapter 4). The results of the pilot study led to the first version of the survey forms and the laboratory observation sheet that was used in Study 1. Study 1 was conducted to test the applicability of the surveys and the observation sheet (see Section 4.4.3, Chapter 4). Another goal for Study 1 was to test whether the post-lab survey was suitable for measuring the frequency of interactions in the face-to-face laboratories. After Study 1, the items about interactions in the survey forms were shown to be valid; and the post-lab survey was deemed to be suitable as the main form of collecting data after the completion of the laboratory activities.

Further improvements to the survey forms were made after the analysis of Study 1. It was found that the frequency of interactions was not enough to answer all of the research questions. To answer research questions 1.3, 1.6, 1.7, and 1.8, modifications were made by adding two items, namely the importance of interactions and the overall satisfaction levels. Section 5.2.1, Chapter 5 presents the details of the modified Likert Scale Items. Further analysis of the reliability of the scale items was conducted through factor analysis. The detailed information about the statistical analysis is presented in Chapter 5.

3.2.2 Validity and Reliability in the Remote Laboratory

In the remote laboratory, instruments designed for the face-to-face laboratories were taken as guidelines. Similarly, there are also three parts in the instruments used for the remote laboratory, namely Student Interactions, Student Opinions, and Student

Satisfaction. In the three parts, the categorisation of Student Interactions is the same as those of face-to-face ones; while the other two parts were justified to suit for the needs of the remote laboratory. To be specific, the section of 'Student Opinions' was newly added to collect information about students' feelings on the remote laboratory; while for the section of 'Student Satisfaction', more items were incorporated than in face-to-face laboratories, to provide richer information. A pilot study was implemented in May 2017 and the surveys were revised thereafter (see Section 8.3, Chapter 8). After this, modifications were made to transfer the paper-and-pencil based form to the Internet-based form. During this process, descriptions were revised to adjust the online format. In addition, to make understanding of the survey content clearer, one researcher was in the classroom when the surveys were distributed at the first class, ready to answer the students' questions before and when the forms were being completed. Please see Section 8.3, Chapter 8 for details.

3.2.3 Data Analysis Procedures

There were some common data analysis methods in the four studies. Firstly, data were transformed to excel spreadsheets from the paper-based survey forms in the first three studies. Figures were graphed in excel spreadsheets to show (1) the ranking of interactions in the pre-lab survey (RQ 1.1 in face-to-face and RQ 2.1 in remote laboratories); (2) the frequency and importance of interactions in the post-lab survey (RQ 1.2 and 1.3 in face-to-face and RQ 2.2 and 2.3 in remote laboratories); (3) the relationship between the frequency, importance of interactions and laboratory types (RQ 1.5 and 1.6); (4) the relationship between the importance of interactions and satisfaction (RQ1.8); and (5) the satisfaction items in the remote laboratory (RQ 2.4). Except for graphical expressions, two analytical packages were used to address the other RQs about the relationship between interactions and student achievement levels, and the link between interactions and satisfaction. In the process of choosing suitable data analysis methods, firstly the characteristics of the data were considered. Then the normality of the data was calculated. Both the laboratory marks and the number of interactions were continuous values, so the correlation was measured by Pearson's Product-Moment Correlation. Pearson's product-moment correlation coefficients were conducted through SPSS to analyse the relationship between student interactions and student achievement levels (RQ 1.4). On the other hand, since the values of the frequency of interactions were nonparametric and the values of satisfaction were ordinal, Spearman's Rank Order Correlation coefficients were calculated in SPSS to investigate the relationship between the frequency of interactions and satisfaction levels (RQ 1.7) and the relationship between the frequency of interactions, student opinions, and the satisfaction variables with the overall satisfaction item (RQ 2.5). The choice of statistical methods is described in the corresponding part in the following chapters.

3.3 Ethical Issues

The research presented and reported in this thesis was conducted in accordance with the National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number # RDSE-61-15. The Ethics form was revised and accepted on 27 June 2019 to accommodate the participation of students from UNE. To provide trust in the data-gathering and data-analysis processes, the research gave full consideration to the participants and the learning environments. This study did not require the identification of individuals nor institutions, although identification of the achievement level types is necessary because this provides information for the analysis of correlation of learning outcomes and interactions. As a researcher and part of the research design, the author endeavoured not to interfere with the learning process. The students were positive and supportive of this project and the participation rates varied from 46.7% to 67.4% in all of the four studies.

This study firstly obtained permission from the Curtin University Human Research Ethics Committee (HRECs). Each student was provided with a Participant Consent Form and informed that the project would be carried out in line with the National Statement on Ethical Conduct in Human Research (2007). Details of the Permission can be found in the pre-lab survey forms in Appendix A. The students were also informed that their participation in the study was completely voluntary and that they could withdraw from it at any time. In addition, the students fully understood that even though their student IDs were collected, the information would be used to group students based on their achievement levels, not to be used to identify individuals and no individual details would be reported. In the laboratory observation process, the researchers were concerned only with the overall interactions, not on individual behaviours.

In Study 4, the students at Curtin University were separated into two groups. One group included 13 students in total who worked in pairs (one student working individually) to complete the remote laboratory, with the author present, observing their behaviours, answering questions that were raised during the laboratory process, and interviewing the students at the end. The other group included the remaining students enrolled in the unit who completed the remote laboratory by themselves at specific time sessions. Before the laboratory, permissions were obtained from all of the students and the students voluntarily chose the group in which they would be involved.

3.4 The Four Studies

In this research, there was an initial study, followed by three subsequent studies. In each study, different research questions were addressed to suit the needs of them (Table 3.4). The analysis of each study is conducted independently of each other, while some of the analysis methods are used in all of the studies. Details are listed as follows. Study 1, Study 2 and Study 3 were undertaken in a first-year introductory chemistry laboratory class at Curtin University, a globally multicultural comprehensive Australian university. The participants from Study 1 and Study 2 were from the same unit – *Introduction to Chemistry*, in different years. This unit is designed for non-major students who had limited chemistry background Only two classes were involved in Study 1 in 2016, while all of the 19 classes of the unit were analysed in 2018. Participants from Study 3 were second-year undergraduates who had richer chemistry laboratory experiences. For Study 4, participants were second-year Chemistry undergraduates from Curtin University and the University of New England (UNE).

In addition to the general research questions to be addressed, a different focus was made for each Study. For Study 1, the focus was on the development of data collection methods. For Study 2, the focus was on the relationship between the character of interactions and the nature of laboratory activities in face-to-face laboratories. For Study 3, the focus was on the influence of students' prior experience or knowledge on their interactions. For Study 4, the focus was on the influence of technology on the learners' perceptions of interactions. Details of each study will be illustrated in the subsequent chapters.

3.5 Chapter 3 Summary

In this chapter, the quantitative and qualitative methods, the general reliability and validity of the data collection methods, and the ethical issues were presented. General information about how each study addresses the research questions, as well as the general data analysis methods, were also described. Following this chapter, Chapter 4 describes the detail of Study 1 that additionally provides the foundation of the methods applied throughout this thesis.

Table 3.2 Descriptions of the Four Studies

Study Name	Time of Duration	Major	Data Collection Method	Number of Participants	Lab Name Analysed	Research Questions to address
Study 1	08/2016 -10/2016	First - year biomedical/health sciences	Pre-lab & Post-lab survey (F2F-Version 1) Lab observation (F2F-Version 1)	29 Out of 43	Introductory analytical; Intermolecular forces; Analytical titration	1.1, 1.2 and 1.4
Study 2	03/2018 -05/2018	Same as Study 1	Pre-lab & Post-lab survey (F2F-Version 2) Interviews	336 Out of 618	Introductory analytical; Ion identification; Analytical titration	1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7 and 1.8
Study 3	08/2017 - 10/2017 and 08/2018 -10/2018	Second - year chemistry	Pre-lab & Post-lab survey (F2F-Version 2)	74 Out of 122	Synthesis of organic compounds	1.1, 1.2, 1.3, 1.4, 1.7 and 1.8
Study 4	Jul/2018*	Second - year chemistry	Pre-lab & Post-lab survey (Remote) Lab observation (Web-based) Audio recordings & interviews	43 out of 92	Enthalpy of vaporisation of n-Octane	2.1, 2.2, 2.3 and 2.4

*Note: *UNE Students Involved*

CHAPTER 4: DEVELOPING AN UNDERSTANDING OF UNDERGRADUATE STUDENT INTERACTIONS IN CHEMISTRY LABORATORIES

The content of Chapter 4 has been published and the citation is given below:

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4.0 Chapter Outline

This chapter presents details of Study 1. All of the surveys and the laboratory observation sheet used are Version 1. Section 4.1 presents background information about studies in science laboratories that inform this study. Section 4.2 describes the theoretical framework suitable for this study. The theoretical framework was similar to the one introduced in Section 1.2, Chapter 1. However, it was modified to meet the needs of Study 1. Section 4.3 explains the research questions that this paper aims to address, namely the importance of interactions before the commencement of laboratories, the frequency of interactions after the completion of laboratory activities, and the relationship between interaction types and student learning outcomes. Section 4.4 examines the methods developed for Study 1. Section 4.5 gives the results from the survey forms and the laboratory observation sheet. Section 4.6 investigates the findings. Section 4.7 presents the limitations of the study. Section 4.8 provides suggestions for future work.

4.1 Introduction

While most researchers agree that laboratory work is a vital component of the science curriculum, its educational value relative to the high cost has been frequently criticized (Hofstein & Lunetta, 1982; Hofstein & Lunetta, 2004; Johnstone & Al-Shuaili, 2001; Moore, 1989; Scanlon et al., 2002). Information from studies in laboratory classes is therefore required to distinguish productive from non-productive learning in these classes and thereby create an effective learning environment (National Research Council, 2012).

In response to the call for an increased amount of research in laboratory settings, several studies have explored students' perceptions and their intended goals in traditional or reformed undergraduate laboratories (Chopra, O'Connor, Pancho, Chrzanowski, & Sandi-Urena, 2017; DeKorver & Towns, 2015; Galloway & Bretz, 2015, 2015b; George-Williams, Soo, Ziebell, Thompson, & Overton, 2018). Other studies have developed structured observation instruments to improve instructional practices (Lund et al., 2015; Velasco et al., 2016). However, only a few of the studies have focused on the analysis of student interactions and the relationship with their learning (Stang & Roll, 2014; Xu & Talanquer, 2013).

Interactions between individuals are an essential element in any social discourse and none more so for students in a formal learning environment such as a chemistry laboratory. While much research on laboratories has been focused on the products of learning and skills developed and used by students, an important aspect of laboratory learning is understanding the interactions in which students engage when undertaking laboratory work. This then became the rationale for the present study where we sought to investigate the different types of interactions discussed below. This understanding can lead to the improved design of laboratory work, for example via the enabling and promotion of beneficial interactions or the better balancing of different interaction types during the activities undertaken by students.

4.1.1 Nature of Interactions in Science Laboratories

Students may undergo different learning experiences and attain various learning outcomes even though they are provided with the same material, have the same instructor, and learn the same content in the same classroom (George-Williams et al., 2018; Kousa, Kavonius, & Aksela, 2018). This finding suggests that students' learning may, therefore, depend upon their interactions during the laboratory activity; this hypothesis is at the core of the present study. Indeed, interactions in laboratories between students and their environment have a direct impact on learners' performance and their learning outcomes according to the theory of distributed cognition (Cole & Engeström, 1993; Nakhleh et al., 2002). In science laboratories, the environment can comprise elements such as other students, instructors, equipment, computers, and laboratory manuals (Cohen & Ball, 1999; Högström et al., 2010). Accordingly, the main interactions between the learner and the environment in science laboratories can be classified into four categories (Moore, 1989; Sutton, 2001):

1) Student-Student (S-S) Interactions, which refer to interactions among students within or between groups;
2) Student-Instructor (S-I) Interactions, which refer to interactions between students and the instructor;
3) Student-Equipment (S-E) Interactions, which refer to students manipulating equipment such as glassware, using chemicals, consulting the laboratory manual, or accessing the Internet in the laboratories; and

4) Indirect/Vicarious interactions (I-I), which refer to students learning by observing others or listening to others' conversations.

The first two types of interactions (S-S and S-I) are both interpersonal and occur in two-way communication whereas S-E and I-I are one-way in face-to-face laboratories because students only take in information from these materials and may not receive instant responses.

The effectiveness of the four types of interactions in science laboratories has different research approaches. Studies of S-S interactions were mostly cased studies, involving detailed analyses of students' behaviours in groups (Krystyniak & Heikkinen, 2007; Xu & Talanquer, 2013). Analysis of the S-I interactions considered their frequency and the initiators of the conversation (Lund et al., 2015; Stang & Roll, 2014; Velasco et al., 2016). Analysis of S-E interactions identified introductions to the equipment and how to use equipment to complete tasks but less on the frequency of interactions and their effect on learning outcomes (Tofan, 2009). Studies of indirect interactions relate to distance learning rather than face-to-face laboratories (Kawachi, 2003; Sutton, 2001). Despite this general recognition of the importance of interactions, research has not yet been conducted to connect these student interactions with learning outcomes. Thus, in this study, we seek to characterise the importance and frequency of these four types of interactions (S-S, S-I, S-E and I-I), as well as their relationship to students' achievement levels in the laboratory activities.

4.1.2 Measurement of Interactions in Science Laboratories

Multiple tools have been used to capture and analyse student behaviours in science laboratory classes: interviews with participants (Högström et al., 2010), classroom observations (Velasco et al., 2016; Xu & Talanquer, 2013), and analysis of audio and/or video recordings (Krystyniak & Heikkinen, 2007). These tools are used to improve students' learning experiences or learning outcomes or to understand teacher behaviours, and their use has largely been applied to the development of instructional practices (Egbert, 1991; Sadler et al., 2011; Stang & Roll, 2014).

Direct observation is a useful method to identify "what people are actually doing" (Bernard & Bernard, 2012) and when conducted in a structured way, observations can provide richer and more reliable information (American Association for the Advancement of Science, 2013). Existing structured observation protocols are described as being holistic, segmented or continuous (American Association for the Advancement of Science, 2013; Hilosky et al., 1998; Sadler et al., 2011; Sawada et al., 2002; Velasco et al., 2016; West et al., 2013). All of these observation protocols have been proven to be capable of showing specific interactions in laboratories. However, all of the protocols focus on reform, or how to improve, instructional effectiveness, not on the learners' actions, behaviours and interactions. Even though some student behaviours are recorded in the observation protocols described above, the data are insufficient to characterise the students' learning behaviours. The present study attempts to fill this gap by developing a new protocol with observation sheets to describe the frequency of various interactions from the viewpoint of students.

Observations, however, are time-consuming and may not be applicable in certain circumstances. Thus, in this study, we principally used self-reporting to collect data on the frequency of interactions in first-year chemistry laboratories. Self-reporting using surveys has been used a great deal in distance education to characterise students' thoughts and perspectives about their learning processes (Kuo, Walker, Schroder, & Belland, 2014; Sher, 2009). Surveys have the advantages of their suitability for collecting large amounts of data and being a viable way of understanding participants' opinions. However, there are some concerns that surveys may be too subjective to present a reliable result (Mega, Ronconi, & De Beni, 2014). Accordingly, observations were used as an objective source of information to confirm the validity of the student's self-reported survey data.

4.2 Conceptual Framework

The overarching goal of the research presented in this article is to design a meaningful learning environment for chemistry laboratories. In pursuit of this aim, we modified and used a framework derived from the Model of Educational Reconstruction (MER) (Duit et al., 2012; Komorek & Kattmann, 2008) to guide the research method (Figure 4.1). In this model, based on a constructivist epistemological position (Phillips, 2000), the learning environments, student perspectives, and course content are interrelated and influence each other. In other words, the MER model in Figure 4.1 integrates three lines of educational research (Duit et al., 2012):

- The investigation of students' perspectives of a given activity – in this case, their perspectives about the importance and frequency of interactions in the laboratory
- The clarification and analysis of the science subject matter – in this case, students meeting the intended laboratory learning outcomes on laboratory principles and techniques, as measured by their marks
- The design of the learning environment – in this case the chemistry laboratories and the experimental equipment and materials with which the students interacted.

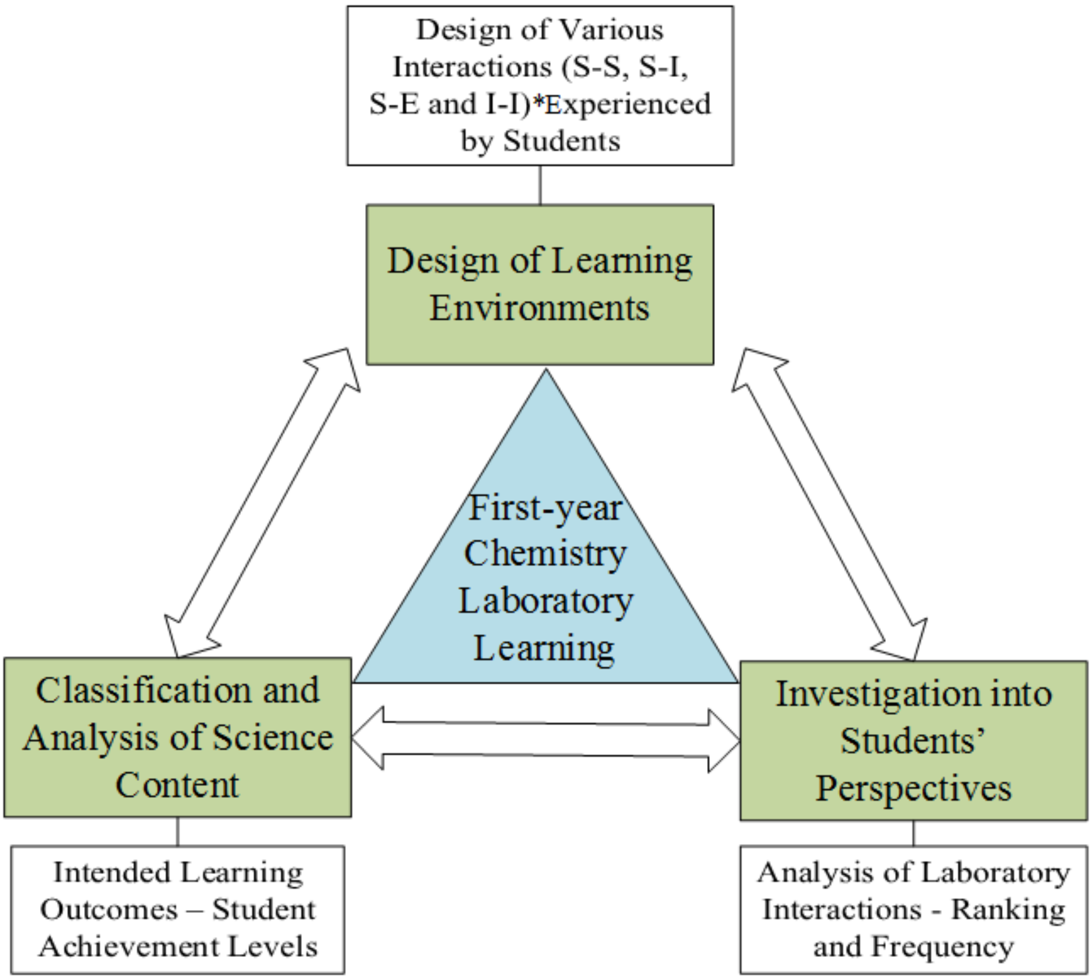

Figure 4.1 Conceptual framework derived from the Model of Educational Reconstruction (MER)

Note: S-S = Student-Student, S-I = Student-Instructor, S-E = Student-Equipment, and I-I = Indirect.

In this model, this integration allows consideration of students' perspectives of the interactions that not only improve researchers' understanding of the laboratory learning processes but also increases an understanding of the principles and techniques of the laboratory work being taught and learned. Based on the results of the analysis, the laboratory environment, the curriculum, or the design of the laboratory activity can be reconstructed.

4.3 Research Questions

The goal of this study is to understand the importance and frequency of interactions in face-to-face chemistry laboratories that include student-student, student-instructor, student-equipment, and indirect interactions. The research questions guiding the study in face-to-face laboratories were:

1) What do undergraduate students consider to be important interactions for effective learning in introductory chemistry laboratories? (RQ 1.1)
2) What type and range of interactions do students engage in during face-to-face laboratory work? (RQ 1.2)
3) What is the relationship between patterns of student interactions and students' grades for the laboratory activity? (RQ1.4)

Results from the pre-lab survey were used to gather students' ideas about the importance of interactions; post-lab surveys and observations were used to gain information about the frequency of interactions, from students' and the observer's views, respectively. Further analysis using data from the pre- and the post-lab survey was implemented to answer question 3.

4.4 Methods

4.4.1 Participants and Description of the Laboratory

This study was undertaken in a first-year introductory chemistry laboratory class in a globally multicultural comprehensive Australian university. The students were from two separate laboratory classes in the Department of Chemistry, taking chemistry as a minor while majoring in Biology. The students' chemistry background was very limited; most had not studied chemistry in high school and a few who had studied chemistry, failed their examinations.

Laboratory sessions were conducted fortnightly, having a length of three hours each session, and included four different types of laboratory activities, namely, principles of measurement, intermolecular forces - solubility in liquids, quantification of acetic acid in vinegar and standardisation of hydrochloric acid (HCl) with a standard solution of sodium carbonate (Na_2CO_3). The learning outcomes were designed to build practical skills, combine practice and theory, as well as improve communication and teamwork abilities.

The structure of all laboratories had similar patterns: a pre-lab exposition conducted by the instructor describing key principles, highlighting laboratory procedures or possible hazards, and explaining briefly the data-analysis procedures. Students were then randomly assigned into groups (mostly in pairs, with a small number of three-person groups) before proceeding to use the laboratory equipment, analyse data, and answer the questions in the laboratory manual. While the students were working, the instructors would check their pre-lab questions, answer students' questions, and observe the whole class. Although the laboratory was scheduled to last three hours, students could leave early if they had successfully completed all the activities. Students' results were evaluated before they left the laboratory.

The pre-lab exposition process involved the instructor talking and the whole class listening, occasionally with one or two students answering the teacher's clicker questions. This form of S-I interaction happened between the instructor and all the students; there were far fewer one-to-one S-I interactions or indirect interactions.

The laboratory manual was the key resource for students. Before the students entered the laboratory classroom, they were required to answer the pre-lab questions relating to laboratory safety or specific concepts in the laboratory manual, ensuring that they had read the laboratory manual and done some pre-lab preparation. In the laboratory class, students would follow information about procedures from the laboratory manual, write down data, do further analysis following instructions in the laboratory manual, and answer relevant questions in the laboratory manual.

4.4.2 Data collection

After obtaining permission from the Human Research Ethics Committee (HRECs), two main forms of data collection, namely surveys (both pre-lab and post-lab) and direct observations (Bernard & Bernard, 2012) were used to provide a triangular description of laboratory interactions. Each student was provided with a

Participant Consent Form and informed that the project would be carried out in line with the National Statement on Ethical Conduct in Human Research (2007). The students were also informed that their participation in the study was completely voluntary and they could withdraw from it at any time. Pre- and post-lab surveys were based on students' self-reports (Herrington & Nakhleh, 2003). The pre-lab survey was administered just once before the beginning of the first lab whereas the post-lab survey was administered after each lab class. Observations were made of all laboratory sessions during the semester. Of course, in any laboratory it is not possible to observe all students all the time. To eliminate any bias, the focus of the observations was not on any particular student or student group; rather by walking around the laboratory, a general sense of student interactions was recorded. The observer did not provide feedback to the students or instructors during the observation process.

The students' behaviours were not affected by being observed and the reasons are as follows. At the beginning of the first class, the observer informed the students that she would be unobtrusive and try not to interfere with their laboratory process. She also informed them that she was not an instructor and could only answer project-related questions if they arose. During the observation process, the observer always stood in the corner instead of closely behind a group of students. In addition, because the students' chemistry background was not strong, they focused on the laboratory process, having no time to consider the observer.

4.4.3 Survey Forms and Observation Recording

Survey forms and the laboratory observation sheet were designed as follows. Research-group members first discussed the possible interactions as a group and then made their own lists of candidate interactions. Based on laboratory observations conducted by group members, single versions of the survey forms and laboratory observation sheet were refined through discussion informed by results from studies in the literature. From the distance education literature (Moore, 1989; Sutton, 2001), with adaptations to be more suitable for face-to-face laboratories, interactions were differentiated according to four main items from the students' perspectives: Student-Student, Student-Instructor, Student-Equipment, and Indirect interaction. Details of these are presented in Table 4.1. The categories of interactions originated from the work from Sadler et al. (2011), in which the interactions of students were divided into various types based on the features. Relevant changes were made after real-time observation conducted by members of the research team.

Table 4.1 Interaction Types, Interaction Categories, and Sources

Interaction Type	Interaction Category [3]
Student-Student (S-S) verbal interaction [1]	Talking about lab procedures/equipment
	Analysing data
	Talking about basic concepts
Student-Instructor (S-I) verbal interaction [1]	Talking about lab procedures/equipment
	Analysing data
	Talking about basic concepts
Student-Equipment (S-E) interaction [1]	Engaging with lab procedures/equipment
	Analysing data
	Engaging with basic concepts
Indirect Interaction (I-I) [2]	Observing other students' behaviours
	Listening to other student-student conversations
	Listening to other student-instructor conversations

Note: [1](Moore, 1989) [2] (Sutton, 2001); [3] (Sadler et al., 2011)

The pre-lab survey was designed to capture students' thoughts and perceptions about the importance of laboratory interactions before they began the work in the laboratory guided by the manual. A single means of collecting ranking items was used. In the pre-lab survey, we asked the students whether or not they agreed with their laboratory marks being used for our research analysis. Most students chose 'yes', while a few chose 'no'. We then only used the data from those students who allowed their laboratory marks to be used. This is why we have fewer participants when addressing research question 3. As shown in Table 4.2, thirteen possible kinds of interactions were listed and students were asked to choose the five most important items and rank them from 1 to 5 in order of descending importance.

Table 4.2 Pre-lab Survey Form Showing Possible Laboratory Interactions

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 laboratory	
Talking to a lab instructor you learn	About the procedures/lab equipment	
	How to analyse your results	
	About the basic science theory behind the laboratory	
During the prelab, you learn	About the procedures/lab equipment	
	How to analyse your results	
	About the basic science theory behind the laboratory	
Reading the laboratory manual/notes you learn	About the procedures/lab equipment	
	How to analyse your results	
	About the basic science theory behind the laboratory	
You learn about the basic science theory behind the laboratory by using the Internet on a smart device		

The post-lab survey was used to collect students' self-reporting of the frequency of their interactions after they had just finished the laboratory work. In this survey, as shown in Table 4.3, a list of possible interactions that may have occurred in the laboratory class was provided, similar to the pre-lab survey, but with some minor differences. Students were asked about their reflections on the frequency of different components of the four main kinds of interactions. In each item, students circled whether they thought they had exhibited this specific behaviour "never", "a few", or "many" times. The reason that we chose to use this kind of differentiation as opposed to ranges with numbers, such as "less than 5 times", was because it was hard for the students to count or remember the actual number of times that they had engaged in the types of interaction. In addition, the design of the Likert scales in this study was based on the work of Vagias (2006). In measuring the scales of responses, 'a few times' can exert different numbers, as three or a range of upper limits. However, in this study, the only concern was to differentiate the frequency of interactions based on the three scales, namely two extreme values ('never' and 'many times'), and those between them ('a few times'). Therefore, it is not compulsory to identify whether 'a few times' means two or three, or more. As long as the frequency is higher than 'never' and less than 'many', it can be attributed to 'a few'.

Table 4.3 Post-lab Survey Form Showing Possible Laboratory Interactions

Interaction Type	**Frequency of Interactions**		
1. (Student-Student Interactions) Did you talk to another student about	Never	A few times	Many times
1.1 The procedures, protocols or lab equipment?	1	2	3
1.2 The basic science concepts behind the lab?	1	2	3
1.3 Analysing your results?	1	2	3
1.4 Discipline topics not directly related to the lab?	1	2	3
1.5 Topics not related to the lab?	1	2	3
2. (Student-Instructor Interactions) Did you ask the instructor about ...			
2.1 The procedures, protocols or lab equipment?	1	2	3
2.2 The basic science concepts behind the lab?	1	2	3
2.3 Analysing your results?	1	2	3
2.4 Discipline topics not directly related to the lab?	1	2	3
2.5 Topics not related to the lab?	1	2	3
3. (Student-Equipment Interactions) Did you ...			
3.1 Read the lab manual/instructions associated with this lab?	1	2	3
3.2 Use the Internet for technical assistance, data analysis or for concepts behind this lab?	1	2	3
4. (Indirect Interactions) Did you learn by observing someone else's interactions in the lab, such as			
4.1 Observing another student's experimental setup or behaviour	1	2	3
4.2 Listening to a student/group of students asking another student for help/advice	1	2	3
4.3 Listening to a student/group of students asking a teacher for help/advice	1	2	3

The Laboratory Observation Form shown in Table 4.4 was based on the development of one observation tool – the Laboratory Instructional Practices Inventory (LIPI) (Sadler et al., 2011) and was informed by research on the collection of interactions between teaching assistants and students (Stang & Roll, 2014). The author acted as an observer recording verbal interactions and students' non-verbal expressions such as their gestures and watching other groups. Behaviour was recorded as a type of interaction irrespective of how long it lasted. A new activity was recorded if the students changed that activity or were interrupted. For example, students analysing data, even if it lasted several minutes, was considered as one activity but if students stopped analysing data to answer another person's question, it was considered that a new activity had begun.

Inter-observer reliability (IOR) was assessed through the development process. Before the study reported in this article, the observer and another member of the research team went to several first-year chemistry laboratories to conduct preliminary data collection. They watched the same groups of students and conducted independent observations. IOR was assessed using a two-way mixed, consistency, single-measures intra-class correlation coefficients (ICC) (McGraw & Wong, 1996) to assess the degree that coders provided consistency in their recordings of the occurrences of interactions across subjects. The resulting ICC was in the excellent range, average ICC = 0.91 (range 0.87–0.95) (Cicchetti, 1994), indicating that coders had a high degree of agreement and suggesting that the occurrences of interactions were recorded similarly across coders. The high ICC suggests that a minimal amount of measurement error was introduced by the independent coders, and therefore statistical power for subsequent analyses is not substantially reduced. Recordings of the occurrences of interactions were therefore deemed to be suitable for use in answering research question 2 of the present study (Hallgren, 2012).

Table 4.4 Laboratory Observation Form

Item of Interactions	Recordings of Frequency
With students	
Lab procedures, protocols or equipment	
Analyse their results	
Discipline science concepts	
Topics unrelated to the lab	
With instructors	
Lab procedures, protocols or equipment	
Analyse their results	
Discipline science concepts	
Topics unrelated to the lab	
Indirect/Eavesdropping	
Another student asking a student	
Another student asking a teacher	

The focus of direct observations was on the nature of verbal interactions. Compared with the post-lab survey, items of nonverbal interactions, especially those related to using the laboratory manual, were not included because there were too many nonverbal behaviours in the laboratory, such as setting up the apparatus or walking around to find some glassware. Although these were by necessity omitted, student-apparatus and student-manual interactions occurred with a high frequency according to the observations.

4.4.4 Pilot Study

A pilot study to assess the validity and reliability of the data collection tools was implemented by collecting data from three science and engineering laboratory classes during semester 2, 2015 (Carter et al., 2015; Treagust et al., 2016). After the pilot study, students' opinions were sought, and subsequent improvements were made to the original survey forms. For example, the pre-lab survey was changed from a Likert scale for each item to the current form because students tended to assign each item as very important and were therefore difficult to ascertain the relative importance of the interactions.

Results from the pilot study showed that, even though there were minor differences, the students in science and engineering classes had similar expectations about the importance of interactions in laboratories; in addition, students had similar self-assessments about the frequency of their occurrences. We were thus confident that the instruments could be generalised as one easy-to-manipulate tool to collect student-interaction information in both science and engineering laboratories. Furthermore, the findings of this study and unpublished results from our research team which were proceeded after the pilot study also had high consistency, giving us the assurance that the instruments are reliable to present validated results (Wei et al., 2017).

4.4.5 Data Analysis

We used figures to illustrate: (1) ranking of interactions in the pre-lab survey; (2) frequency of interactions in the post-lab survey; (3) frequency of interaction in the laboratory observation sheet; (4) ranking of interactions sorted by student academic levels; 5) frequency of interactions by student academic levels (Robbins, 2013).

To achieve (4) and (5), we classified students into three levels according to their final laboratory marks. These marks were combined with their individual marks and their laboratory test examination scores. We classified the students with a laboratory-grade of 85% or more as the highest achieving students; students in the 70%-84% range as the middle-level students; and lower than 70% as the lowest-achieving students.

4.5 Results

4.5.1 Ranking of Interactions - Results from the Pre-lab Survey

To respond to RQ 1.1. “What do undergraduate students consider to be important interactions before the conduct of the chemistry laboratories?”, students’ expectations and perceptions about the importance of the different kinds of interactions which may be helpful for their learning were collected. Student rankings of the importance of potential laboratory interactions are shown in Figure 4.2.

Combining ranks 1, 2, 3, 4 and 5 together, before they began to do the laboratory, the highest total of the ranks indicated that students thought that interactions from an instructor would be the most important. Twenty-eight of the 43 students considered that they would ask the instructor about laboratory procedures, while 24 out of 43 and 17 out of 43 students expected that the instructor would help them with analysis of results or address theoretical concepts, respectively. Interactions relating to laboratory procedures were ranked as having the highest importance, across all of student-instructor, pre-lab, and student-lab manual interaction categories.

Of all of the interactions, the students thought that the prelab demonstration or laboratory manual would be the least important interactions to help analyse results. This is reasonable because in the pre-lab exposition the instructor mainly talked about procedures and concepts while the laboratory manual focused on procedures and sometimes concepts. Overall, the instructor was expected to be the main source of information as opposed to the other students.

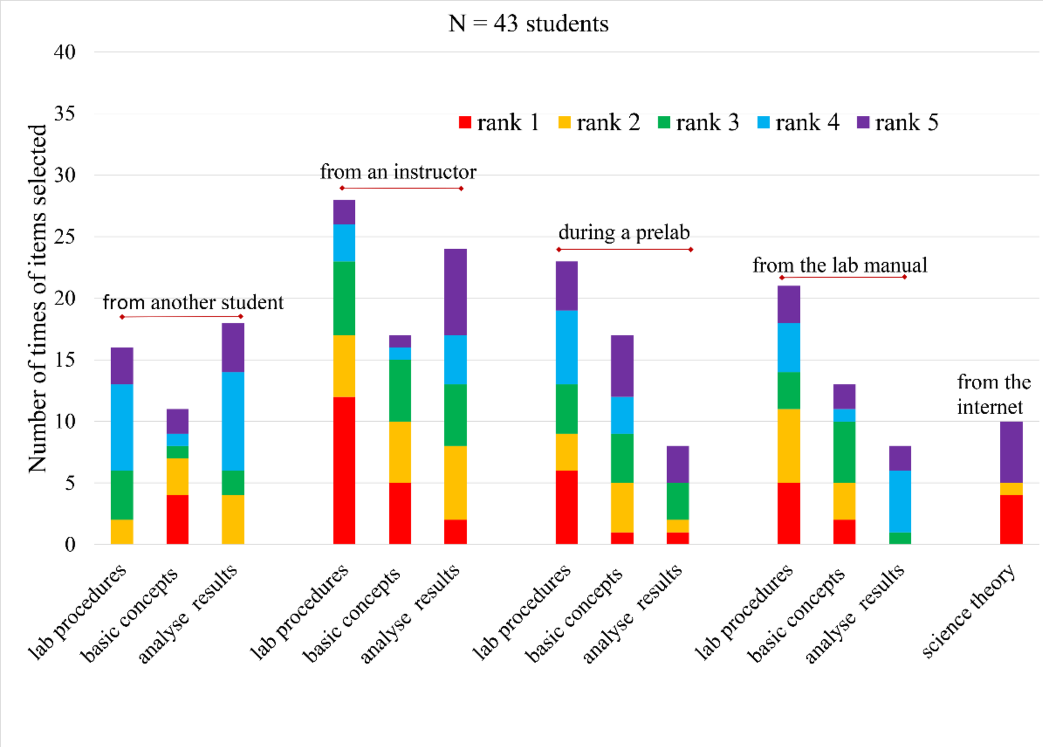

Figure 4.2 Student expectations (number of times of items selected) of the importance of the potential interactions sorted by task types before undertaking the laboratory work

Note: Data obtained from the pre-lab survey, total number of selections = 43 x 5 = 215.

4.5.2 Frequency of Interactions

Results from the Post-lab Survey Both self-report and direct observations were implemented to respond to RQ 1.2. “What type and range of frequency of interactions do students engage in during chemistry laboratory work?”. The post-lab survey results presented in Figure 4.3 show that students thought that they had communicated more frequently with their peers than with the instructors. They chose the item ‘analysing results with other students’ as the most frequent behaviour (around 60%) while talking about procedures with each other was the second highest (approximately 54%). Students also reported that referring to the laboratory manual and discussing basic concepts with other students (40% and 35%, respectively) were higher than all of the interactions with instructors (lower than 30%). Both the frequency of interactions with instructors and the indirect interactions had a relatively lower percentage. Overall, the most frequent interactions occurred between a student and other students. It should be noted that there were more responses in the post-lab survey compared with the pre-lab survey because the students needed to complete the post-lab survey at the end of each class, while they only did the pre-lab survey once at the beginning of the sequence of laboratories. Several items were not included here because of their low value; these were 'topics not directly related to the laboratory' (1.4 & 2.4 in Table 4.3) and 'topics unrelated to the laboratory' (1.5 & 2.5 in Table 4.3) (both S-S and S-I).

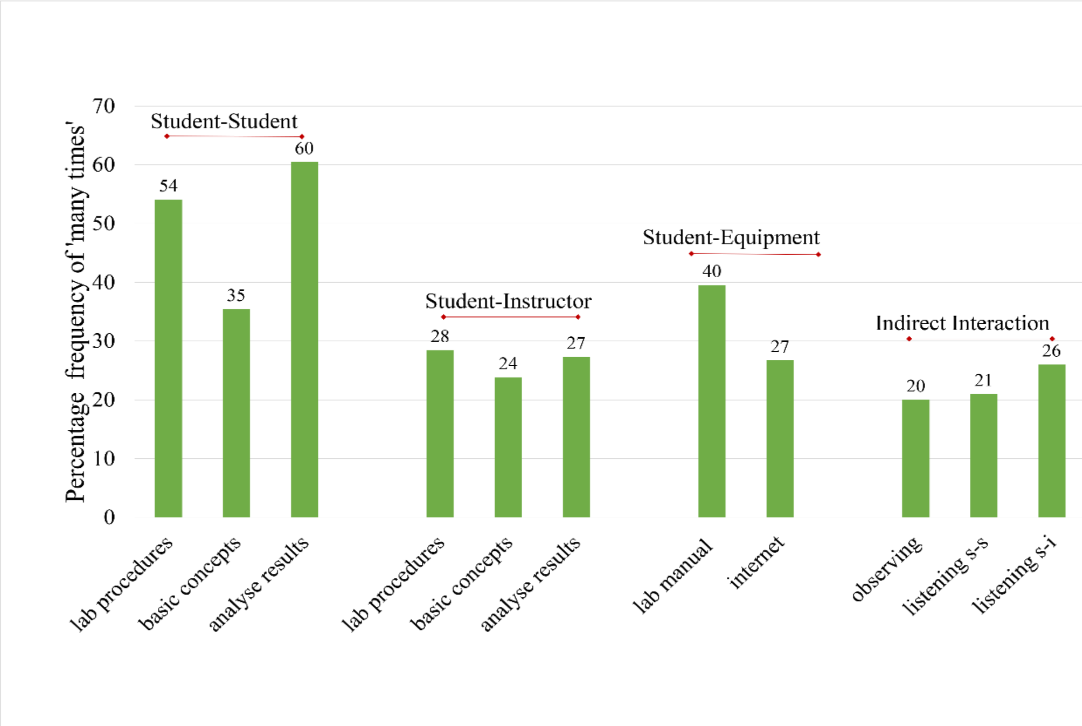

Figure 4.3 Relative percentage frequency of the four types of interactions, sorted by task types, as reported to be 'many times' by students after undertaking the laboratory work

Note: 1. Data obtained from the post-lab survey, the percentage of each item is not equal to 100% as only data of 'many times' are illustrated, not including data of 'never' and 'a few times'. 2. The total number of responses = 171 from seven sessions.

Results from laboratory observations both the pre-lab and post-lab survey results are based on students' feedback. To provide a more objective view, direct observation was also conducted. After combining all the seven laboratory observation results and dividing the number of occurrences of each item by the value of the overall occurrences (Figure 4.4), we observed that around one-third of student interactions were student-student talking about procedures. The second most frequent interaction was students asking instructors about basic procedures. Students also reflected on their results with each other or discussed them with instructors (clustered among 16% to 17%). Interactions not related to the topic of the experiment (both S-S and S-I) had a very low percentage. As indicated earlier, accurate documentation of indirect interactions is very hard in a laboratory class environment and consequently, the data had low values. Because the observer focused on the whole class's verbal discourses, to make the observation unobtrusive, the observer would not move closer to listen carefully to the actual conversation content. This meant that even though some of the facial and/or physical features were not recorded as interactions, they were important clues for the observer to define the underlying interaction. The categorization of interactions also was dependent on the task content. Specifically, the observer recorded more procedural interactions when students were setting up apparatus and more results of analysis interactions were recorded when students were analysing their data. Thus, fewer occurrences relating to discipline concepts were recorded than for procedures and results analysis. Furthermore, the observer categorised unrelated topics only if the students were laughing loudly or talking about irrelevant topics loudly. Thus, there may be some quieter unrelated topics not being recorded.

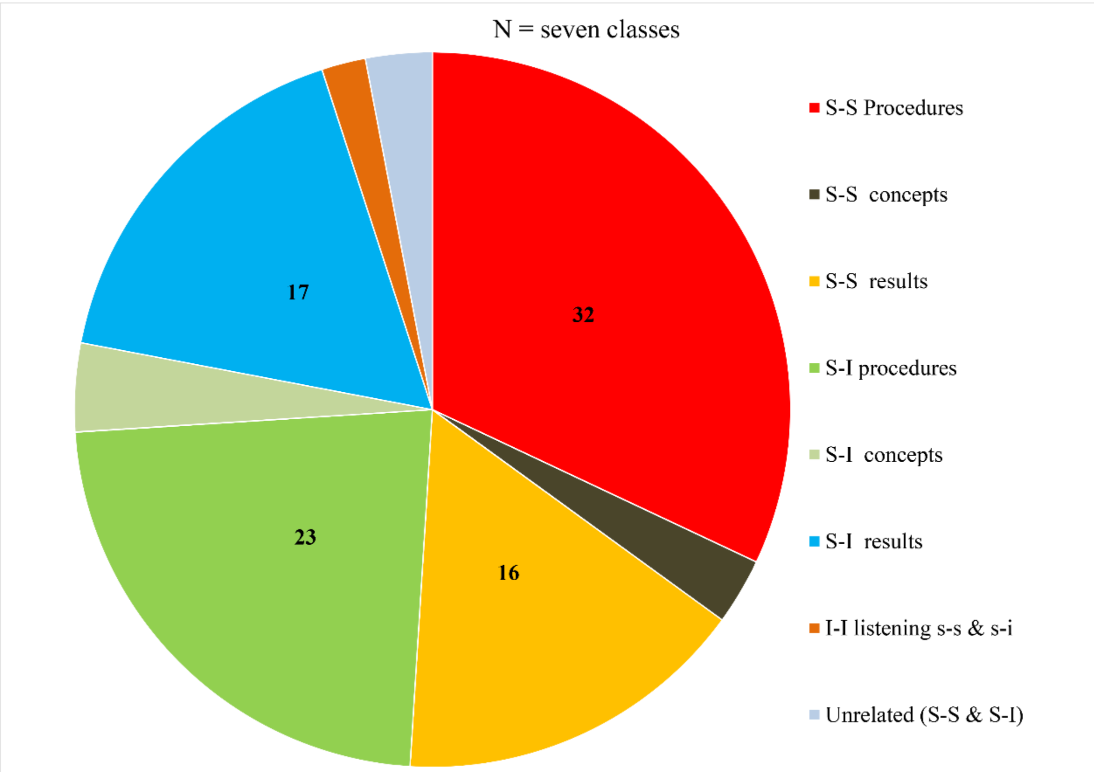

Figure 4.4 Observation results: proportions of each type of activity recorded during seven three-hour classes

The results from observations shown in Figure 4.4 show good agreement with the students' self-reported results in Figure 4.3. In that the S-S: procedures and S-S:

results gave the highest proportions and frequency of interactions, respectively. Interactions with the laboratory manual were not recorded through the observations because these were so numerous that it proved impossible to separate them into individual occurrences. Nevertheless, the similarities between the results of self-reporting and observation suggesting students' self-reports can be used reliably as the main data collection technique in the present and other similar studies.

4.5.3 Relationship between Interactions and Student Achievement Levels

To address RQ 1.4. "How do the frequency of interactions and student learning outcomes correlate in chemistry laboratories?", the ranking responses of student categorised at the three levels of achievement were analysed.

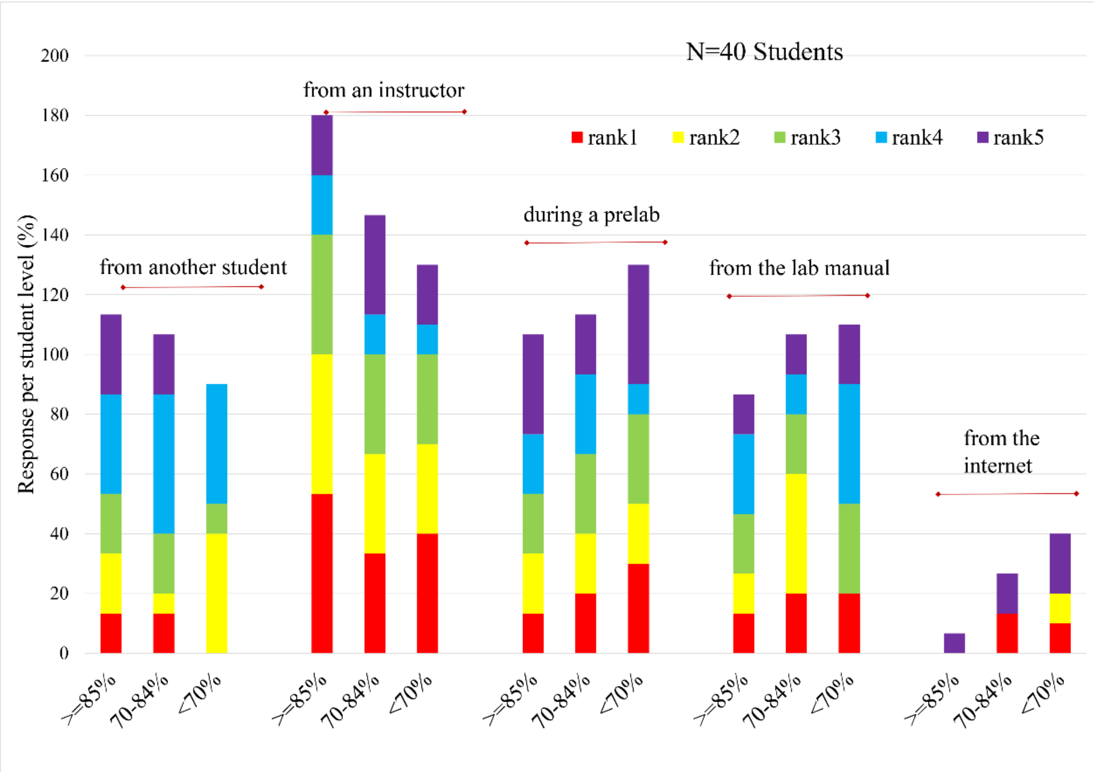

Figure 4.5 Student expectations of the importance of the potential interactions sorted by three student achievement levels before undertaking the laboratory work

Note: 1. Data obtained from the pre-lab survey (total number of selections = 40x5 = 200). 2. Achievement levels are: >= 85% equals the highest achieving level, 70% – 84% equals to the middle-level, and < 70% equals to the lowest-achieving level; 3. each column of >= 85%, 70% – 84% and < 70% sum to 100%.

As shown in Figure 4.5, the highest achieving students anticipated that two-way interactions were more important, talking more with their peers or instructors. On the other hand, the lowest-achieving students ranked one-way interactions (listening to the pre-lab demonstration, referring to laboratory manual, or surfing the Internet) as more important.

Secondly, we analysed the responses from the post-lab survey according to the three levels of student laboratory achievement (Figure 4.6 & Figure 4.7). The results in Figure 4.6 show that each of the three groups of students reported that they interacted 'a few times' more often than 'never' or 'many'. However, the high-achieving students reported that they interact 'many times' more than students in the other two achievement levels.

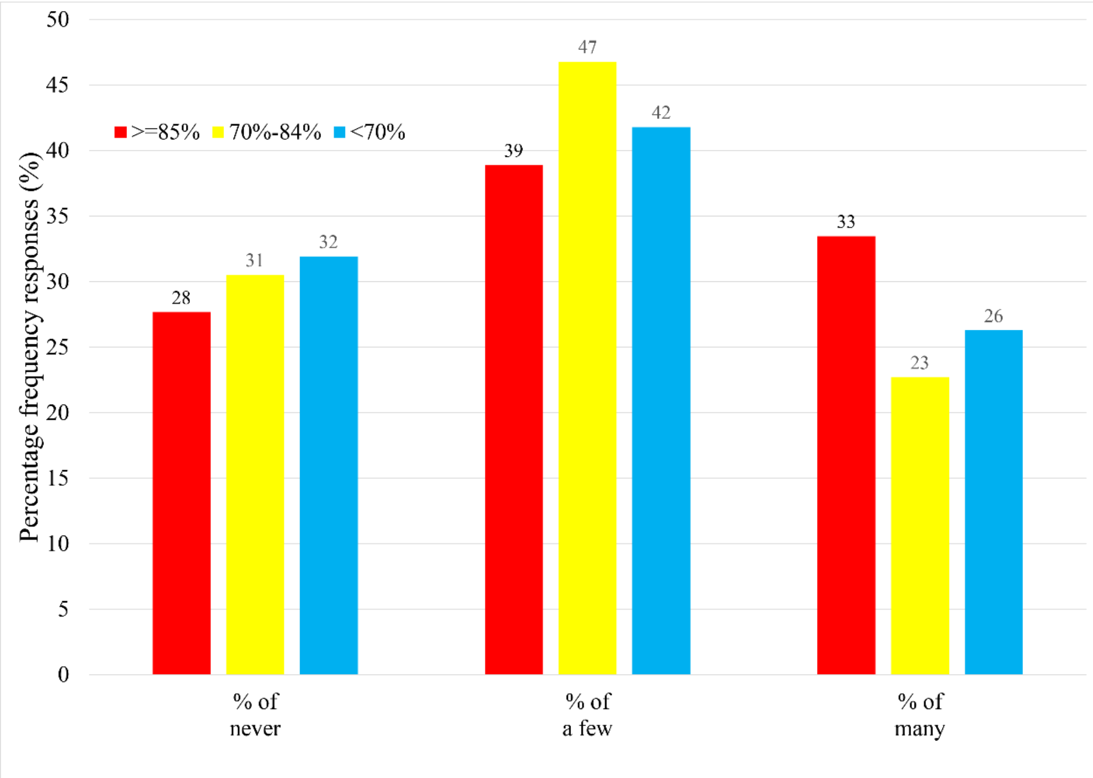

Figure 4.6 Relative percentage of the reported frequency of engagement level of laboratory interactions sorted by student achievement levels after undertaking the laboratory work

Note: 1. Data obtained from the pre-lab survey (total number of responses equal to 132), seven sessions. 2. Each column of >=85%, 70% – 84% and <70% sum to 100%

We, therefore, made a more detailed analysis of the categories of 'many times'; the results are shown in Figure 4.7. Compared with the low- and middle-achieving students, a relatively higher percentage of the highest achieving students reported that they interacted many times in all possible interactions.

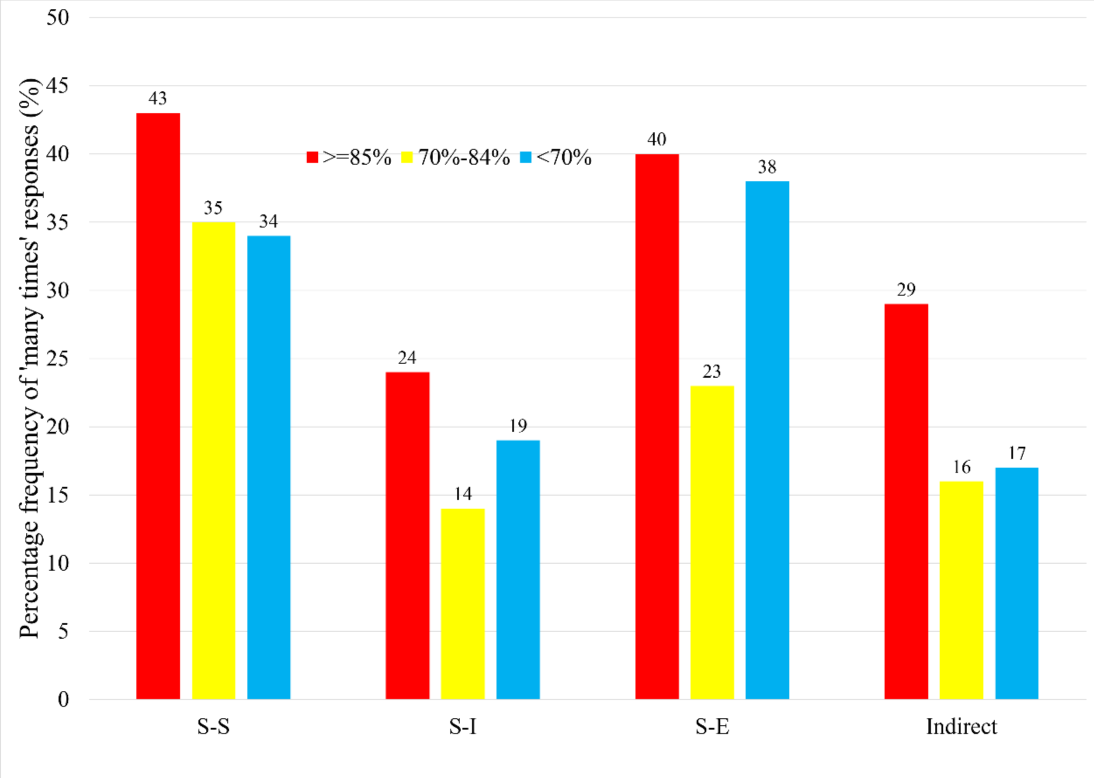

Figure 4.7 Distribution of interactions reported as 'many times' across the four types of interactions, sorted by the three student achievement levels

Note: Data obtained from the post-lab survey (total number of responses = 132). 2. The percentage of each item is not equal to 100% as data of 'many times' are illustrated, not including data of 'never' and 'a few times.

4.6 Discussion and Conclusions

This study was based on the analysis of one traditional undergraduate laboratory program of a first-year general chemistry course comprising 43 students who were studying Chemistry as part of their Biology degree. This research aims to provide recommendations for creating a more effective learning environment in chemistry laboratories. To achieve this aim, the research was guided by a theoretical framework developed from the Model of Educational Reconstruction (MER) that brought together the three elements of the learning environment, student perspectives, and achieving the course content.

The pre-lab survey addressed the first research question regarding students' perspectives on the relative importance of interactions. It was found that before they commenced the laboratory program, the students thought that asking the instructor about procedures could be the most important interactions. The reason for students asking instructors instead of their peers may be because their chemistry background was not strong and it was natural that people would seek assistance from a relatively authoritative person. Additionally, the first-year students were familiar with the high-school teacher-driven teaching style and tended to ask for help from instructors. This is in line with former findings that students acted more as initiators in S-I interactions than did the instructors (Velasco et al., 2016).

With regard to the frequency of interactions that actually occurred, the students reported that they talked with each other more often than with the instructors during the laboratory sessions. This observation is consistent with ideas of socio-constructivism that underpins the MER framework in that meaningful learning for students is situated in social collaboration and interactions with other people, especially with peers. Students' self-reports and observations both showed that interactions over procedures occurred most frequently, with interactions about results the second most frequent, while interactions about concepts were less often, which is in line with the former finding of Kyle et al. (1979). Considering the fact that the students only had limited chemistry knowledge before this laboratory work and they were not given much freedom in these "cookbook style" laboratories, it is reasonable that more interactions were about following procedures. The instructor gave their marks at the end of each class, so the students had to hand in one complete laboratory notebook by the end of the class. This may explain why students thought that they spent more time on analysing results with their peers – to finish the task in time. Compared with these two kinds of goal-achieving interactions, interactions relating to discipline concepts occurred less often. The learners were possibly more focused on getting good scores than thinking about theory, or they might have been too busy manipulating equipment than considering the basic concepts. Sandi-Urena and his group members (2011) showed that students who were constantly challenged to scrutinize and solve problems were using metacognitive and problem-solving skills. Thus, questions and tasks with groups should be carefully designed to provoke students' thinking, self-assessment and argument development. Indirect interactions have not been studied in detail by researchers for face-to-face laboratories. However, students reported that they had engaged in a large number of these interactions as could be expected because people generally repeat behaviours that are well received and avoid those that result in punishment (Bandura & Walters, 1977). Students learn how to set up or manipulate some glassware by observing other groups, as well as listening to other people's conversations. Students in laboratories may also avoid errors by learning from other groups' mistakes.

With regard to the third research question, students with different achievement levels had different views on the importance and frequency of interactions. The preference for interactions with other people (instructors or other students) by high-achieving students might show that they were more confident (Austin, Hammond, Barrows, Gould, & Gould, 2018) and were not afraid of getting instant feedback. High achieving students implemented more interactions across all the four items (S-S, S-I, S-E, and I-I) compared with the other two groups. Other research has shown that high-achieving students were more self-regulated and the motivation to self-regulate was one of the driving factors in their academic achievement which is consistent with the MER (Austin et al., 2018; Mega et al., 2014). Thus they understood that learning from mistakes and correcting these mistakes were important in the learning process (Austin et al., 2018). That the lower achieving students preferred one-directional or interactions without instant feedback is consistent with research from Kousa et al. (2018), which showed that low-achieving students were likely to use the Internet, books or magazines to learn. Students' achievement level should be taken into consideration for curriculum designers (i.e., to prepare pre-lab activities, to improve the laboratory manual) and the instructors (i.e., to initiate some interactions with some students, assign groups according to student achievement levels) to meet each type of students' needs.

4.7 Limitations

A limitation of this article is the sample size being investigated, which comprised 43 students enrolled in one institution. Another limitation is that although it is assumed that people choose to act more frequently if they think something is important, more frequent interactions do not necessarily mean more meaningful engagement (Wagner, 1994). Whether there is a connection between high frequency of interaction between Student-Student and the anticipation of learning from instructors needs further analysis.

A further limitation is that the findings of observation are based on content analysis of verbal interactions at a whole-class level. The observer justified the features of the interactions by listening to students' conversations, their gestures and, for example, their watching of other groups. However, since there is a total of 20 students in the classroom, the observer sometimes could not unobtrusively walk closer to a sub-group to listen to its conversation. The use of audio and video recordings in the observation process could be used to overcome this limitation. It is also suggested that observations of a focused sub-group of students be conducted to provide an insightful understanding of the students' behaviours.

4.8 Implications for Practice

Although we recognise foregoing limitations, we believe that the findings reported in this chapter can provide information about interactions occurring in chemistry laboratories and highlight features that may guide future laboratory observations and the development of strategies to promote effective engagement in laboratories.

Firstly, for S-S Interactions, our research has shown that most of the laboratory work happens between students so the importance of S-S interactions should not be overlooked in planning laboratory activities even though a high frequency of S-S interactions does not necessarily mean a high constructive learning process. S-S interactions could be cooperative, competitive or individualist, and among them, cooperative interactions have been identified as best to promote peer tutoring, information exchange and academic achievement (Johnson, 1981; Johnson & Johnson, 1987). These findings suggest that basic structured guidance may be provided to encourage productive interactions among students. Considering student achievement levels, high-level students tend to be the leader of a group because they have high self-efficacy and are likely to interact more. In this way, if different level students were in one group, the low achieving students may lose the opportunity to express their opinions. By contrast, if low achieving students were allocated separately, they may lose the chance to learn from more competent peers. More research is needed to identify how these factors influence students' laboratory learning.

Secondly, for S-I Interactions, the pre-lab survey illustrated that students thought that interacting with instructors could be more important for their learning. Various studies also showed that teaching assistants' (TAs) play important roles in the learning process (Herrington & Nakhleh, 2003; Rodriques & Bond-Robinson, 2006; Stang & Roll, 2014). Currently, most of the instructors are PhD students, most of whom do not have an educational research background and lack of teaching experience. It is, therefore, necessary to provide suitable training programmes to help 'new' teachers be more confident and more effectively improve students' learning (Brouwer et al., 2017; Mocerino, Yeo, & Zadnik, 2015; Yang & Liu, 2004). We emphasize that in this training, not just the method of transferring knowledge, but also the way of communicating with students (i.e., how to talk with students to promote their thinking skills, to scaffold their learning instead of reducing their motivations, how to interact with different types of students) should be included.

Thirdly, for S-E Interactions, our study showed that the laboratory manual was considered to be a vital component of student learning. To address the problem that more time is spent on procedures or analysis of results than learning the major concepts of the discipline, the laboratory manual may be developed with logical design and the learning objectives included encouraging students' concepts. We believe that a well-designed laboratory manual can influence students' learning especially for the lower-achieving students, who assumed that the laboratory manual was more important than the high level achieving students before the laboratory. We also believe that asking for students' and the instructor's opinions about the laboratory manuals will help to improve them.

Fourthly, for I-I Interactions, our study showed that indirect or vicarious interactions can guide observers' behaviours in the learning process. This implies that indirect interactions should not be neglected in course design and class processes. Since most of the indirect interactions will happen between different groups in proximity, it might be beneficial to take indirect interactions into consideration when the instructors are assigning groups. Further research needs to be implemented to understand more about the influence of indirect interactions in chemistry laboratories.

Overall, to balance the frequency and length of these interactions with student engagement, learning experience and learning outcomes should be included in curriculum design, instructor training and laboratory class processes. In addition, students may need to be given some information about interactions during the orientation. The three elements in MER - students' perspectives, laboratory content and learning environment mutually influence each other and they should be taken into account when designing science laboratory learning.

4.9 Chapter 4 Summary

This chapter comprised the first study, which was the foundational step of all the studies of this thesis. In this study, the theory of MER and findings from literature review guided the design of the first version of the pre- and post-lab survey forms, as well as the items in the laboratory observation sheet. Results from the laboratory observation validated the findings from the post-lab survey. Therefore, in the following two studies in face-to-face chemistry laboratories (Study 2 and Study 3), the post-lab survey was be implemented as the main data collection method in terms of the frequency of the interactions. Chapter 5 is a further investigation of the reliability and validity of the data that resulted from the instrument in face-to-face laboratories.

CHAPTER 5: DESIGN AND VALIDATION OF AN INSTRUMENT TO MEASURE STUDENTS' INTERACTIONS AND SATISFACTION IN UNDERGRADUATE LABORATORY CLASSES

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Research in Science Education. doi:10.1007/s11165-020-09933-x

5.0 Chapter Outline

This chapter describes and evaluates the instrument designed in this thesis to measure interactions and student satisfaction in undergraduate face-to-face laboratories. Section 5.1 introduces the necessity of designing an instrument for measuring interactions and satisfaction in undergraduate laboratories, from the viewpoint of students. Section 5.2 describes the methods used to undertake this study. Section 5.3 examines the results of reliability and validity and discusses the applicability of each part of the instrument. Section 5.4 examines the implications for the understanding of undergraduate science laboratories, by conducting this instrument. Section 5.5 proposes the implications for future research of using this instrument in undergraduate laboratories. Finally, Section 5.6 illustrates the limitations of this study.

5.1 Introduction

The laboratory has long been thought to be an essential aspect of science teaching (Hofstein & Lunetta, 2004; Millar, 2004) and has become more important in facilitating teaching and learning across STEM disciplines in order to connect to real-world events. Various learning objectives, such as improving students' understanding of science disciplines, increasing their interest and motivation, and enhancing practical skills, are assumed to be developed through laboratory work. However, there are contrasting opinions about the effectiveness and benefits of laboratories compared to a large amount of money, personnel, resources, and time spent on them (Elliott et al., 2008). Although there have been many studies that involve laboratories over recent years, there is a need for further studies that can provide sufficient evidence to sustain and validate the integral role of laboratories in chemistry education and science education more generally.

A large number of previous studies, attempting to analyse learning through laboratory classes, identified instructor activities to engage students in meaningful learning that was consistent with current educational goals (Sadler et al., 2011; Velasco et al., 2016; West et al., 2013). In addition, systematic observation tools were also implemented to understand the impact of professional development on instructors' behaviours (Viskupic et al., 2019). While instructors do play pivotal roles in the teaching process, students' perspectives also need to be incorporated into laboratory design because the students are the key stakeholders who are actually engaged in conducting experiments, analysing data, and constructing knowledge. Further, research has shown that students' perceptions of the laboratory learning environment are mostly inconsistent with those of teachers (Tsai, 2003); hence the need for this study which has its emphasis on the design of an instrument that captures students' perceptions of laboratory learning.

One method of investigating students' ideas of the laboratory was by the use of a questionnaire or instrument. Various instruments, or tools, had been designed to probe different facets of science and engineering learning, including the *Attitude toward the Subject of Chemistry Inventory (ASCI)* (Barrie et al., 2015), the *Meaningful Learning in the Laboratory Instrument* (*MLLI*) (Galloway & Bretz, 2015), the *College Chemistry Self-Efficacy Scale (CCSS)* (Uzuntiryaki & Çapa Aydın, 2009), the Physics Learning Profile and Physics Learning Self-Efficacy (PLSE) (Lin, Liang, & Tsai, 2015), and the Constructivist Multimedia Learning Environment Survey (CMLES) (Maor & Fraser, 2005).

The above instruments provide valuable information about students from one or more aspects of the science laboratory. However, none of these studies measured social factors, the relationship between human behaviours and their environment. The importance of the social environment on learning originated from the cultural-historical approach and was reinforced as distributed cognition (Cole & Engeström, 1993) which emphasized that knowledge was a process, not an entity rooted in the mind of one individual (Nakhleh et al., 2002). From this viewpoint, learners construct knowledge not in a static way, but by interacting with the environment.

The laboratory has a unique characteristic in that the social environment is less formal than the typical classroom and where the learning process can play crucial roles in students' learning experience. In this way, the extent to which learners interact with the laboratory environment, the instructors and each other, may have a powerful influence on the learners' laboratory experiences. On the other hand, students' ratings on satisfaction levels with individual laboratories may reflect students' learning experience and consequently be an evaluation of their learning process. However, according to Hofstein and Lunetta (2004), little attention has been paid to the promotion of communication and collaboration in science laboratories, and less on the analysis of group process and reflective discourse. A review of the more recent literature shows that there also is a scarcity of studies pertaining to the correlation between the frequency of interactions and satisfaction in undergraduate science laboratories, Therefore, the purpose of this paper is to present the development of a new instrument and associated statistical analysis for measuring student interactions and satisfaction in science laboratories.

This paper presents the design and validation of an instrument entitled *Interactions in Undergraduate Laboratory Classes* (*IULC*) that measures a range of interactions and students' satisfaction in undergraduate chemistry laboratories. The instrument is designed to collect information about the frequency of interactions (per laboratory class – never, once, a few times, many times), the learners' overall satisfaction levels (per laboratory class – 5 Likert scales, Strongly Disagree to Strongly Agree), and the importance of these interactions (ranked in order). Evidence of the quality of the instrument and possible uses are addressed. The link between IULC and the one introduced in Chapter 4 are as follows: the post-lab survey used in Chapter 4 (first phase) set the foundation for the final design of IULC; IULC (second phase) was developed based on the revision of the post-lab survey in Chapter 4. Detailed information about the two phases is included in the following section.

5.2 Methodology

5.2.1 Development of UILC

Background to the Development of the Instrument (first Phase) Initially, a group of seven education researchers with different research and teaching backgrounds, in education, physics, chemistry, and engineering, considered and documented the possible interactions that he/she assumed might occur in undergraduate laboratories during a fixed period of time. The ideas were shared and discussed, a literature review search was conducted, and on-site laboratory class observations were carried out, resulting in the first development of the Interactions in Undergraduate Laboratory Classes (IULC) instrument (the format of this version was shown in Section 4.4.3, Chapter 4). In this version, interaction classifications in the IULC fell into four types: Student-Student (S-S) Interactions, Student-Instructor (S-I)

Interactions, Student-Equipment (S-E) Interactions, and Indirect Interactions (I-I) (Moore, 1989; Sutton, 2001). Specifically, the interactions were divided into different sub-items based on the content of behaviours between students and the laboratory environment. For example, in S-S and S-I interactions, topics related to the laboratory content were divided into procedures, results or concepts, while unrelated topics were separated into not directly related or purely unrelated. The type of activity when students discussed chemistry concepts that were not part of the current experiment was assigned as 'not directly related'. Also, the types of topics discussed by students such as sports or entertainment were assigned as 'not related'. A previous study (see Chapter 4 for details) only included the frequency of interactions in the laboratory using the four types. Two methods to measure the frequency of interaction were conducted, namely a self-reported form (the post-lab survey) and the on-site observation conducted by the observers. The design was to provide a multi-dimensional data collection method on the measurement of the frequency of interactions. Results from observers aligned well with the students' self-report with regard to the frequency of interactions. It proved that the self-reported instrument was suitable for the introductory chemistry unit and therefore the instrument was used as the only data collection method to a broader context. However, after the initial study was implemented, a need was seen to better account for the nature of the chemistry laboratory learning environment. Therefore, modifications were made to correlate the interactions with the students' satisfaction.

Final Design of the Instrument (second Phase) in the final version of the IULC instrument shown in Figure 5.1, two new parts, Satisfaction and the Importance of interactions (Parts 2 and 3) were included. The Frequency of interactions (Part 1) meant the occurrence of interactions in the science laboratories provided a quantitative measure of student behaviours. The four options regarding the frequency were 'never', 'once', 'a few times' and 'many times'. In the previous instrument, only three options were used. After discussion in the research team, it was found that more detailed information was needed to understand the frequency of students' interactions. Therefore, in this step of design, 'once' was added to classify the frequency of interactions more specifically. In addition, 'a few times' means the times of more than once, while not once. The addition of 'once' also made the coverage of the frequency of interactions relatively complete. Results from Part 1 illustrated how the frequency of each item occurred when the students were undertaking the laboratories. The overall satisfaction levels (Part 2) were designed as a single measure to depict the overall experience of the students immediately after the completion of the laboratory work. The responses for the satisfaction item ranged from less satisfying to a very satisfying experience, and five values were assigned from strongly dissatisfied (1) to strongly satisfied (5). In the agree-disagree rating scales, five, seven or eleven categories were commonly used options. The number of categories in this agree-disagree rating scales was assigned as five in the study. Five instead of seven or eleven categories were chosen because using five answer categories had higher quality than seven or eleven in agree-disagree scales (Revilla, Saris, & Krosnick, 2013).

For further analysis between overall satisfaction with the factors of frequency and importance, the importance of interactions (Part 3) was introduced to understand what types of interactions the students believe were important for learning. Part 3 required the students to select five important interactions (ranked from 1-5 in terms of relative importance) out of the previous 15 interactions in Part 1. The respondents were required to choose five, not three or more than five, out of the total 15 interactions. Three choices could not provide enough information about the importance of interactions, while more choices might cause confusion and need more time to complete the form. Therefore, five was the most appropriate number used for this study. Part 3 was added because we became more aware that more frequent interactions did not necessarily mean the interactions played important roles in learning. A comparison between the frequency and the importance of interactions was assumed to provide a deeper understanding of student behaviours. For example, a less prominent type of interaction may be an indispensable part of the learning process. It was also believed that the multiple dimensions in the revised instrument had the possibility to provide richer information than the first version (Table 4.3). The details are listed in Figure 5.1.

Date: ____________ Time: ___________ Unit: ____________________________________

Student ID								Family Name	Given Name(s)

Part 1: Reflecting on the laboratory class you just completed

1. (*Student-Student Interactions*) **Did you talk to another student about ...**	**Never**	**Only once**	**A few times**	**Many times**
1.1 the procedures, protocols or lab equipment?	0	1	2	3
1.2 the basic science concepts behind the lab?	0	1	2	3
1.3 analyzing your results?	0	1	2	3
1.4 discipline topics not directly related to the lab?	0	1	2	3
1.5 topics not related to the lab?	0	1	2	3
2. (*Student-Teacher Interactions*) **Did you ask a teacher about ...**				
2.1 the procedures, protocols or lab equipment?	0	1	2	3
2.2 the basic science concepts behind the lab?	0	1	2	3
2.3 analyzing your results?	0	1	2	3
2.4 discipline topics not directly related to the lab?	0	1	2	3
2.5 topics not related to the lab?	0	1	2	3
3. (*Student-Equipment Interactions*) **Did you ...**				
3.1 read the lab manual/instructions associated with this lab?	0	1	2	3
3.2 use the Internet for technical assistance, data analysis or for concepts behind this lab?	0	1	2	3
4. (*Indirect Interactions*) **Did you learn by observing someone else's interactions in the lab, such as ...**				
4.1 observing another student's experimental setup or behavior	0	1	2	3
4.2 listening to a student/group of students asking another student for help/advice	0	1	2	3
4.3 listening to a student/group of students asking a teacher for help/advice	0	1	2	3

Part 2:

(Student satisfaction) **Did you think…?**	**Strongly Disagree**	**Disagree**	**Neither Agree nor Disagree**	**Agree**	**Strongly Agree**
Did you think the quality of this experiment compared favorably with your other face-to-face laboratory experiments?	1	2	3	4	5

Part 3: Please **choose ONLY 5 of those 15 items (from 1.1 to 4.3)** that you think are most important in helping you successfully complete the lab that you just finished and **rank them.**

Rank	1	2	3	4	5
Item Name					
Example	*2.2*	*1.3*	*1.4*	*3.2*	*2.4*

Figure 5.1 Items and students' choices for the three parts of the IULC instrument

5.2.2 Participants

In order to validate the results from the IULC instrument, a typical first-year undergraduate chemistry laboratory class with a high number of student enrolments was selected as the test-case upon which to base an analysis of the instrument's accuracy. As the data of this chapter came from Study 2, the participants were the same as those from Study 2. They were first-year undergraduates who were enrolled in the same unit as those from Study 1, while in different years. Compared to other units, many more students were enrolled in this unit and therefore more data could be collected. In addition, in most universities, the number of first-year chemistry non-major students is large and the analysis on their perceptions on interactions was presumed to provide wide usage for the development of relevant courses.

The student participants involved in this study were undergraduate students not majoring in chemistry, from 19 classes at one university. Many students had a limited chemistry background; some students had never studied chemistry in senior high school, while a few others, who had studied high school chemistry, had failed the examinations. This unit has been designed to provide a chemistry background for the students' future learning in the areas of biology and biomedical sciences.

5.2.3 Laboratory Content

The IULC instrument was used to collect data toward the end of laboratory classes. The goals of the laboratory involved in this study, named as 'Identification of common ions in solution', included conducting qualitative chemical tests, inferring chemical concepts from experimental observations and using an appropriate style to report the findings. In this experiment, the students were provided with a brief pre-lab explanation of the safety rules and key procedures at the beginning of the class. The students, arranged in random pairs, started the laboratory to mix the different solutions together as specified in the laboratory manual, to observe the phenomenon, record the observations and answer the questions in the laboratory worksheet.

5.2.4 Data Collection and Data Screening

Before the beginning of Lab Session 1, the students were provided with a Participant Consent Form and informed that the project would be carried out in line with the National Statement on Ethical Conduct in Human Research (2007). The students were also told that their participation was completely voluntary, and they could withdraw at any time. Each student was provided with a survey toward the end of the laboratory and 204 out of the 575 students completed the survey in Lab Session 2. All data were collected in paper form and then transformed into Excel spreadsheets for further analysis. All of the data analysis was conducted using R version 3.5.1 (Graesser et al., 2018). Any response with multiple answers and missing data were excluded for each part of the instrument.

5.2.5 Data Analysis Strategy

Multiple methods were conducted in terms of the three parts of the instrument. For the first part of the instrument, namely, the frequency of the interactions, three steps were conducted to analyse the data. The first step was descriptive analysis; the second stage was factor analysis (Exploratory Factor Analysis and Confirmatory Factor Analysis); and the third step was the analysis of internal consistency. All descriptive statistics were performed in SPSS 25.0 for each item score. Mean scores are reported in both scales for better understanding and comparison. Examination of skewness and kurtosis (both less than 2) revealed good normality of the item scores. The data obtained from Part 1 of the instrument was validated via Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). In the process of internal consistency, a single-factor CFA model was used to determine the suitability of either Cronbach's alpha or omega total as an estimate of scale internal consistency.

Factor Analysis A good approach to explain data from self-reporting instruments is factor analysis (FA) (Bryant, Yarnold, & Michelson, 1999) which reduces the number of variables to some latent sets and to find the links between the measured factors and the latent dimensions (Taherdoost, Sahibuddin, & Jalaliyoon, 2014). Among the two types of factor analysis, Exploratory Factor Analysis (EFA) is used when there are no clear expectations about the number of factors, while Confirmatory Factor Analysis (CFA) is used to validate the fit of presumed theories or expectations about the number of constructs (Williams, Onsman, & Brown, 2010). In this study, the data resulted from Part 1 were randomly split into two parts initially (Creswell & Creswell, 2018). For one part of the data, an Exploratory Factor Analysis of the results was conducted to identify the underlying factors in the instrument. For the other half, a Confirmatory Factor Analysis was conducted to assess how well the model fits the data. A one-factor model was implemented as a comparison. In the whole study, the following values were used as cut-offs: comparative fit index (CFI) or Tucker–Lewis index (TLI) ≥ .95, the root mean square error of approximation (RMSEA) ≤ .06, the standardized root-mean-squared residual (SRMR) < .08 (Hu & Bentler, 1999).

Scale Reliability Firstly, it should be pointed out that in this process to increase the sample size, the two parts of the data were recombined together to test the reliability. For scale reliability, the analysis process was as follows: firstly, results from the factor analysis were analysed to check whether the items were unidimensional. Consequently, an overall internal consistency value or a single-administration reliability coefficient under each interaction scale was calculated (Komperda, Hosbein, & Barbera, 2018). Secondly, to determine which coefficient was appropriate in this study, a single-factor CFA model for each interaction scale was analysed using the congeneric and tau-equivalent model (Komperda, Pentecost, & Barbera, 2018). In the congeneric model, the degrees of association between each item and the common construct are not necessarily the same, while in the tau-equivalent model, the factor loadings are restricted to be equivalent (Cho & Kim, 2015; Graham, 2006; Harshman & Stains, 2017). Cronbach's Alpha is appropriate under a condition when the assumptions for the tau-equivalent model were met, and Omega is suitable when the assumptions for the tau-equivalent model are not met but fit for the congeneric model (Komperda, Pentecost, et al., 2018). In this study, as shown below in Table 5.3, two items fit the tau-equivalent model and three items fit the congeneric model. The coefficient value was calculated by the R package userfriendlyscience (Version 0.7-2) (Gadermann, Guhn, & Zumbo, 2012; Peters, 2018).

For the second part of the instrument, the overall satisfaction, because the values of satisfaction were ordinal, so the Spearman correlation coefficients were conducted to find the strength of the relationship between students' perceptions of the frequency of interactions and their overall satisfaction (Field, 2009).

For the third part of the instrument, the percentage of responses to the importance of the types of interactions was calculated. The results of 'Many Times' obtained in Part 1 of the instrument were graphed with the results of Part 3 as a comparison between the frequency and importance of interactions.

5.3 Results and Discussion

5.3.1 Analysis of the Frequency of Interactions (Part 1 of the Instrument)

To address RQ 1.2. "What type and range of frequency of interactions do students engage in during chemistry laboratory work?", the item response distributions in terms of Part 1 of IULC, the frequency of interactions, are presented in Figure 5.2. Overall, more interactions occurred between student-student talking about results and reading laboratory manuals, whereas students tended to interact less about unrelated or not directly related topics with instructors. In addition, interactions with other students happened more than those with instructors.

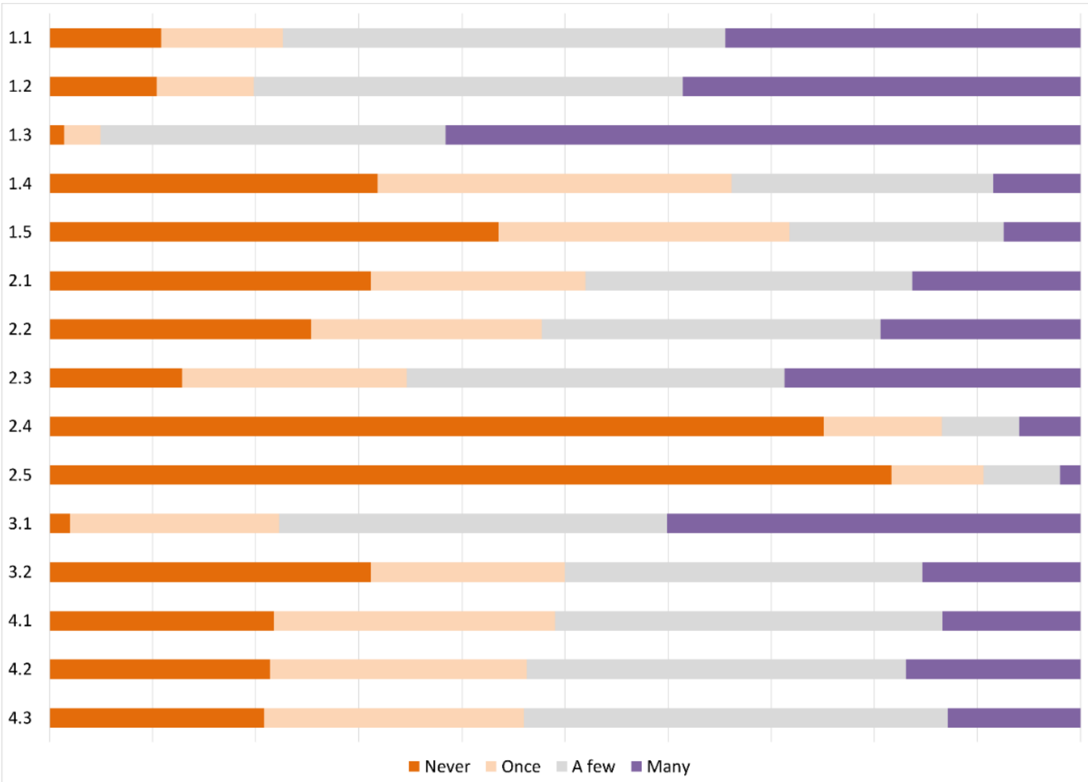


Figure 5.2 ***Distribution of student responses to the frequency of interactions (Part 1) of IULC***

Note: 1. N = 204. 2. The items on the vertical axis refer to the item numbers in the instrument. For a full description of the items see Figure 5.1.

Out of the 204 responses, 195 without missing data were used for factor analysis. A random separation led to the two parts of data, with the first part including 109 responses and the second part including 86 responses. EFA was conducted with the first part of the data and CFA was carried out using the second part of the data.

Exploratory Factor Analysis (EFA) Initially, a large number of values from the two-by-two matrix correlation fell in the midrange (0.30-0.70), indicating that factor analysis is highly likely to be applicable in this context. The rotation process was an oblique method, varimax rotation. After the initial exploratory factor analysis was conducted, all items fell clearly into five factors, with factor scores in the range 0.61–0.97. No significant cross-loadings were found, all secondary loadings had eigenvalues that were at least 0.25 smaller than the dominant loadings.

Table 5.1 Interaction Items with Factor and Loading Profiles

Factors and items	**Factor Loadings**				
	F1	***F2***	***F3***	***F4***	***F5***
Factor 1 (F1): I-I					
Listening to S-S	.87				
Listening to S-I	.76				
Observing Others	.65				
Factor 2 (F2): S-S Lab-related Interactions (SSR)					
Procedures		.83			
Results		.72			
Concepts		.63			
Factor 3 (F3): S-I Lab-related Interactions (SIR)					
Concepts			.79		
Results			.69		
Procedures			.61		
Factor 4 (F4): S-I Lab-unrelated Interactions (SIU)					
Not Directly Related				.95	
Not Related				.65	
Factor 5 (F5): S-S Lab-unrelated Interactions (SSU)					
Not Related					.97
Not Directly Related					.68

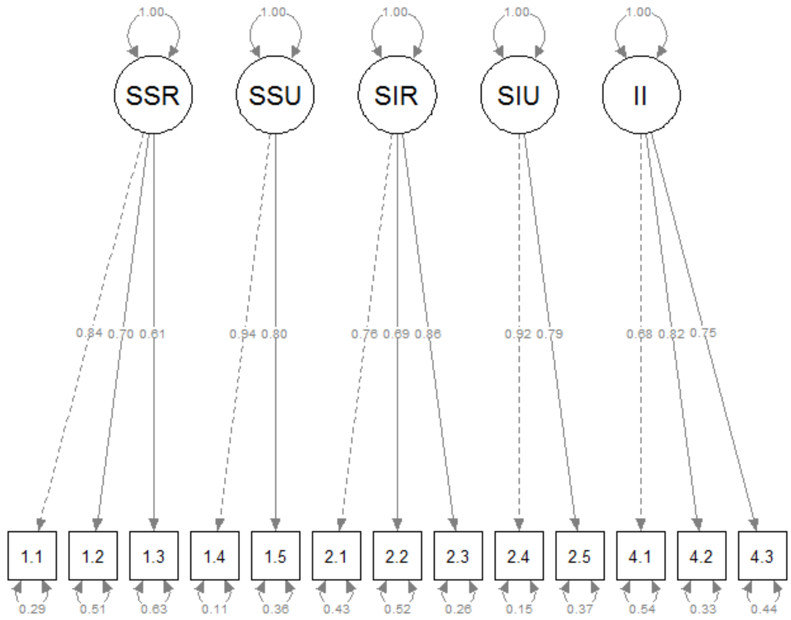
Five strong distinct factors emerged and the instrument statements organized by factors and ranked by loadings magnitude within the factor are shown in Table 5.1. The percentage of variance explained by each factor was: Indirect interactions (13.1%), S-S Lab-related (11.5%), S-I Lab-related (11.2%), S-I Lab-unrelated (10.5%), and S-S Lab-unrelated (10.4%). The cumulative percent of variance explained by the factors was 56.7%.

The first factor, named as Indirect Interactions, involves indirect interpersonal practical interactions, including listening to conversations between and among learners and/or instructors, as well as observing other students' behaviours. This scale comprises the learning that happens indirectly or is assumed to have happened among some group of students.

The second factor is about S-S Lab-related Interactions, with three items, namely S–S procedures, concepts, and results. All of these items can be viewed as student-centred interactions pertaining to laboratory activities with their peers.

The third factor includes three items, accounting for S-I talking about concepts, procedures, and results. All of these items are concerned with aiming productive interactions between learners and instructors. This scale accounts for the guidance about how the demonstrators assist the learners' laboratory process. The fourth and fifth factors are both interpersonal interactions that are not directly or indirectly related to the individual laboratory context, between students and other students/instructors. There are concerns about the factors that do not include three to five items within them (Raubenheimer, 2004). However, in these two situations, the plausibility of the two-item factor scales is considered to be acceptable where the scales fit into the theoretical assumption of the differentiation of interactions in laboratories and both of the two items within factor four and factor five represent the domain of each variable (Gosling, Rentfrow, & Swann, 2003; Kim, Ku, Kim, Park, & Park, 2016; MacCallum, Widaman, Zhang, & Hong, 1999). Furthermore, the two items, 'not directly related' and 'not related' among S-S or S-I interactions, belonged to the events between people that were not included in the laboratory content which was a practical outcome of laboratory interactions (Gosling et al., 2003). These two items did not belong to factor one and factor two, which were both interactions between people pertaining closely to the ongoing laboratory activity. The initial theory suggested that the items under S-I and S-S interactions were different, the EFA results confirmed the assumption that some activities were connected directly with the existent laboratory content (Factor 2 and 3), while others were not connected directly with the content (Factor 4 and 5). As is shown in Figure 5.3, these results are confirmed in the CFA (Hurley et al., 1997).

Confirmatory Factor Analysis (CFA) was conducted to estimate the goodness of fit for the five-factor method.



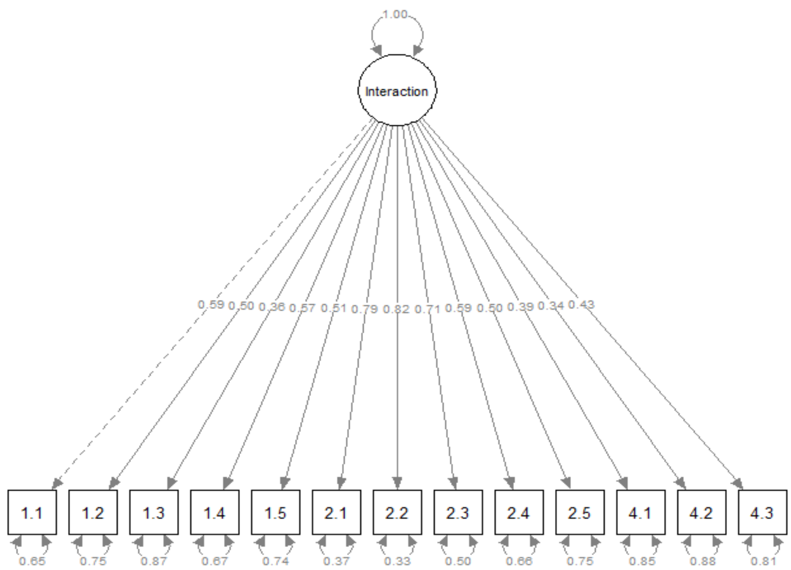


Figure 5.3** **Standardized parameter estimates for one-factor and five-factor models

Note: 1. the large ovals designate the latent variables, the small circles report the residual variances, and the rectangles indicate the observed variables. Items were set to load on their assigned factors only. 2. All factor loadings are significantly different from 0 ($p < 0.05$). 3. N = 86.

A five-factor measurement model was conducted, with thirteen items from Figure 5.3 showing the same five types of interactions based on results from EFA. An alternate one-factor model was also conducted to investigate more parsimonious models. The fit indices of the five-factor model were: CFI = .954; TLI = .935, RMSEA = .073, and SRMR = .058. The five-factor model fit the data reasonably well according to accepted criteria (Hu & Bentler, 1999). By contrast, the fit indices of the one-factor model were: CFI = .508; TLI = .410, RMSEA = .218, SRMR = .146. The fit statistics for the one-factor model were uniformly worse than those for the five-factor model and the CFI did not meet the accepted criteria. Therefore, the five-factor model was more tenable even though in factor 4 and factor 5 only two items were included.

Scale Reliability Results from factor analysis showed that this was not a unidimensional model, therefore, additional CFA models were analysed to test the assumptions of congeneric and tau-equivalent models. The results are listed in Table 5.2.

Table 5.2 the Congeneric and Tau-Equivalent Data-Model Fit for Each Scale

	Scale	χ^2	*p*	**CFI**	**TLI**	**RMSEA**	**SRMR**
The Congeneric data-model fit	I-I	176.755	<.001	**1.000**	**1.000**	**.000**	**.000**
	SSR	149.858	<.001	**1.000**	**1.000**	**.000**	**.000**
	SIR	206.155	<.001	**1.000**	**1.000**	**.000**	**.000**
	SIU	N/A	N/A	N/A	N/A	N/A	N/A
	SSU	164.475	<.001	**1.000**	**1.000**	**.000**	**.000**
The Tau-equivalent data-model fit	I-I	176.755	<.001	**.981**	**.971**	.093	**.065**
	SSR	149.858	<.001	.841	.761	.245	.131
	SIR	206.155	<.001	**.960**	.940	.144	.088
	SIU	147.692	<.001	**1.000**	**1.000**	**.000**	**.000**
	SSU	164.475	<.001	**1.000**	**1.000**	**.000**	**.000**

The scale reliability tends to have lower inter-item correlations in conjunction with the fact that only two items were included in one factor (Gosling et al., 2003). However, in the study of this thesis, the values of Cronbach's alpha and Omega were all acceptable scale reliabilities.

Table 5.3 Scale Internal Consistency Estimates, either Omega or Cronbach's Alpha Presented

Scale	*F*1(I-I)	*F*2 (S-S Lab-related)	*F*3 (S-I Lab-related)	*F*4 (S-I Lab-unrelated)	*F*5 (S-S Lab-unrelated)
Internal consistency	.80#	.78#	.82#	.86^	.83^

Note: # were omega values, ^ were Cronbach's alpha

Of the five tau-equivalent model values, only S-S Lab-unrelated and S-I Lab-unrelated showed acceptable data-model fit according to the cut-off values used in this study (CFI or TLI ≥ .95, RMSEA ≤ .06, SRMR < .08). For these two values, Cronbach's alpha was reported in Table 5.3. Three of the five tau-equivalent model values did not fit the cut-offs; therefore a value of Cronbach's alpha was not appropriate. However, in the congeneric model, the three scales meet the criteria and omega was suitable to be reported in Table 5.3. The scale reliability tends to have lower inter-item correlations in conjunction with the fact that only two items were included in one factor (Gosling et al., 2003). However, in the study of this thesis, the values of Cronbach's alpha and Omega were all acceptable scale reliabilities.

5.3.2 Analysis of Overall Satisfaction (Part 2 of the Instrument)

To address RQ 1.7. "How does the frequency of interactions and student satisfaction correlate in chemistry laboratories?", Spearman's rank-order correlation made to correlate the frequency of interactions in terms of the previous five scales and the overall satisfaction is shown in Table 5.4. As the values of satisfaction were ordinal, so Spearman's rank-order correlation, instead of Pearson's *r (Field, 2009)*. There was a lower overall number of respondents compared with results from those from Part 1 because some students left Part 2 blank while the first part was completed.

As seen from Table 5.4 that the Spearman's rank-order correlation coefficients for S-I Lab-related and S-I Lab-unrelated (number of 'many') and satisfaction were positive and significant, while the coefficients for S-S Lab-related and S-I Lab-unrelated (number of 'never') and satisfaction were significantly negative. This illustrated that the more S-I lab-related and S-I lab-unrelated interactions appeared, the more satisfied that the students were with the laboratory. Similarly, the more that S-S Lab-related and S-I Lab-unrelated interactions not happening, the less satisfied that the students were with the laboratory. By contrast, the other interactions had no significant correlation with the satisfaction levels.

To compare the results from Figure 5.2 and Table 5.4 firstly S-I lab-related (SIR) activities did not occur as many times as S-S Lab-related ones (SSR). However, it was the number of many times of SIR, not SSR that had a significant correlation with the satisfaction levels. Furthermore, even though S-I Lab-unrelated (SIU) interactions did not occur very frequently at all, they still related significantly with the satisfaction levels.

Table 5.4 Spearman's Rank-Order Correlation Coefficient for the Frequency of Factors/Items with Overall Satisfaction

Scale	Number of 'never' and satisfaction	Number of 'once' and satisfaction	Number of 'a few' and satisfaction	Number of 'many' and satisfaction
Factor 2: SSR	-.160*			
Factor 3: SIR				.166*
Factor 4: SIU	-.176*			.147*

*Note: *correlations are significant at the .05 level, only statistically significant values were illustrated, (N = 187)*

5.3.3 Analysis of the Importance of Interactions (Part 3 of the Instrument)

To address RQ 1.3. "What do undergraduate students consider to have been important interactions after the completion of the chemistry laboratories?", The importance of interactions obtained from Part 3 was analysed.

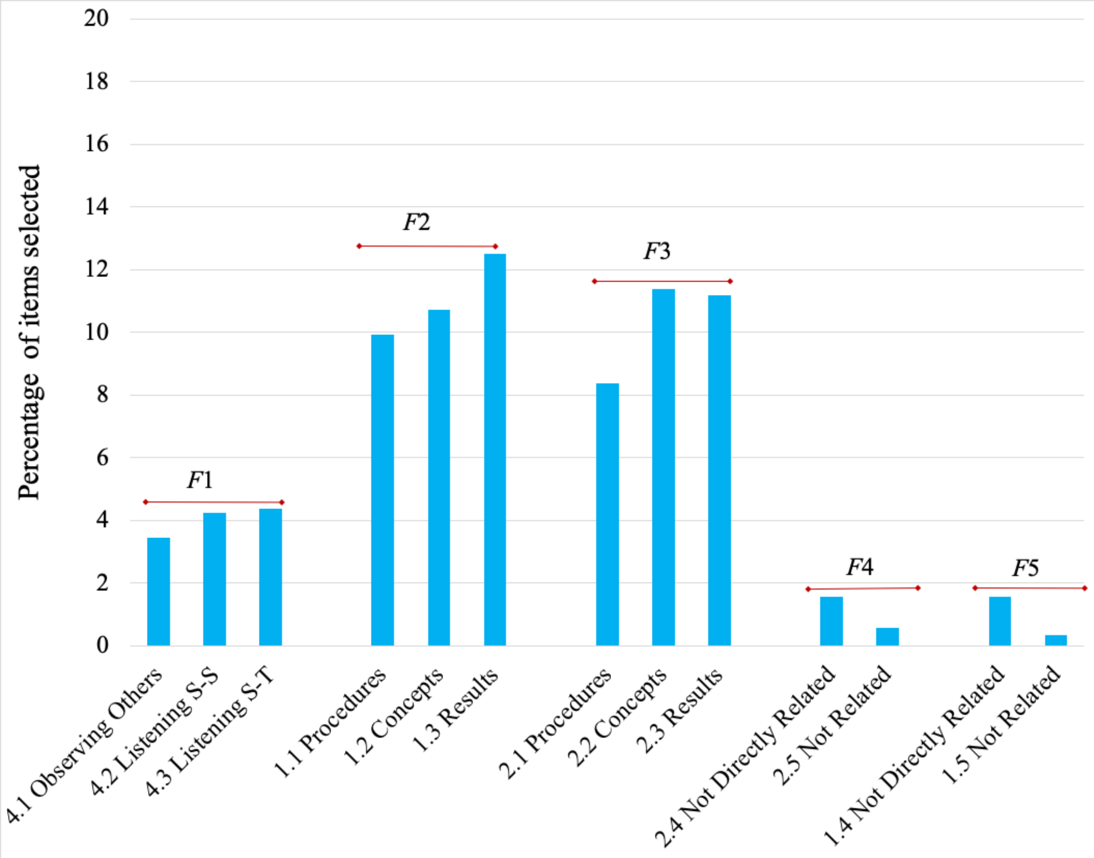


Figure 5.4** **Percentage of importance of the five scales, sorted by task types, reported by students after undertaking the laboratory work.

Note: Data obtained from the post-lab survey N = 179

The data in Figure 5.4 showed that to interact with the other students about results was the most important interaction, followed by S-I concepts, S-I results, and S-S concepts respectively. Interestingly, I-I was reported to be important types of interactions in the laboratories. It is also shown in that there were more Lab-related interactions between the students than among S-I.

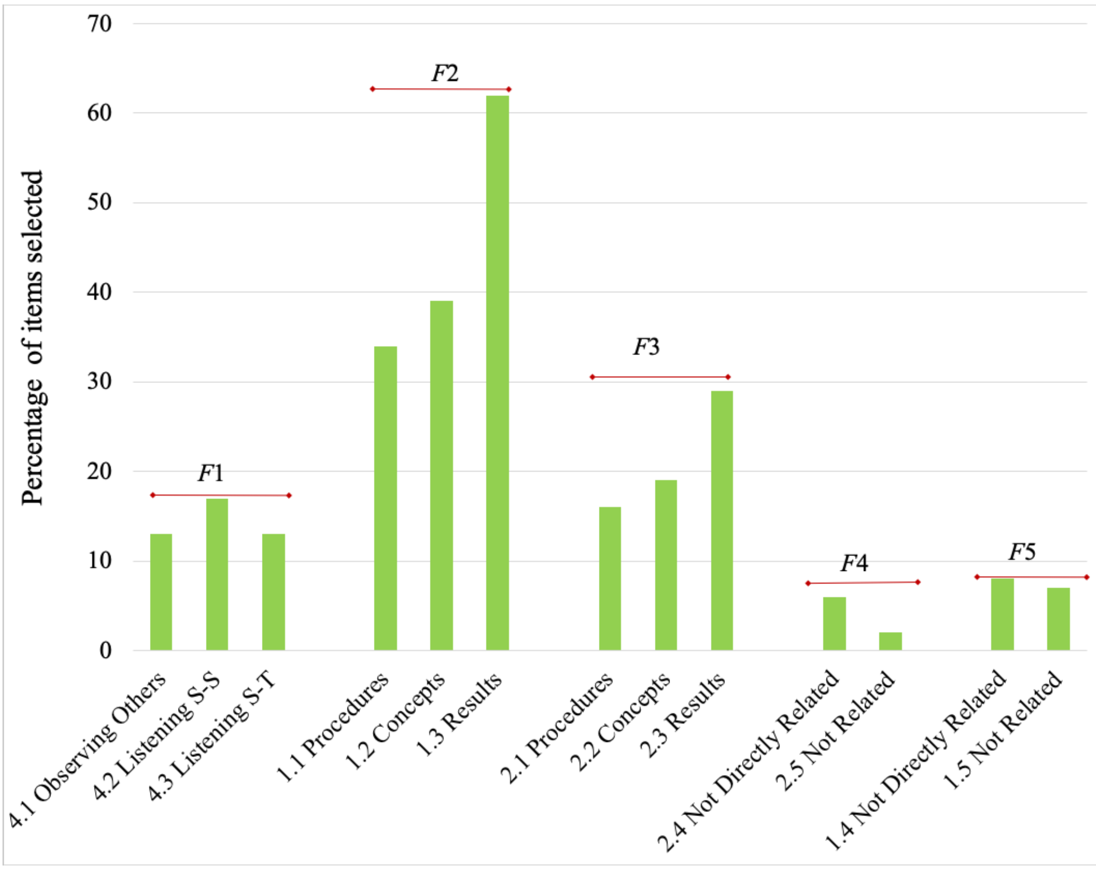


***Figure 5.5* Percentage of 'many times' of frequency of the five scales, sorted by task types, reported by students after undertaking the laboratory work.**

Note: 1. Data obtained from the post-lab survey (N = 203) 2. The percentage of each item is not equal to 100% because only data of 'many times' are presented, data of 'never', 'once' and 'a few times' are not included

To provide more information about the connection between the importance of interactions and the frequency of them, the frequency of 'many times' were graphed in Figure 5.5 separately (the distribution of all responses has been included in Figure 5.2). The comparison between the two sets of data presented in Figures 5.4 and 5.5 focused on the difference between the five factors, not on individual students. Therefore, the two sets of data were not paired by the individual respondent. To compare Figure 5.4 and Figure 5.5, it can be seen that generally, more S-S interactions occurred more frequently than S-I interactions. However, compared to S-S interactions, even though S-I interactions were assumed to relative importance, the frequency of S-I interactions occurred much less frequently. Among the S-I interactions, concepts were reported to be important, but happened less frequently than with results.

5.4 Implications for the Improved Understanding of Teaching and Learning in Undergraduate Laboratories

Motivated by, and aligned with the theory of distributed cognition, the development of the IULC instrument presented in this paper captured student experiences from the viewpoint of learners in a science laboratory. Consistent with the implied theoretical background, the students' interactions and satisfaction with specific laboratories were influenced by the learning environments. Thus, the present work is able to contribute to the literature of social characteristics of undergraduate science laboratories by providing an instrument that can be used to collect students' perceptions of laboratory interactions and satisfaction levels.

Exploratory and confirmatory factor analysis was conducted to analyse the internal structure of the test-data resulted from the first part of the instrument. Five factors emerged from the exploratory factor analysis, and the results were validated by the confirmatory factor analysis. The two parts, Satisfaction, and Importance were analysed based on the five-factor dimensions. Correlation analysis was conducted to investigate the relationship between the five-scale interactions and student achievement levels. Both the students' laboratory marks and their final examination marks had no significant correlations with the interactions (results not presented in this chapter). However, the results obtained using the IULC instrument was able to identify significant relationships between the interactions and their satisfaction levels and these links are briefly discussed below.

Even though SIR interactions did not occur so often, these were reported to be very important after the completion of the laboratory. Considering that only S-I interactions, both lab-related and lab-unrelated, had positive correlations with the satisfaction levels, the frequency and length of productive S-I interactions need to be further studied. Stang and Roll (2014) suggested that increasing the number of interactions between teaching assistants and students had positive effects on students' motivation and engagement. In addition, Velasco et al. (2016) reported that most of the S-I verbal conversations were initiated by students and they were independent of the instructors' instructional styles. It is, therefore, necessary to include pedagogy strategies in laboratory instructor training programs to encourage productive and effective S-I interactions.

Indirect Interactions had long been ignored or taken as granted in undergraduate laboratories. However, from this study, at least the students thought they had learned a lot in this way. It is suggested more emphasis is placed upon the effects of Indirect Interactions in the curriculum and laboratory design.

5.5 Implications for Future Research in Undergraduate Laboratories

The instrument developed, validated and trialled in this research provides information about students' experiences from the viewpoint of social factors. The instrument is easy to use when collecting data from students' self-reporting of the frequency of interactions in science laboratories. The aim of this instrument was not to assess the efficiency or effectiveness of learning in chemistry laboratories, but rather to provide a concise overview of the interactions occurring in the laboratory activity. Results from this instrument can be further used to investigate the influences of interactions on students learning in all science disciplines. In addition, the results obtained through the use of the instrument can be used for curriculum designers, laboratory instructors, as well as the students. For example, the interrelations between the frequency of interactions within three categories of student achievement levels were identified and suggestions were made for educators and learners (Wei et al., 2018). Educators interested in the learning process and learning outcomes of various laboratory types could use the present instrument as a first-step analysis that informs research on students' learning in different laboratories.

5.6 Limitations

The first limitation of this study is that the instrument was used to collect data only at one university; further studies in other institutions can evaluate the applicability and generalizability of this instrument. A second limitation is that when designing the instrument, there were few sub-items under the S-E laboratory manual and S-E Internet interactions. This may be the reason why no aggregated factors were identified relating to S-E. However, it is believed that the laboratory manual is an influencing factor in the learning process and future studies will investigate the effect of laboratory manuals on learning. A third limitation of this study is the sample size which resulted in split data for Confirmatory Factor Analysis of only 86 students: however, this number was acceptable for the research reported (MacCallum et al., 1999). In addition, the subjects-to-variables ratio locates moderately within 5-10. However, this shortage was offset by the follow-up face-to-face interviews with chemistry educators and laboratory instructors after the implementation of factor analysis. Discussion with experienced laboratory instructors affirmed that the variables were representative domains for interactions in chemistry undergraduate laboratories. Nevertheless, further studies should include a larger number of participants. Furthermore, while small changes in the wordings of instruments can influence the results, the applicability of this instrument needs to be further validated in other institutions and with a broader range of students (Komperda, Hosbein, et al., 2018). Additionally, in this study quantitative data collection was assigned priority; it is suggested that further qualitative data collection and analysis method be performed to test the 'trustworthiness' of the description of interactions in individual science and engineering laboratories (Luckay & Laugksch, 2015). A fourth limitation is that there are only two items within two factors (S-S Lab-unrelated and S-I Lab-unrelated). However, the items and the five factors aligned well with the theory of distributed cognition. In the theory of distributed cognition, the environment plays important roles in the learning process. In the undergraduate chemistry laboratories involved in this chapter, the feature included in the five factors all had influences on students' learning. For interpersonal interactions (S-S and S-I), laboratory content-related and unrelated interactions were significant items in the learning process. Based on these results, the two-item factors contributed to an understanding of the research. In addition to the reasons of theories, there were previous studies where factors containing two items existed (Gosling et al., 2003). Therefore, the two factors were reliable and are retained in this instrument.

5.7 Chapter 5 Summary

This chapter has investigated the reliability and validity of the data from the instrument in face-to-face laboratories. This chapter is the final part of the methodology of this thesis. In face-to-face laboratories, the methods in this thesis went through three stages, a preliminary design of the pre- and post-lab surveys and laboratory observation that was used in Study 1. In this stage, survey, without laboratory observation, was used as the only data collection method after the laboratory to measure the frequency of interactions, details included in Chapter 4. The second stage was the statistical analysis of the second version of the post-lab survey. Data from the post-lab survey (or to be specifically the UILC instrument) were validated by performing statistical analysis, details included in Chapter 5. In remote laboratories, a pilot study was conducted to test the applicability of the items in the pre- and post-lab surveys and the laboratory observation sheet. After that, multiple methods were used to investigate the interactions in remote laboratories. Details will be presented in Chapter 8. The next chapter will illustrate results about Student-Equipment Interactions in face-to-face undergraduate laboratories because even though in this chapter S-E interactions were not included in the results of factor analysis, while S-E was assumed to be important.

CHAPTER 6: INTERACTIONS IN NON-MAJOR AND CHEMISTRY-MAJOR UNDERGRADUATE CHEMISTRY FACE-TO-FACE LABORATORIES

6.0 Chapter Outline

This chapter describes the purpose, the design and procedures, the results and discussions of Study 2 and Study 3 in terms of the first-year chemistry non-major and second-year chemistry-major undergraduates respectively. Considering that the results from Study 1 (Chapter 4) showed that the post-lab survey agreed well with the findings from on-site observations in measuring the frequency of interactions, in Study 2 (large-scale first-year non-major F2F) and Study 3 (second-year chemistry-major F2F), the post-lab surveys (the IULC instrument) were deemed suitable to be reliably used as the main data collection method. In Chapter 5, part of the data from Study 2 was used to validate the results from the instrument of IULC. The individual research questions are presented in this chapter at the beginning of each section where the data are analysed and discussed. Section 6.1 describes the different aims of Study 2 and Study 3. Section 6.2 examines the research methods used for the two studies by listing the participants, the chemistry content of the laboratory studied, and the data analysis process. Section 6.3 summarises the results of Study 2 and Study 3, the overall findings and comparisons that were undertaken. Section 6.4 discusses the results of the two studies from the perspective of interactions and satisfaction.

6.1 Purposes of Study 2 and Study 3

Study 2 investigated the first-year university chemistry non-major students and Study 3 investigated second-year chemistry-major students' perceptions of interactions and learning experience in chemistry laboratories. The purpose of Study 2 was to investigate the way that first-year university students with little or no chemistry knowledge perceived the frequency and importance of interactions, as well as their overall satisfaction with the first-year laboratories. The further purpose of Study 2 was to analyse the influences of laboratory types, namely procedural, conceptual and procedural/analytical, on student interactions. The purpose of Study 3 was to analyse how undergraduates with chemistry background perceived the importance, the frequency of interactions and the satisfaction with regard to the laboratory activities in organic chemistry.

6.2 Methods

After Study 1, several improvements to the research methods were implemented. The first change was to the data-collection method. Study 1 had shown that the post-lab survey was a reliable data-collection method for the purpose of the present research goals. Thus, in Study 2 and Study 3 only post-lab surveys at the end of each laboratory were used as the method to collect information about the frequency of interactions. The second improvement was in the pre-lab survey where of items to measure indirect interactions were added, covering more relevant interactions. The third improvement was the addition of two features in the post-lab survey, namely, the importance of interactions and the overall satisfaction of an individual laboratory (as introduced in Section 5.2.1, Chapter 5). All of these led to the final version of the IULC instrument (Figure 5.1, Chapter 5). Now it was possible to compare the results of the pre- and post-lab surveys. The fourth improvement lay in the further validation of the instruments, using the method of factor analysis (as illustrated in Chapter 5 and not presented here). Methods and results from the updated version (Version 2) of the pre- and post-lab surveys (IULC) are presented below.

6.2.1 Participants and Description of the Laboratory

Similar to the participants in Study 1, the students' chemistry backgrounds were very limited in Study 2; most had not studied chemistry in high school and a few who had studied chemistry, failed their examinations. In contrast to Study 1, the students in Study 2 were from all of the 19 classes of the same chemistry unit, instead of two classes. The students were working in groups, mostly in pairs, with a lesser number working as three in a group. The students were required to work mostly at benches while occasionally moving to the fume hoods due to risk reasons. The roles of the demonstrator were generally directive; they only provided brief guidelines during the pre-lab demonstration and provided help when necessary. The students were required to complete the task as independently as possible.

The data collection with regard to second-year students (Study 3) lasted two semesters, focusing on two classes in 2017 and then being expanded to all of the four classes of the unit of *Chemical Reactions and Mechanisms* in 2018. The students were all majoring in chemistry, and had finished three semesters of undergraduate study at Curtin University, with at least 150 hours of laboratory activities. The students were required to work individually. However, two students shared the same fume hood and some equipment in some laboratory activities. Similar to Study 2, the students performed in the laboratory activities independently and only asked for help when necessary. Demonstrators also presented guidelines briefly during the pre-lab demonstration. Students from Study 3 and Study 2 were two different groups, there were no overlap between them.

Similar to Study 1, at the commencement of the first class of Study 3, the students were informed about the present research project and were told that their participation was totally voluntary. The pre-lab survey was subsequently distributed. After the completion of the laboratory, the students were given the post-lab survey. The unit aimed to explore mechanisms in organic chemistry and how the mechanism influences the outcome of the laboratory experiments. There were some periods in the laboratory process when the students were not engaged with experimental manipulation because the reaction needed some time to complete.

The theoretical framework for this thesis pointed out the need to explore the relationship between interactions and the laboratory characteristics in the specific learning environment of chemistry laboratories. Previous studies also stated that undergraduates' verbal interactions were related to the nature of laboratory activities (Velasco et al., 2016; Xu & Talanquer, 2013). As the laboratories of students in Study 3 had the same characteristics (procedural organic), no analysis about the relationship between interactions and the nature of laboratories in Study 3 would be conducted. To explore the student interactions in the laboratory activities, in Study 2 the nature of the laboratories was classified based on the analysis of the laboratory goals, the tasks and the questions asked of students in the laboratory manual. After discussing with one expert of chemistry education in our research team, in Study 2 three types of laboratories were indicated, namely procedural (i.e., to learn the usage of glassware), conceptual (i.e., infer chemical concepts), and procedural/analytical (i.e., following procedures and calculating quantities). Lab Session 1 was assigned as a typical procedural laboratory, Lab Session 2 was conceptual, and Lab Session 3 and 4 were both procedural/analytical. In the classification, results of Lab Session 3 and Lab

Session 4 were combined because they belonged to the same laboratory type. Details of the three types of laboratories are listed in Table 6.1.

Table 6.1 Characteristics of the Experiments Involved in Study 2

Laboratory Name	Nature of Laboratories	Brief Description of Laboratory Activity
Principles of measurement	Procedural	Being familiar with three liquid volumetric measurement apparatus by comparing the uncertainties of them: the measuring cylinder, the burette and the pipette
Identification of common ions in solution	Conceptual	Determine the solubility rules for cations and anions by carrying out a series of chemical reactions and observing the changes that take place.
Identification of acetic acid in vinegar	Procedural/analytical	Determine the concentration of acetic acid in vinegar from a standardised solution of NaOH
Standardisation of HCl with a standard solution of Na_2CO_3	Procedural/analytical	Determine the concentration of HCl from a standardised solution of Na_2CO_3

In the analysis, firstly, the overall results from Study 2 and Study 3 compared the differences between first-year and second-year undergraduates, aiming to understand how laboratory experiences influence students' interactions and satisfaction. However, the laboratory environment is really complex and many factors might influence student behaviours. For example, the nature of laboratories, the working formats (individually or in pairs), the style of instructors, or the nature of laboratory content. For the cohorts of Study 2 and Study 3, the laboratory experience was significantly different. For those in Study 2, the students had almost no prior laboratory experience, while students in Study 3 had not only rich experience in chemistry laboratories in high school, but also at least 150 hours' university chemistry laboratory working time. Therefore, the most significant difference among the students from Study 2 and Study 3 was laboratory experience and it was used as the impacting factor on analysing the differences of the two groups of students. Secondly, further comparisons between the three types of laboratories in Study 2 (procedural, conceptual, procedural/analytical) were undertaken to investigate the impact of laboratory characteristics on different kinds of student interactions.

6.2.2 Data Analysis

As in Study 1, data were presented in figures to show (1) the ranking of interactions from the pre-lab survey (see Figure 4.2, Chapter 4); and (2) the frequency of interactions from the post-lab survey (see Figure 4.3, Chapter 4). However, the results from the factor analysis illustrated that there were five scales in terms of interactions. In this chapter, the figures are presented using the five scales, and the form is different from the figures given in the earlier chapter (Chapter 4). Different from the analysis of Study 1 where the correlation between the frequency of interactions and learning outcomes (laboratory marks) were graphed visually (see Figure 4.5 and Figure 4.6, Chapter 4), in this chapter the analysis of the frequency of interactions and student learning outcomes were conducted in SPSS to provide statistical results.

6.3 Results

6.3.1 Importance of Interactions - Results from the Pre-lab Survey

To address RQ 1.1. "What do undergraduate students consider to be important interactions before the conduct of the chemistry laboratories?", students' expectations and perceptions about the importance of the different kinds of interactions which may be helpful for their learning were collected. Student rankings of the importance of potential laboratory interactions are shown in Figure 6.1.

The cohorts in Study 2 were from the same unit as Study 1 (Chapter 4), though enrolled in different years. A much larger sample was analysed in Study 2 compared to Study 1 with 19 classes involved in Study 2 and only two classes in Study 1. Even though with these difference in the scale of samples, the results of Study 2 had high similarity with those of Study 1 (Figure 4.2, Chapter 4). This has provided evidence, to some extent, of the reliability of the instruments used in the research because the students with similar background had similar reports and the results from the smaller number of participants were shown to be applicable to the much large number of participants. To be specific, firstly, the instructor was considered to be the most important source of interactions before the laboratory, while the highest sub-item locating on results, instead of procedures. Secondly, interactions with procedures still had the highest importance across pre-lab demonstrations and the laboratory manual.

The newly added indirect interaction had high importance, especially in the aspect of listening to other S-I conversations. The type of listening to other S-I conversations could be assigned as one type of vicarious interaction with an instructor, emphasizing the importance of the instructor on a second occasion. From the observation, the students were mostly accessing the internet for science theories, therefore, under the item 'from the internet', 'science theory' was mentioned in Figure 6.1.

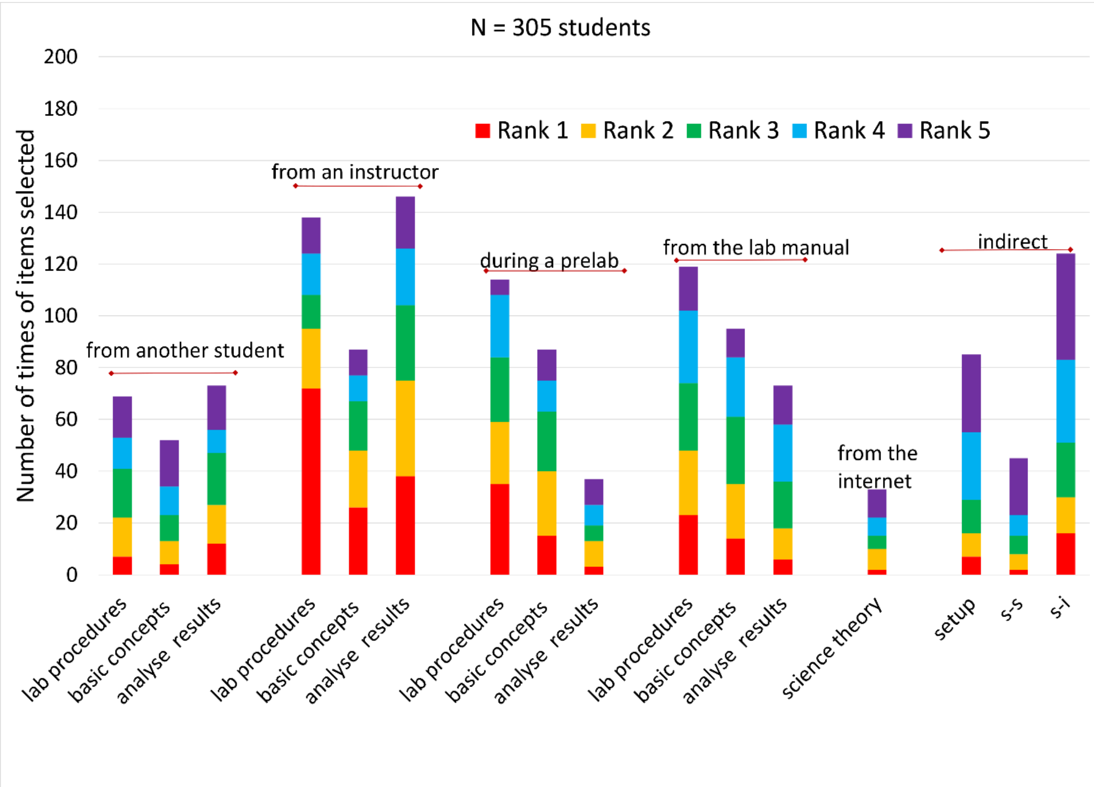


Figure 6.1 First-year non-major students' expectations (number of times of items selected) of the importance of the potential interactions sorted by task types before undertaking the laboratory work

Note: 1. Data obtained from the pre-lab survey, Study 2 (total number of selections = 305 x 5 = 1525). 2. s-s: listening to student-student conversations, s-i: listening to student-instructor conversations

Similar to Study 1, in Study 2, the two direct interpersonal interactions (S-S and S-I), concepts were both considered to be least important. The similarities were within expectation because, in the first-year chemistry undergraduate laboratories, more time was assigned to finish the laboratory activities (including procedures and results) based on the laboratory manual, while there was less time for addressing concepts. Another similarity is that the pre-lab demonstration and laboratory manual were expected to have the least function in addressing results. This was not out of expectation either because the pre-lab demonstration was mostly to address key concepts and potential risks or to introduce the usage of some equipment. By contrast, the results were supposed to be achieved after the completion of the laboratory procedures and were the outcome based on individual groups' work.

In Study 2 (see Figure 6.1), before the commencement of the laboratory, the students expected the laboratory manual to be important for their learning while the Internet had a less important ranking. Although it was more important to be used for procedural guidance, the laboratory manual had a similarly highly presumed importance in terms of concepts and results. However, reading procedures from the laboratory manual was less important than an instructor discussing procedures or results, as well as being less than listening to student-instructor talks.

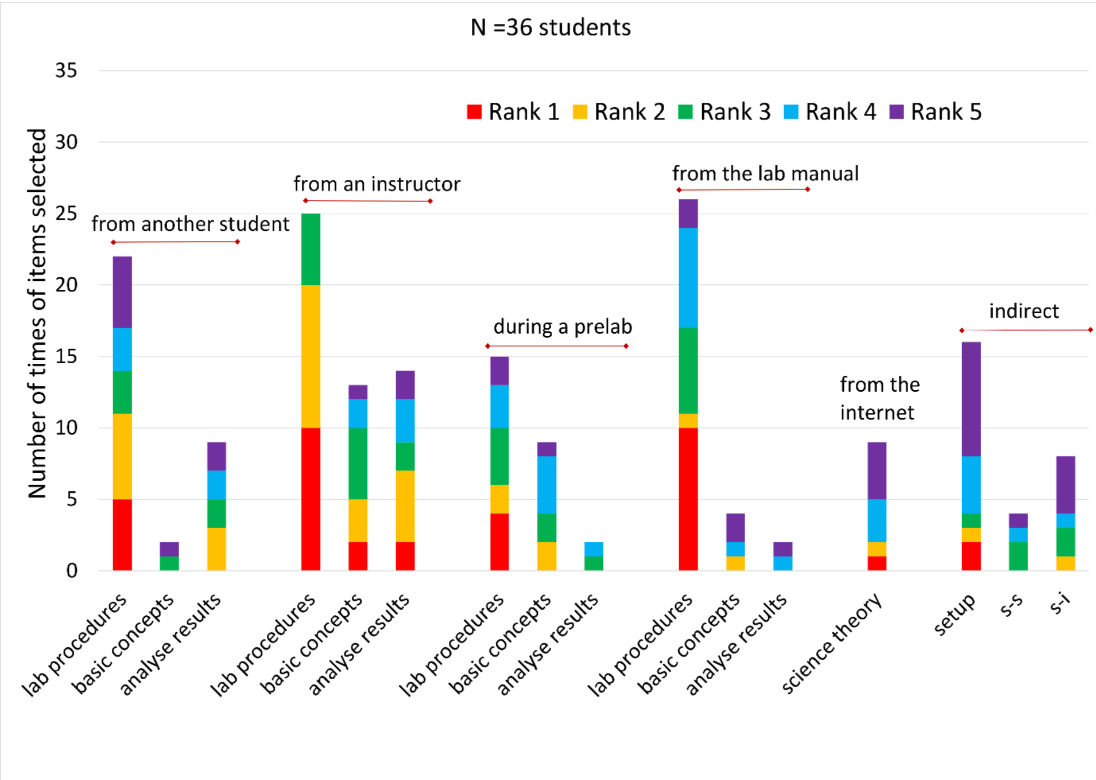


Figure 6.2 Second-year chemistry-major students' expectations (number of times of items selected) of the importance of the potential interactions sorted by task types before undertaking the laboratory work

Note: 1. Data obtained from the pre-lab survey, Study 3 (total number of selections = 36 x 5 = 180).
2. s-s: listening to student-student conversations, s-i: listening to student-instructor conversations

In Study 3 (see Figure 6.2), for the second-year students, information about procedures from the laboratory manual was expected by students to be the most important item in all of the 15 items. However, the rankings of acquiring concepts and results from the laboratory manual fell significantly and had very low values. In both Study 2 and Study 3, the Internet was not considered to be an important source of interaction.

While the laboratory manual was expected to be important in both of the two studies, there were some variations. For the first-year undergraduates in face-to-face laboratories (Study 2), the laboratory manual was less important than the instructors. With regards to the second-year undergraduates in face-to-face laboratories (Study 3), the laboratory manual was considered the most important resource in students' expectations.

6.3.2 Frequency of Interactions - Results from the Post-lab Survey

Results from post-lab were used to address Research Question 1.2. "What type and range of frequency of interactions do students engage in during chemistry laboratory work?". A visual comparison of the percentage of 'many times' between Study 2 and Study 3 is illustrated in Figure 6.3.

Overall, the first-year undergraduates responded that interactions with other students in terms of laboratory results and procedures occurred more significantly, while the remaining interactions happened much less frequently. With regards to the second-year undergraduates, interactions between students and instructors relating to the laboratory procedures were the most frequent type, followed closely by the interactions about procedures among students and observing others setting up the apparatus. Interestingly, the indirect interactions between students also showed a substantial occurrence. The difference between first-year and second-year behaviours was evident. The non-major students tended to interact with their peers more, while the chemistry-major students with more experience were likely to interact with the instructor about procedures.

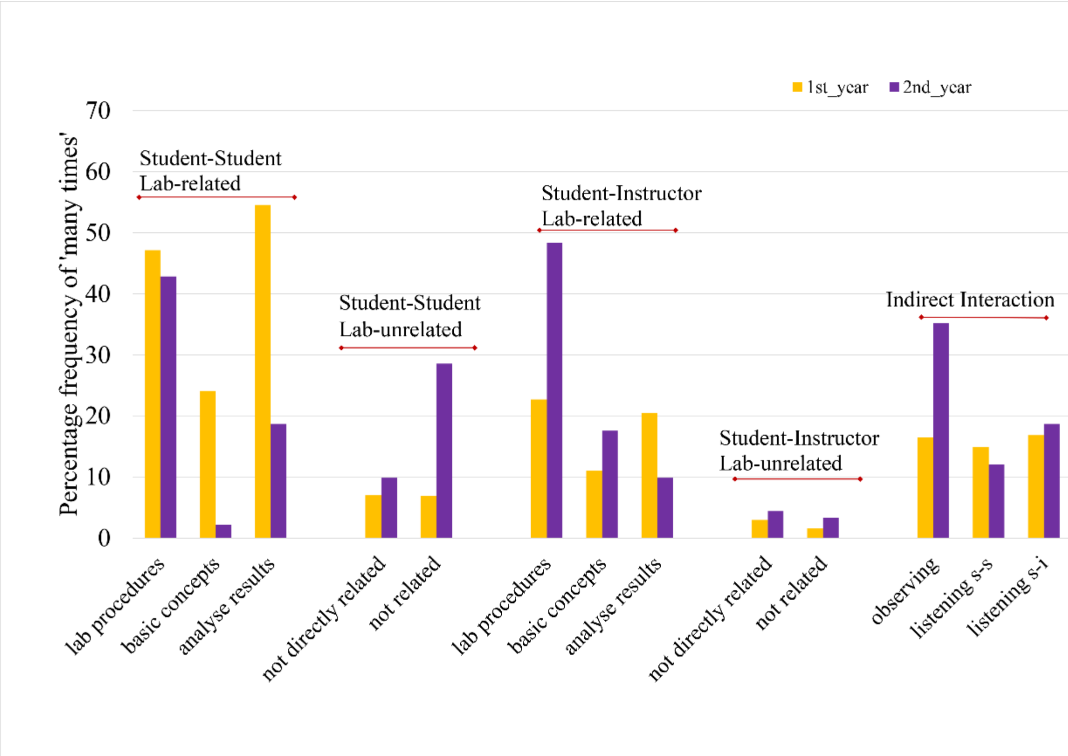


Figure 6.3 Relative percentage frequency of the interactions, sorted by task types, as reported to be 'many times' by first-year non-major and second-year chemistry-major students after undertaking the laboratory work

Note: 1. Data obtained from the post-lab survey, Study 2 (total number of responses = 772) and Study 3 (total number of responses = 202). 2. The percentage of each item is not equal to 100% as we are only illustrating data of 'many times', not including data of 'never', 'once' and 'a few times'.

6.3.3 Importance of Interactions - Results from the Post-lab Survey

To address RQ 1.3: "What do undergraduate students consider to have been important interactions after the completion of the chemistry laboratories?", analysis of the importance of interactions was conducted based on results from the post-lab survey, based on the five scales. In Figure 6.4 only the combined sum of rank 1 to rank 5 are shown, not the individual rank.

Overall, first-year undergraduates from Study 2 reported that the S-I Lab-related and S-S Lab-related interactions were important for completing the laboratory. Specifically, these two interpersonal interactions relating procedures and results were considered more important than concepts. For the second-year students in Study 3, S-I interacting about procedures was the most important type of interaction, closely followed by S-S procedures. In addition, S-I interacting about concepts and observing others setting up apparatus both showed distinctive importance.

To compare the reports from first-year and second-year undergraduates, both groups reported that interactions with instructors were important, with the first-year students allocating similar importance to procedures, results and concepts and the second-year students prioritising the importance of procedures. Furthermore, the first-year students assigned more importance to S-S interactions related to results, while the second-year students did not.

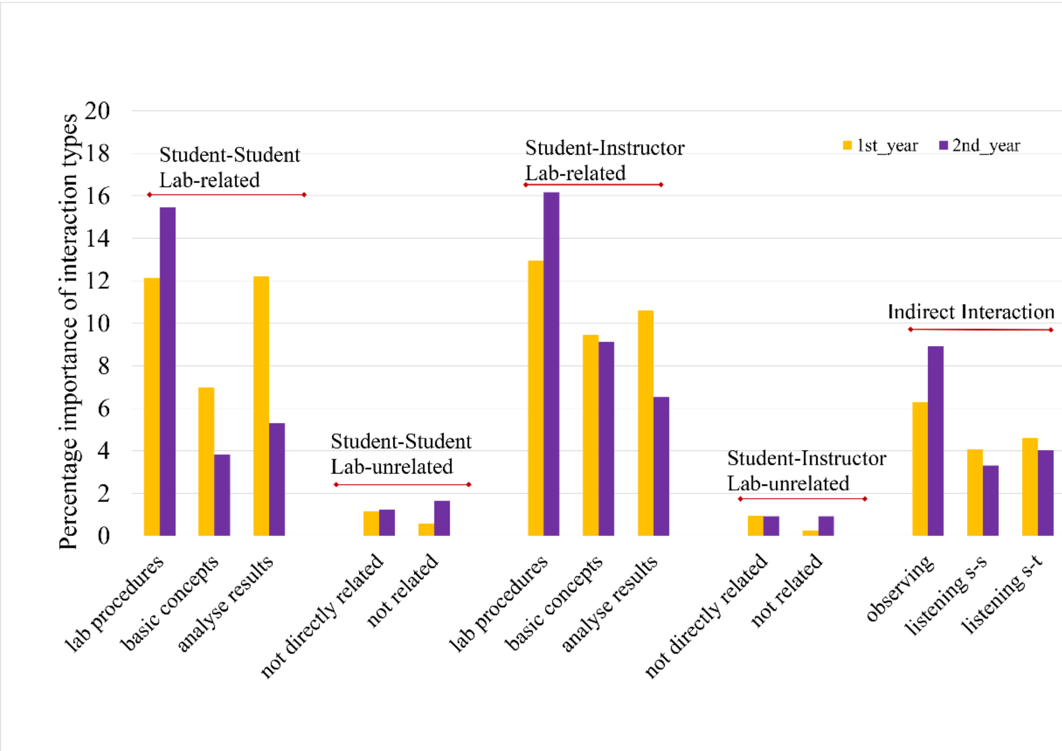


Figure 6.4 Relative percentage importance of the interactions, sorted by task types, reported by first-year non-major and second-year chemistry-major students after undertaking the laboratory work

*Note: 1. Data obtained from the post-lab survey, Study 2 (total number of responses = 693*5) and Study 3 (total number of responses = 193*5). 2. The percentage of each item is not equal to 100% as only data from the five factors are illustrated.*

6.3.4 Frequency of Interactions and Learning Outcomes

To address RQ 1.4. "How do the frequency of interactions and student learning outcomes correlate in chemistry laboratories?", the number of interactions in terms of the five scales was correlated with the learning outcomes as measured by the laboratory marks and unit completion, for Study 2 and Study 3. Both the laboratory marks and the number of interactions were continuous values, so the correlation was measured by Pearson's Product-moment Correlation. Course completion was recorded on a scale of 1 and 0 as ‘pass’ and ‘fail’.

From Table 6.2 and Table 6.3, it can be seen that between the number of interactions and the learning outcomes, no important correlations were found.

Table 6.2 Pearson’s Product-Moment Correlation Coefficient for the Interactions with Laboratory Marks

	Number of ‘never’ and laboratory marks	**Number of ‘once’ and laboratory marks**	**Number of ‘a few’ and laboratory marks**	**Number of ‘many’ and laboratory marks**
Study 2				
Scale 1: I-I (II)	.079*	-.097*		
Scale 5: S-S Lab-unrelated (SSU)				-.121**
Study 3, no significant values were found				

*Note: *p < .05, **p < .01, N=705 in Study 2; N=191, in Study 3. Only statistically significant values were illustrated*

Table 6.3 Pearson’s Product-Moment Correlation Coefficient for the Interactions with Laboratory Completion

	Number of ‘never’ and course completion	**Number of ‘once’ and course completion**	**Number of ‘a few’ and course completion**	**Number of ‘many’ and course completion**
Study 2				
Overall Interactions	.076*	-.093*		
Scale 5: S-S Lab-unrelated (SSU)	.117**			-.123**
Study 3				
Overall Interactions	.140*	.152*	-.206**	
Scale 1: I-I (II)			-.157*	
Scale 2: S-S Lab-related (SSR)		.198**		
Scale 4: S-I Lab-unrelated (SIU)	.205**		-.194**	
Scale 5: S-S Lab-unrelated (SSU)		.141*		

*Note: *p < .05, **p < .01, N=705 in Study 2; N=191, in Study 3. Only statistically significant values were illustrated*

A further comparison between the number of interactions and learning outcomes were made based for each laboratory type, and no important correlations were found. An example of results from Study 2 is listed in Appendix B.

6.3.5 Frequency of Interactions and Laboratory Types

To address RQ 1.5. "How do the frequency of interactions and laboratory types correlate in chemistry laboratories?", the percentage of 'many times' in each type of laboratories were calculated according to the three types of laboratories in Study 2, see Figure 6.5.

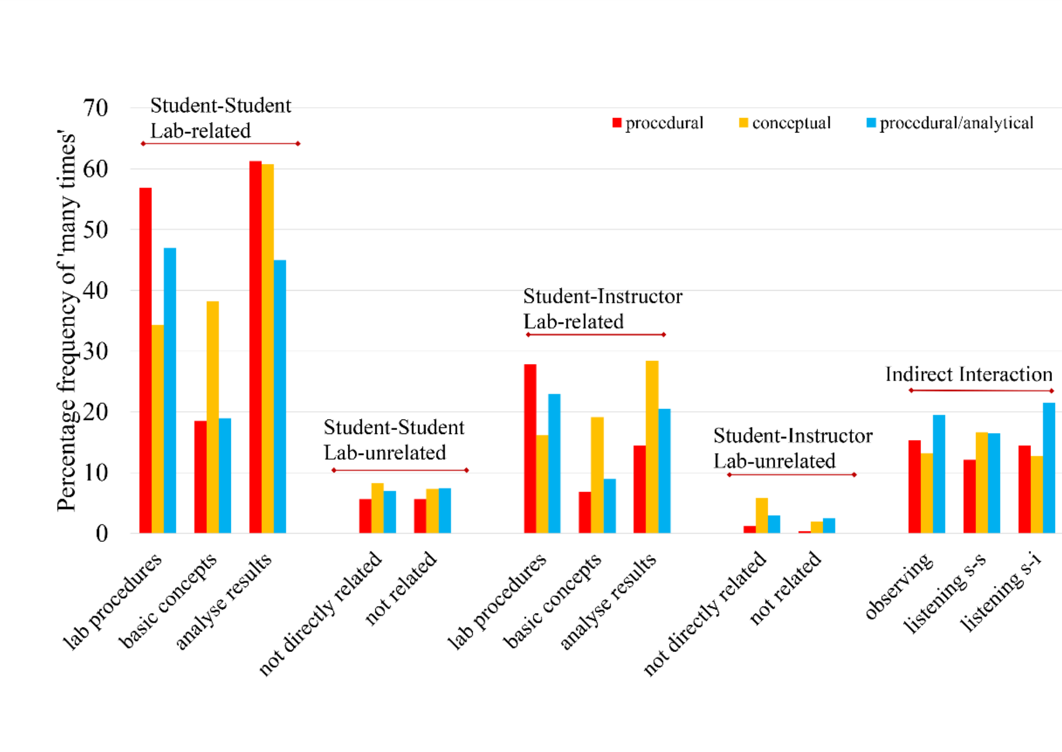


Figure 6.5 Relative percentage frequency of the interactions according to three laboratory types, sorted by task types, as reported to be 'many times' by first-year non-major students after undertaking the laboratory work

Note: 1. Data obtained from the post-lab survey, Study 2 (total number of responses: Procedural, N = 248, Conceptual, N = 204, Procedural/Analytical, N = 320.). 2. The percentage of each item is not equal to 100% as only data of 'many times' are illustrated, not including data of 'never', 'once' and 'a few times'. 3. I-I: Indirect Interaction, s-s: listening to student-student conversations, s-i: listening to student-instructor conversations

It can be seen that in procedural and procedural/analytical laboratories, more S-S and S-I interactions relating to procedures happened, while in conceptual laboratories, more interactions about concepts were exchanged among the students and between the students and their instructors. Therefore, the results indicate that the focus of the laboratory activity drove the type of interactions between students and students, or students and instructors.

6.3.6 Importance of Interactions and Laboratory Type

To address RQ 1.6. "How do the importance of interactions and laboratory types correlate in chemistry laboratories?", the percentage of each item in the importance of the interactions was calculated according to the three types of laboratories in Study 2 (Figure 6.6).

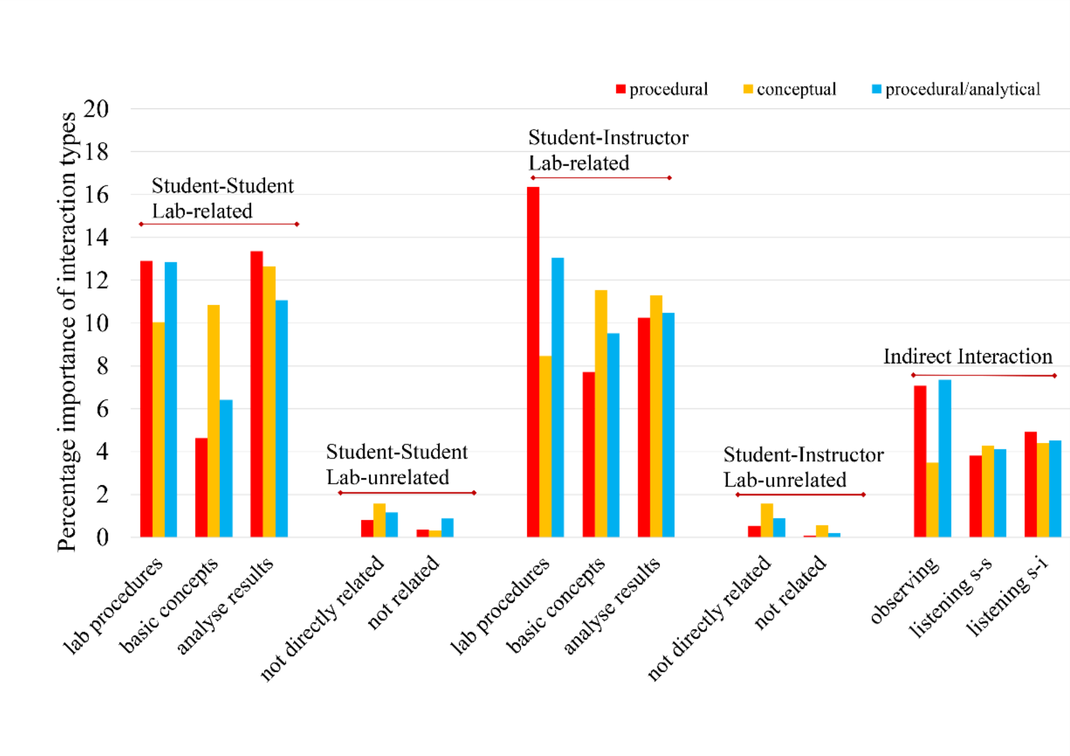


Figure 6.6 Relative percentage of the importance of the interactions according to the laboratory types, reported by first-year non-major students after undertaking the laboratory work

Note: 1. Data obtained from the post-lab survey, Study 2 (total number of responses: Procedural, N=220, Conceptual, N=177, Procedural/Analytical, N=296).

The most important interaction that happened in the procedural laboratory was between student and instructors about procedures, followed by S-S results and S-S procedures. In procedural/analytical laboratories, both S-S and S-I interactions related to procedures were important. In a conceptual laboratory, S-S and S-I results, S-S and S-I concepts were the four most important type of interactions. To compare the results from Figure 6.6 and Figure 6.5, even though S-I interactions happened much less than

S-S interactions, their importance was high, especially the procedural S-I interactions in the procedural laboratory. Only the combined sum of rank 1 to rank 5 are shown in Figure 6.6.

6.3.7 Frequency of Interactions and Student Satisfaction

The overall data of satisfaction levels showed that most of the students in both Study 2 and Study 3 were satisfied with the laboratory being undertaken after completing it. Furthermore, students in Study 3 tended to be more satisfied with the laboratory. Please refer to Figure B1, Appendix B. For further analysis of the correlation between overall satisfaction with the factors of frequency and importance, five values were assigned from 1 to 5 from strongly dissatisfied (1) to strongly satisfied (5).

To address RQ 1.7. “How do the frequency of interactions and student satisfaction correlate in chemistry laboratories?”, correlation analysis was conducted. Since the values were nonparametric and one of the values were ordinal, Spearman’s Rank Order Correlation, instead of Spearman’s *r*, was conducted to investigate the link between the number of interactions (frequency) sorted by the five scales of interactions and the satisfaction levels. The results from the Spearman’s Rank Order Correlation, in both Study 2 and Study 3, are shown in Table 6.4.

For first-year students, the fewer interactions that occurred, the less satisfied they were with the laboratory (Column 1), while more frequent interactions positively correlated with a higher satisfaction level (Column 4). For the second-year students, the number of “never interacting” did not show any correlation with satisfaction, while the number of many times of interactions positively correlated with satisfaction. To sum up, more interactions tended to correlate with positive satisfaction. Specifically, the trend of not interacting decreased the satisfaction was more significant in Study 2, while in Study 3 the S-I Lab-unrelated topics had no correlation with the satisfaction levels. However, it should be emphasized that the correlation values were not high, so the correlations were assumed to be weak, not as strong.

Table 6.4 Spearman's Rank-Order Correlation Coefficient for the Interactions with Overall Satisfaction

	Number of 'never' and satisfaction	**Number of 'once' and satisfaction**	**Number of 'a few' and satisfaction**	**Number of 'many' and satisfaction**
Study 2				
Overall interactions	-.116**	-.105**		.204**
Scale 1: I-I (II)			-.118**	.085*
Scale 2: S-S Lab-related (SSR)			-.092*	.137**
Scale 3: S-I Lab-related (SIR)	-.132**	-.139**		.167**
Scale 4: S-I Lab-unrelated (SIU)	-.096*			.108**
Scale 5: S-S Lab-unrelated (SSU)	-.075*			
Study 3				
Overall interactions			-.262**	.395**
Scale 1: I-I (II)		-.179*	-.199**	.385**
Scale 2: S-S Lab-related (SSR)			-.224**	.326**
Scale 3: S-I Lab-related (SIR)				.187**
Scale 4: S-S Lab-unrelated (SSU)			-.230**	.246**

*Note: *p < .05, **p < .01, N=705 in Study 1; N=191, in Study 2. Only statistically significant values were illustrated*

6.3.8 Importance of Interactions and Student Satisfaction

To address Research Question 1.8. "How do the importance of interactions and student satisfaction correlate in chemistry laboratories?", the students were divided into different types according to their levels of satisfaction. Considering the fact that only an extremely small number of students chose 'strongly disagree and disagree' (20 out of 655, in Study 2 and 6 out of 162 in Study 3) and not many respondents chose 'strongly agree' (70 out of 655 in Study 2 and 32 out of 162 in Study 3), the differentiation was made into two general categories. The respondents of 'strongly disagree', and 'disagree' were combined together and assigned as 'less satisfied'. The respondents of 'agree' and 'strongly agree' were combined together as 'more satisfied'.

For the first-year undergraduates (see Figure 6.7), there were generally no differences on most items between the two types of students. The only two significant differences are found in: (i) the less satisfied students relied more on listening other students' conversations with the instructors, and (ii) the more satisfied students rated the S-I results interactions more important.

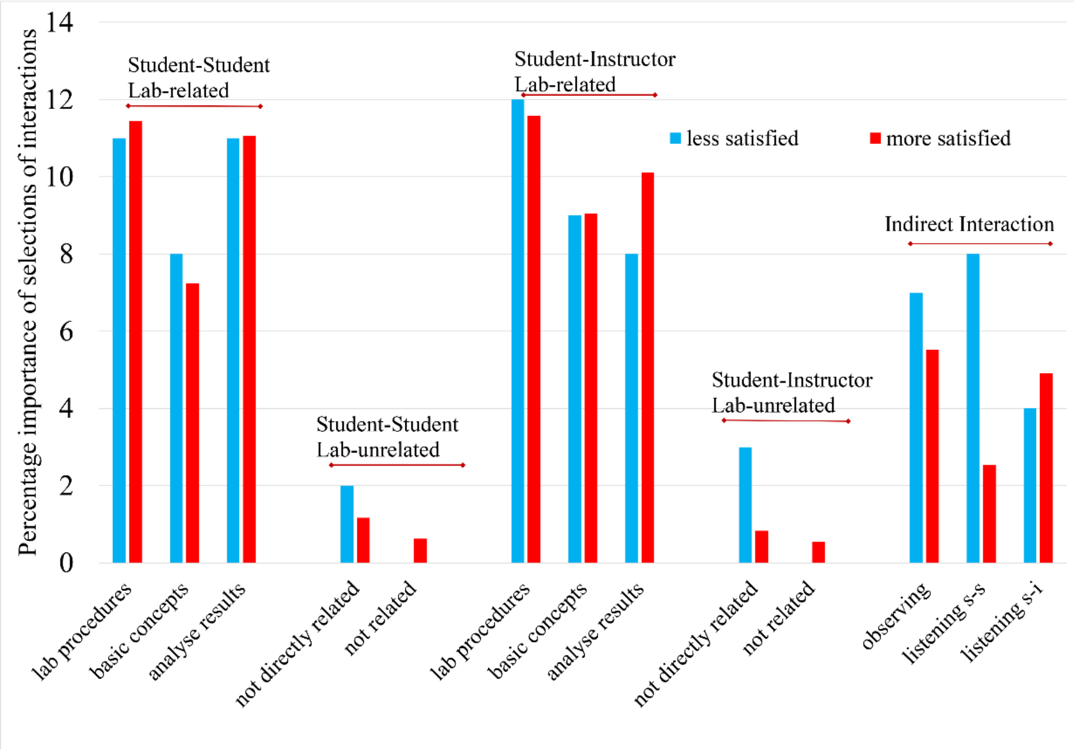


Figure 6.7 Relative percentage of the importance of interactions with regard to first-year non-major students' ratings on satisfaction levels

*Note: 1. Data obtained from the post-lab survey, Study 2 (total number of responses: less satisfied: 20 *5, more satisfied: 70 *5). 2. The percentage of each item is not equal to 100% as only data from the five factors are illustrated.*

For the second-year undergraduates (see Figure 6.8), the difference between the two types of students was clearer. The second-year students were manipulating the laboratory activities individually, thus there might be expectations that they would report interactions with instructors as being more important than with their peers. This assumption seemed to be true based on the results shown in Figure 6.8. However, to take a further look, the more satisfied students reported that interacting with other students about procedures and results was more important compared to those less satisfied students. By contrast, the students who were less satisfied with the laboratory showed that interactions with the instructors about procedures and concepts were more important than their counterparts who were more satisfied with their laboratory experience. The group of students with fewer satisfaction levels preferred to observe others' manipulation, while the students with higher levels of satisfaction thought listening to conversations were more important.

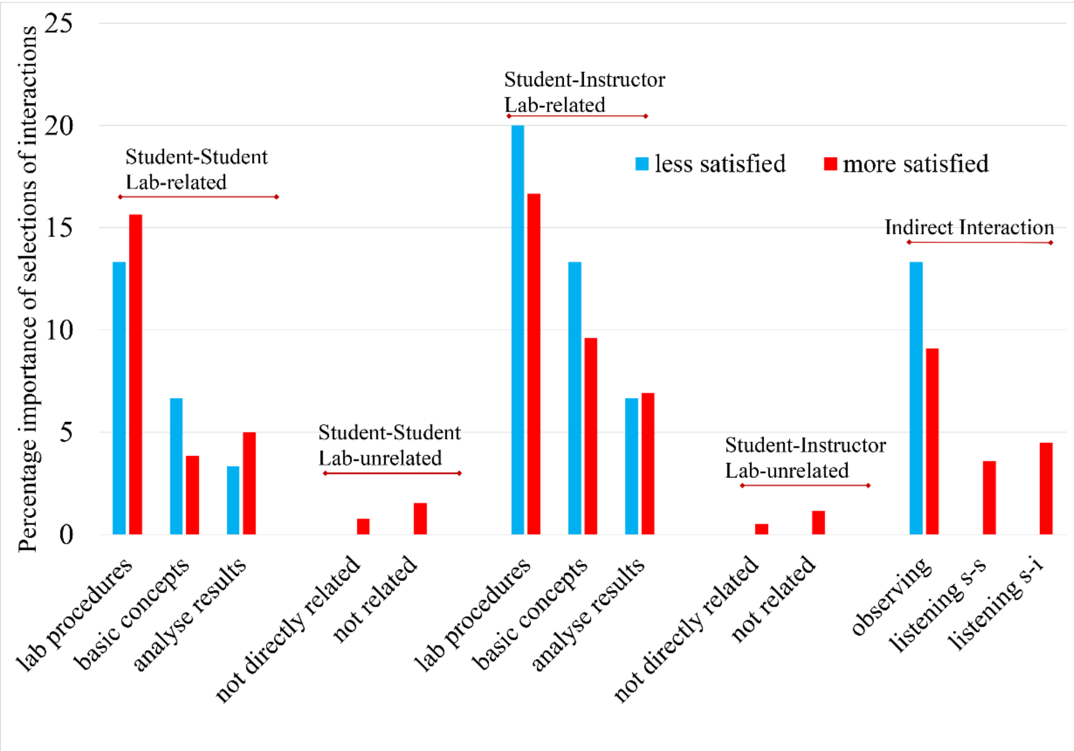


Figure 6.8 Relative percentage of the importance of interactions with regard to second-year chemistry-major students' ratings on satisfaction levels

*Note: 1. Data obtained from the post-lab survey, Study 3 (total number of responses: less satisfied: 6 *5, more satisfied: 32 *5). 2. The percentage of each item is not equal to 100% as only data from the five factors are illustrated.*

6.4 Discussion

The goal of this chapter was to characterize the interactions experienced by non-major undergraduate students in a laboratory component of a traditional general chemistry course (Study 2) and by chemistry-major students in organic laboratories (Study 3). Instrument development and analyses were grounded in the understanding that a productive learning environment (see Figure 1.1, Chapter 1) requires the study of interactions between learners, among learner and instructors, with the learning materials, and indirect learning (Komorek & Kattmann, 2008).

The students expected direct interactions with instructors and listening to S-I conversations were important, compared with S-S interactions. After the laboratory, S-I interactions were still reported to be important, while S-S interactions were as important as S-I interactions. The variance in the expectations and experiences provide some guidance to effective learning in the laboratories, especially for the instructors. For example, the importance of S-S interactions increased significantly after the laboratory. The reason may be that the students were not familiar with the other learners before the commencement of the laboratory, and due to the lack of prior knowledge, they anticipated that the more knowledgeable person (the instructor) to be the most important source of interactions. The expectations did not always guide students' actual behaviour because anticipations did not always result in specific behaviours and contribute to productive learning. A front-of-class demonstration about the importance of S-S interactions may be necessary before the commencement of the laboratory so that the students are made more aware of what learning experiences they should expect.

Students' behaviours were influenced by the characteristic of laboratories; for example, in the conceptual laboratory, interactions related to concepts occurred more frequently and were reported to be important. This finding implies that the students' behaviours could be expected based on the laboratory type and guidance from instructors could be changed accordingly (i.e. to emphasize assistance of concepts in conceptual laboratories).

The relationship between interactions and learning outcomes as well as interactions and satisfaction was investigated. There were no positive correlations between the frequency of interactions and laboratory marks or exam marks. The reason may be due to the inappropriate assessment methods chosen. The laboratory marks were mainly based on the questions in the laboratory manual, and the test marks were assessing the knowledge learned in the term. Neither of them had tested about student behaviours. The lack of a link between interaction and learning outcomes illustrated that the assessment was mostly about the student learning results, not on the learning process. On the other hand, the frequency of interactions has significant positive correlations with satisfaction levels. This means that the frequency of interactions does influence student learning, and it is just not reflected in the laboratory marks or unit pass rates.

Interviews with four groups were conducted to obtain general views about the learning experience, following Lab Session 2 (see Table B1, Appendix B). The students reported that the laboratory was satisfactory, and they acknowledged that clear guidance was helpful in finishing the laboratory process. The guidance can be from the laboratory manual or from the instructors. The students also expressed that meticulous preparation before the laboratory would enhance their learning experience, which was obtained by observing the behaviour of other groups. The combination of different components in a unit, such as a workshop, could be useful in guiding the laboratory process. The students had problems when doing calculations and they asked for help from the instructor or from other students.

There are multiple factors which might influence the learning process and learning experience in addition to prior experience and knowledge and the nature of laboratories, discussed in this chapter. However, the laboratory environment is really complex and it is impossible to analyse the effects of all the influencing factors. For example, the differences between second-year students and first-year students included the format of the classroom (individual work or in groups), and the personality of demonstrators. Previous studies have shown that cooperative interaction was the dominant structure for any classroom compared with competition and individualisation (Johnson & Johnson, 2002). However, '*Cooperation is much more than physical proximity to others, discussing material with other students, helping other students, or sharing materials with other students, although each of these is important in cooperative learning*' (p.12). Basic elements including positive interdependence, individual accountability, face-to-face promotive interaction, social skills, and group processing were included under the term cooperative. In this study, while the roles of laboratory demonstrators were providing general guidance and help, the students were given much freedom to form groups and complete the activities. Therefore, the previous key elements of cooperation were not analysed and they were not controlled in this study. Consequently, only the significant two factors, namely prior experience and the nature of laboratories, were taken into account.

6.5 Chapter 6 Summary

In this chapter, the data on interactions and laboratory types, interactions and satisfaction, interactions and learning outcomes in Study 2 and Study 3 were analysed. Overall, results from the pre-lab survey and the IULC instrument showed that the first-year non-major students (Study 2) and the second-year chemistry-major students (Study 3) had different opinions about the importance and frequency of interactions, as well as the satisfaction levels regarding the laboratories performed. Correlations between interactions and laboratory types, interaction and satisfaction, interactions and learning achievements were also analysed to investigate the relationships between interactions and learning. A summary of the research questions and the main findings are listed in Table 6.5.

Even though Student-Equipment interactions were not included in the five factors, they are an integral component of the science undergraduate laboratories. In the next chapter, data on Student-Equipment Interactions will be summarised and analysed.

Table 6.5 Research Questions and the Main Findings in Study 2 and Study 3

Research Questions	Main Findings
RQ 1.1: What do undergraduate students consider to be important interactions before the conduct of the chemistry laboratories?	First-year non-major students: interactions with instructors were thought to be the most important before the commencement of laboratory activities. Second-year chemistry-major students: interactions with the laboratory manual were the most important before the commencement of laboratory activities.
RQ 1.2: What type and range of frequency of interactions do students engage in during chemistry laboratory work?	First-year non-major students: interactions with other students about results happened the most frequently. Second-year chemistry-major students: interactions with the instructors about procedures occurred the most frequently.
RQ 1.3: What do undergraduate students consider to have been important interactions after the completion of the chemistry laboratories?	First-year non-major students: interactions with other students or the instructors about procedures and results were important. Second-year chemistry-major students: interactions with other students and the instructors about procedures were important.
RQ 1.4: How do the frequency of interactions and student learning outcomes correlate in chemistry laboratories?	No important correlations were found between the frequency of interactions and laboratory marks/unit completion rates for first-year non-major and second-year chemistry-major students.
RQ 1.5: How do the frequency of interactions and laboratory types correlate in chemistry laboratories?	First-year non-major students: the characteristics of the laboratory types (procedural, conceptual or procedural/analytical) influence the frequency of the two interpersonal interactions (S-S and S-I). Second-year chemistry-major students: N/A
RQ 1.6: How do the importance of interactions and laboratory types correlate in chemistry laboratories?	First-year non-major students: the importance of interactions were different in the three types of laboratories. Second-year chemistry-major students: N/A
RQ 1.7: How do the frequency of interactions and student satisfaction correlate in chemistry laboratories?	First-year non-major students: the more interactions of 'never interacting', the less satisfied of the students with the laboratories. The more interactions of 'many times' were chosen, the more satisfied the students were with the laboratories. Second-year chemistry-major students: The more interactions of 'many times', the more satisfied of the students with the laboratories.

CHAPTER 7: STUDENT-EQUIPMENT INTERACTIONS IN FACE-TO-FACE SCIENCE UNDERGRADUATE LABORATORIES

7.0 Chapter Outline

This chapter focuses on the interactions between students and equipment in face-to-face (F2F) laboratories. The equipment amounted to the laboratory manual and the Internet. Section 7.1 briefly proposes background information on studies of S-E interactions. Section 7.2 illustrates results from the following aspects. Firstly, results from the pre-lab survey and the post-lab survey are shown. In each part, results from Study 2 (large-scale first-year non-major F2F) and Study 3 (second-year chemistry-major F2F) are depicted sequentially. Secondly, results showing the correlation of the laboratory manual/the Internet and satisfaction are listed and analysed. Section 7.3 discusses the results of Study 2 and Study 3 on S-E Interactions.

7.1 Introduction

While Student-Equipment Interaction is not included in the five factors of our instrument, it has long been thought to be an important contributor to the students' learning in science laboratories (Southam et al., 2013). It is, therefore, necessary to present the results relating to the laboratory manual and the Internet to justify this assumption. It should be emphasized that to make the analysis possible, all of the interaction items are presented in the results. However, only interactions with the laboratory manual and the Internet are analysed in this chapter because that is the primary focus.

7.2 Results

7.2.1 Importance of Interactions - Results from the Pre-lab Survey (in Figure 6.1 and Figure 6.2, Chapter 6)

Research Question 1.1. "What do undergraduate students consider to be important interactions before the conduct of the chemistry laboratories?" is addressed in this part and the results have been illustrated in Section 6.3.1, Chapter 6. From the pre-lab, the students responded that directly interacting with the instructors would be important for their learning; listening to other students' talks with the instructors was second in importance. Laboratory manual and pre-lab demonstrations in terms of procedures were both similarly important. With regards to the two interpersonal interactions (S-S and S-I), the interactions about concepts both accounted for less importance.

7.2.2 Frequency of Interactions - Results from the Post-lab Survey

To address RQ 1.2. "What type and range of frequency of interactions do students engage in during chemistry laboratory work?", the results from the post-lab surveys in Study 2 and Study 3 were analysed and presented in Figure 7.1 and Figure 7.2, respectively.

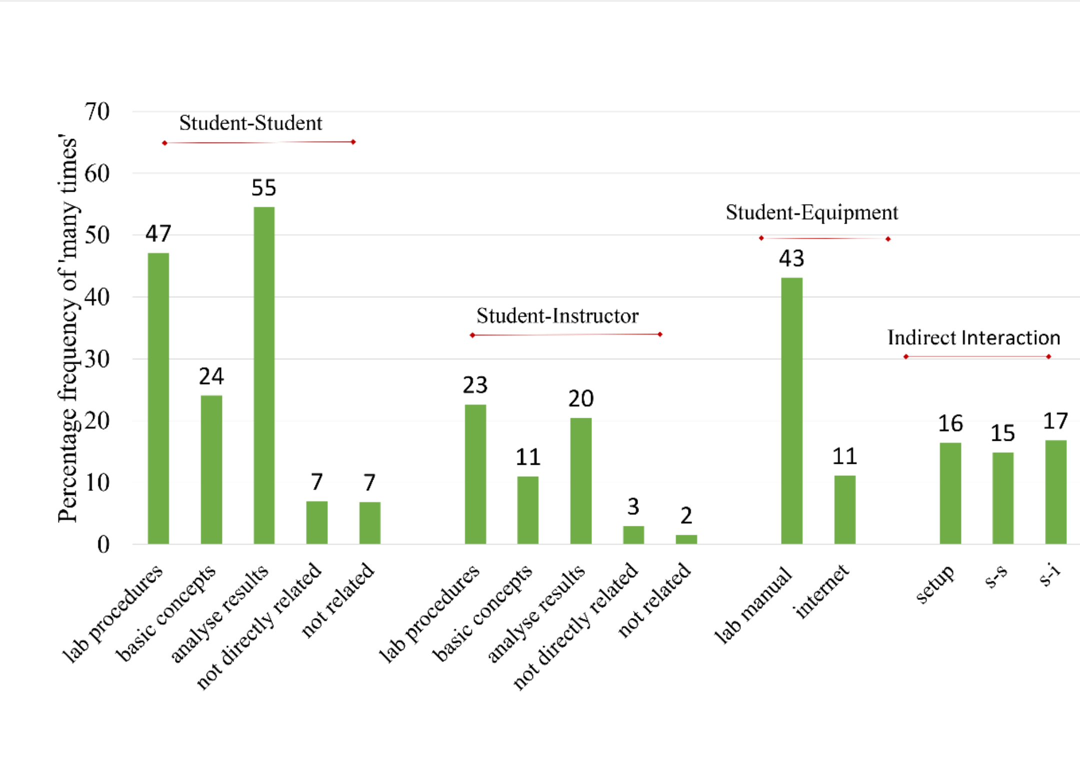


Figure 7.1 Relative percentage frequency of the four types of interactions, sorted by task types, as reported to be 'many times' by first-year non-major students after undertaking the laboratory work

Note: 1. Data obtained from the post-lab survey, Study 2 (total number of responses = 772). 2. I-I: Indirect Interaction, s-s: listening to student-student conversations, s-i: listening to student-instructor conversations. 3. The percentage of each item is not equal to 100% as we are only illustrating data of 'many times', not including data of 'never', 'once' and 'a few times'.

In Study 2 (see Figure 7.1), responses about reading the laboratory manual many times were selected slightly less than 50%. The percentage of student-Internet interactions experienced many times was just 11%. The occurrence of student-lab manual interaction for many times was the third level of frequency, being less than the two interactions of S-S talking about procedures and results. Therefore, these results indicate that the laboratory manual was used frequently in the laboratory process. In Study 3 (see Figure 7.2), the student-laboratory manual was the most frequent type of interaction, with 75% of responses selecting this item as 'many times', significantly higher than all of the other items. Students interacting 'many times' with the Internet increased to more than double those of Study 2.

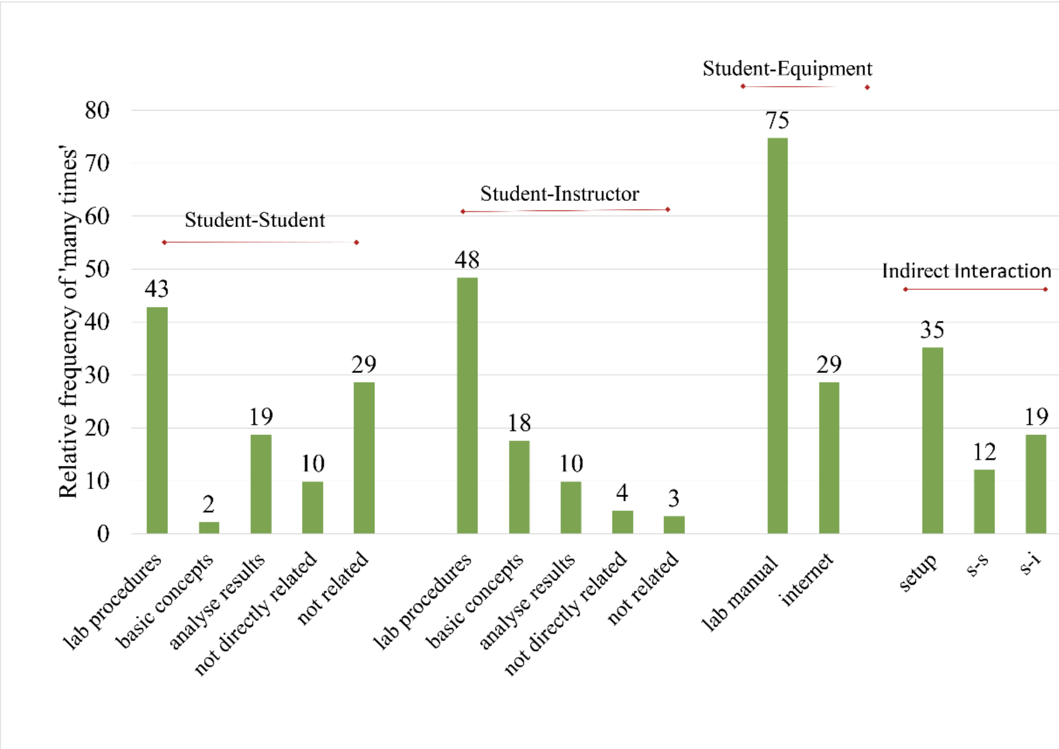


Figure 7.2 Relative percentage frequency of the four types of interactions, sorted by task types, as reported to be 'many times' by second-year chemistry-major students after undertaking the laboratory work

Note: 1. Data obtained from the post-lab survey, Study 3 (total number of responses = 202). 2. I-I: Indirect Interaction, s-s: listening to student-student conversations, s-i: listening to student-instructor conversations. 3. The percentage of each item is not equal to 100% as we are only illustrating data of 'many times', not including data of 'never', 'once' and 'a few times'.

7.2.3 Importance of Interactions - Results from the Post-lab Survey

To address RQ 1.3. "What do undergraduate students consider to have been important interactions after the completion of the chemistry laboratories?", the data from the third part of the post-lab survey were graphed in Figure 7.3 and Figure 7.4. Among all 702 responses in Study 2 (see Figure 7.3), the laboratory manual was reported to be the most important for the laboratory process. Around three-quarters of responses combining rank 1-5 together are located in this item. Even though the laboratory manual did not have the highest value for rank 1, it was higher than most items. Interacting with the Internet was not prominent, only higher than the unrelated/not-directly related topics between S-S and S-I.

In Study 3 (see Figure 7.4), combining ranks 1-5 together, the laboratory manual was reported to be the third most important, lower than the S-S and S-I talking about procedures. However, the responses of laboratory manual as rank 1 was the second-highest, only lower than S-I procedures. The importance of the Internet increased visibly compared to Study 2, higher than S-S and S-I unrelated/not directly unrelated topics, and the indirect interactions between student-student and student-instructor.

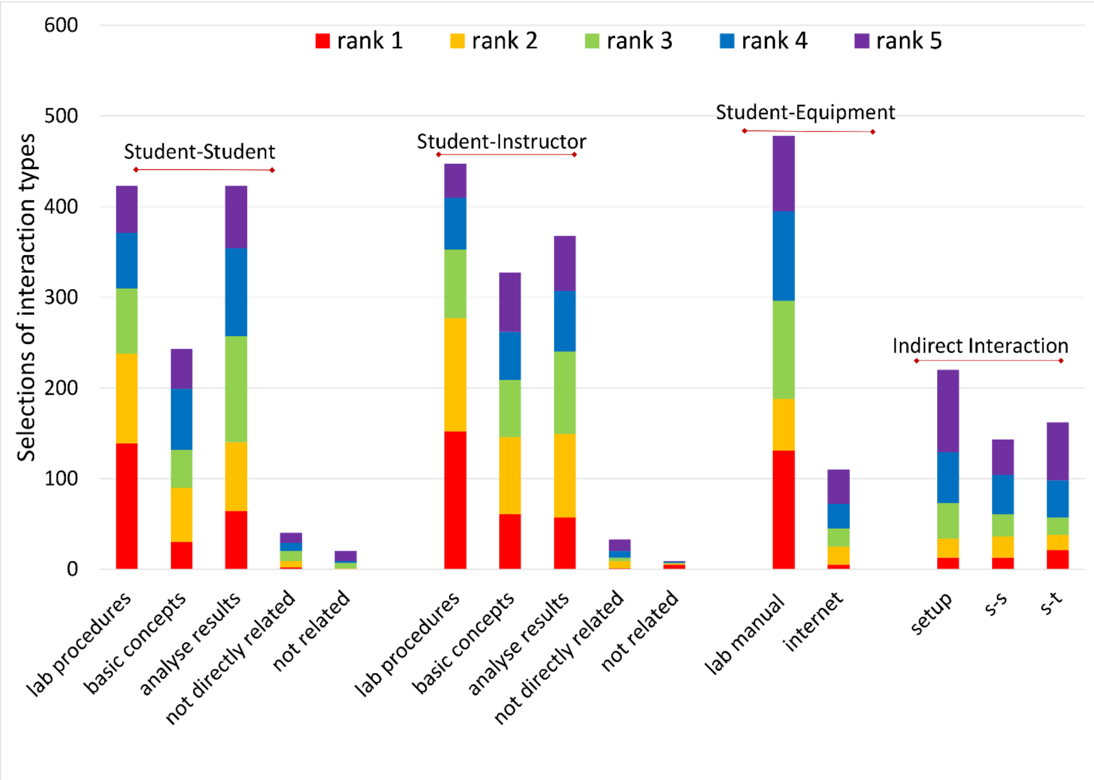


Figure 7.3 Raw number of responses of the importance of the types of interactions, sorted by task types, reported by first-year non-major students after undertaking the laboratory work

Note: Data obtained from the post-lab survey, study 2 (total number of responses = 702)

Similar to the frequency of interactions, the students thought that the laboratory manual was important for their laboratory manipulation. However, there were differences compared to the frequency. For the first-year undergraduates, the laboratory manual was more important even though it occurred less frequently than the S-I interactions. For the second-year students, laboratory manual interaction occurred more often than interaction with instructors, but it was less important than interaction with instructors according to the students' reports.

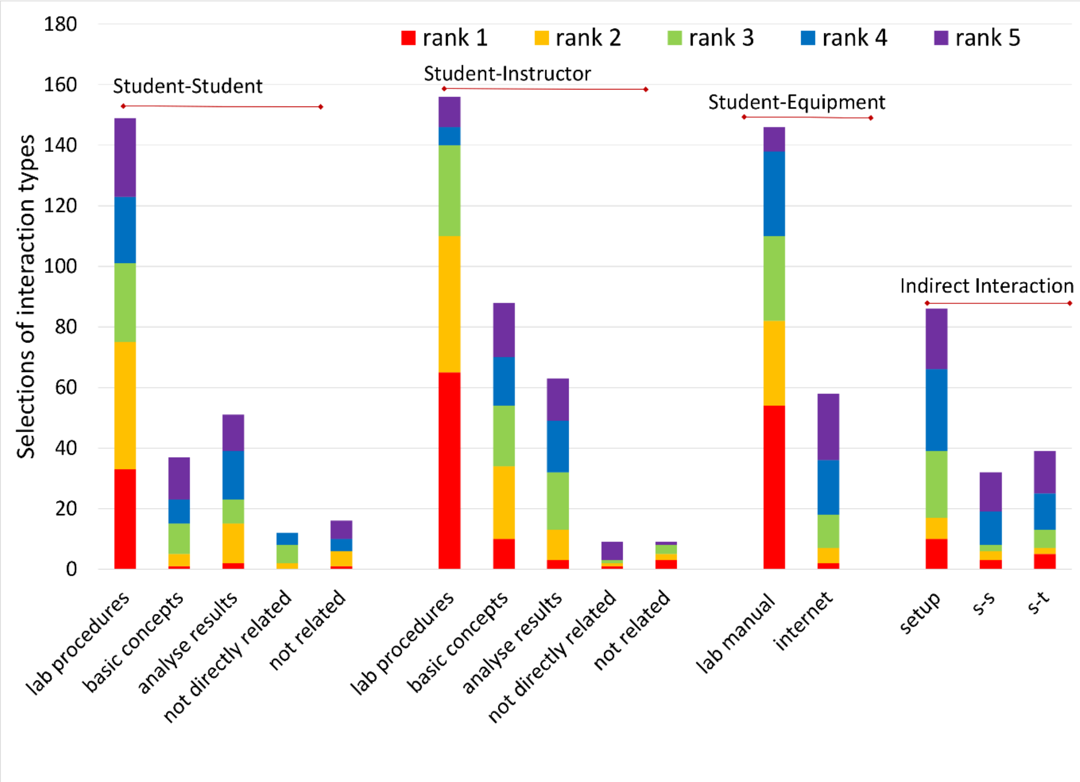


Figure 7.4 Raw number of responses of the importance of the types of interactions, sorted by task types, reported by second-year chemistry-major students after undertaking the laboratory work

Note: Data obtained from the post-lab survey, study 3 (total number of responses = 197)

7.2.4 The Relationship between the Frequency of Student-Equipment Interactions and Satisfaction

To address RQ 1.7. "How do the frequency of interactions and student satisfaction correlate in chemistry laboratories?", the correlation between the frequency of Student-Laboratory manual, and the frequency of Student-Internet interactions, with overall satisfaction were each analysed.

Table 7.1 Spearman's Rank-Order Correlation Coefficient for the Frequency of Student-Laboratory Manual Interactions with Overall Satisfaction

Name of the Study	Number of 'never' and Satisfaction	Number of 'once' and Satisfaction	Number of 'a few' and Satisfaction	Number of 'many' and Satisfaction
Study 2		-.081*		.124**
Study 3	-.210**		-.247**	.288**

*Note: *p < .05, ** p < .01, Only statistically significant values were illustrated*

The first-year non-major chemistry students reported that to interact many times with the laboratory manual positively correlated with their satisfaction levels (Study 2, Table 7.1). The second-year undergraduates with a richer experience and chemistry knowledge also reported similar correlations, albeit the links between the more frequent interactions with laboratory manual and the satisfaction levels were stronger. It seemed that the second-year students relied more on the laboratory manual than the non-major undergraduates.

For the Internet (see Table 7.2), the number of 'many times' of interaction correlated positively with the satisfaction levels for the first-year non-major undergraduates, and the number of 'never' correlated negatively with satisfaction. The second-year undergraduates had no significant relationship between the number of interactions and satisfaction.

Table 7.2 Spearman's Rank-Order Correlation Coefficient for the Frequency of Student-Internet Interactions with Overall Satisfaction

	Number of 'never' and Satisfaction	Number of 'once' and Satisfaction	Number of 'a few' and Satisfaction	Number of 'many' and Satisfaction
Study 2	-.130**			.104**
Study 3				

*Note: ** p < .01, Only statistically significant values were illustrated*

In summary, the more that the second-year students interacted with the laboratory manual, the more satisfied they were with the laboratory, while the frequency of the Internet use had no influence on their satisfaction levels. The frequency to interact with the laboratory manual and the Internet both influenced the learners' satisfaction levels for the first-year undergraduates. However, it should be stated that the correlations mentioned earlier were all weak.

7.3 Discussion

The laboratory manual was self-evidently presumed to be an integral component in undergraduate laboratories. The nature of instruction styles in a laboratory manual definitely can influence the students' learning process. Based on the well-used criteria from Domin (1999), all of the laboratories involved in Study 2 and Study 3 belonged to an exploratory style. This is because everyone including the students know the outcomes, the students were given the procedures and the approach was deductive. Therefore, the nature of different instructional styles in the laboratory manual was not an impacting factor in the analysis. In this study, the role of the laboratory manual was shown to be important and a frequent source of reference. Furthermore, more frequent use of the laboratory manual related positively and significantly with the overall satisfaction level. The Internet was deemed much less important by the students overall, although the second-year students had a relatively higher frequency of interactions with it and assigned more importance to the Internet than the first-year counterparts. In contrast, the first-year students showed a significant correlation between the frequency of the Internet and satisfaction, whereas the second-year students did not.

In most laboratories, it is impossible to perform activities without the guidance of the laboratory manual (Hofstein & Lunetta, 1982). However, compared to the 1970s, studies pertaining solely to the laboratory manual have reduced significantly in recent years. A search using keywords 'laboratory manual' of publications between 2019 to 1998 in four prestigious journals in the area of chemistry education, Chemistry Education and Research Practice (CERP) and Journal of Chemistry Education, Research in Science Education (RISE), and International Journal of Science Education (IJSE) resulted in only three publications investigating the laboratory manual (Bromfield Lee, 2018; Dood, Johnson, & Shorb, 2018; Laredo, 2013). Among them, studies from Laredo (2013) introduced the implementation of problem-based laboratory manual in non-major undergraduate classes. Bromfield Lee (2018) and Dood et al. (2018) were about the introduction of a web-based laboratory manual. Each of the three studies focused more on the reform of presenting the laboratory manual than on its content.

Additionally, research on the use of the laboratory manual in most of the studies was integrated into other research goals which they supplemented. This may be due to various reasons. Firstly, the laboratory manual had been developed and accomplished to a certain extent and not much work could be implemented to improve it. Secondly, researchers were more interested in other aspects in a laboratory (Seery, Jones, Kew, & Mein, 2019; Smith, 2012), such as curricular reform from traditional expository or recipe type to problem-based or inquiry learning (Rusek, Beneš, & Carroll, 2018; Zhao & Wardeska, 2011), or the integration of new techniques or technologies in laboratories (Kolk, Beldman, Hartog, & Gruppen, 2012). Another explanation for this decreasing focus may be that researchers presumed that changes in the laboratory manual did not substantially influence learning. However, the findings of Study 2 and Study 3 herein illustrated that the perception regarding the importance of the laboratory manual was that it was substantially valued by the students. The limited number of studies on laboratory manual seemed to be contradictory to its importance. More focus should be put on the importance of the laboratories in the future.

Criticisms of laboratory work stated that learners tended to follow step-by-step manipulation, while not enough concepts and theories were developed in the laboratory. Given the important role of the laboratory manual in guiding the progression of learning, the change of laboratory manual, together with other factors, can possibly transform the traditional recipe-type laboratory process. At least in the two studies of Dood et al. (2018) and Laredo (2013), the change in the form of a laboratory manual was shown to influence the learner's perception and engagement in the activity. Pre-laboratory work is designed to reduce the working memory demands of a laboratory (Agustian & Seery, 2017; Seery et al., 2019; Winberg & Berg, 2007) and in this study, the pre-lab material is one part of the laboratory manual.

With the involvement of computers in science laboratories, the Internet has been increasingly incorporated into learning in undergraduate science laboratories (Bromfield Lee, 2018; Dood et al., 2018). The Internet can possibly play various functions in laboratory teaching. For example, the Internet can be used to assess students' understanding by allocating individual questions before and/or after the completion of the laboratory class. The Internet can provide an online learning community where participants interact and share information (Shwartz & Katchevitch, 2013). On the one hand, some online laboratories including simulated and remote laboratories are becoming popular. On the other hand, even in face-to-face science laboratories where the Internet is not a compulsory component, the undergraduates tended to search for information from the Internet frequently (Patterson, 2011), as was the situation with the second-year chemistry students in Study 3.

7.4 Chapter 7 Summary

In the previous chapter (Chapter 6), the results about interactions in Study 2 and Study 3 were presented from the viewpoint of the five scales from the factor analysis. However, interactions with the laboratory manual and the Internet should not be ignored even though they were not included in the five factors. Therefore, the relevant data were analysed and summarised in this chapter. Specifically, this chapter has illustrated the results pertaining to Student-Equipment interactions (focusing on interactions with laboratory manual and the Internet) in Study 2 and Study 3. The analysis was listed as the importance of interactions before the commencement of the laboratory, the frequency and importance of interactions resulted from the post-lab survey, and the relationship between the interactions and satisfaction levels. Comparisons were made relating Study 2 and Study 3. Overall, the students' perceptions on the roles of laboratory manual and the Internet varied in the first-year non-major and second-year chemistry major students. The functions of laboratory manuals in undergraduate science laboratories were discussed. This is the final chapter about data from face-to-face laboratories, and the next chapter will introduce studies of the learning process in the remote laboratory.

CHAPTER 8: STUDY 4 – INTERACTIONS IN A CHEMISTRY-MAJOR UNDERGRADUATE REMOTE LABORATORY

8.0 Chapter Outline

This chapter describes the purpose, the design and procedures, and the results of Study 4 which was an investigation of the second-year chemistry-major undergraduate students conducting a remote laboratory. In this study, on-site observations and interviews with focus groups were conducted. Pre- and post-lab surveys were completed by each member of the class. Results from the pre-lab survey addressed Research Question 2.1 and results from the post-lab survey addressed Research Questions 2.2, 2.3, 2.4 and 2.5. Section 8.1 provides the goals of Study 4 and Section 8.2 describes the characteristics of the remote laboratory being studied. Section 8.3 examines the process of the pilot study for Study 4, which set the foundation for the first-step of Study 4. Section 8.4 illustrates the methods used in this study and Section 8.5 presents the results. Lastly, in Section 8.6 the findings of the learning process in the remote laboratory are discussed.

8.1 Purposes of Study 4

Study 4 investigated the second-year university, chemistry-major students' perceptions of the interactions and their learning experiences in a remote chemistry laboratory, named 'the enthalpy of vaporisation of n-octane', designed by the University of New England (UNE). Specifically, Study 4 examined the learning process of the students in conducting remote laboratories, by observing and investigating students' behaviours and by understanding student perspectives on the laboratory activities.

8.2 Background to the Remote Laboratory

The initiative for the design of the remote laboratory comes from the following aspects. Firstly, remote laboratories can suit the needs of distance learners. A large cohort of students at UNE are distance learners, and they used to undertake face-to-face chemistry laboratories when they were attending on-campus intensive classes. During the intensive classes, the students mostly conducted laboratories for several hours in two or three days, which means the workload is really heavy. The remote laboratory is able to address this issue as it can be carried out by the learners at a time and location suitable for them and can be integrated into their distance education curriculum. Remote laboratories can also complement traditional laboratories or even replace some of them because they can provide students with individualised, flexible learning opportunities. This is one of the main reasons that this remote laboratory was created.

However, the strength of the remote laboratory does not just include the convenience provided for distance learners. The remote laboratory can also enhance the development of conceptual understanding. This is because the students can repeat the laboratory multiple times and there is flexibility to suit students with varied learning needs (Viegas et al., 2018). Therefore, it was believed that the students at both Curtin and UNE could benefit from this remote laboratory experience.

The remote laboratory is located in the chemistry department at UNE; enrolled students can control and manipulate the laboratory apparatus by means of the Internet. The laboratory manual instructs the students to vaporise n-octane:

1. Remove air in the system by opening, evacuating and resealing the test tube.

2. Carefully heat the system to a constant temperature. This is achieved by increasing a slider by a small step and waiting for temperature and pressure to stabilise. Note, small variations in external conditions may cause fluctuations and the two temperature sensors are likely to differ. Typical times between readings are up to 10 minutes.

3. When stabilised, record the vapour pressure and temperature.

4. Repeat steps 2 to 4 to a maximum temperature of 100 ºC. (Obtained from the laboratory manual)

The interactive platform is illustrated as a screenshot in Figure 8.1.

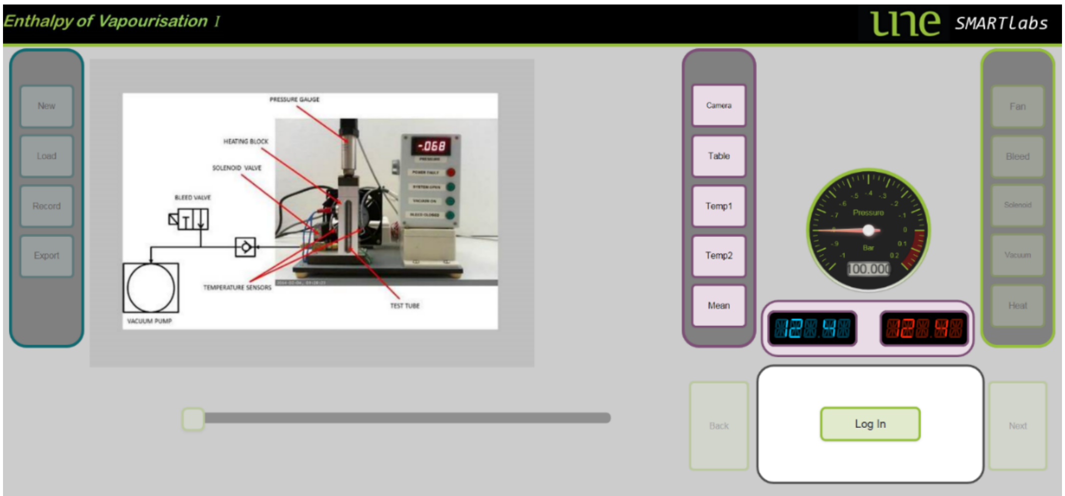


Figure 8.1 A screenshot of the remote laboratory

Note: developed by the University of New England Smartlabs

In this remote laboratory, the technician played part of roles of instructors in a face-to-face laboratory. The technician was supposed to answer students' questions about technical issues, while less on theoretical problems. The technician could be contacted through email or phone.

8.3 Pilot Study

As there were no existent instruments to assess interactions in the remote laboratory, a pilot study was first conducted. In May of 2017, a total of three students, two in a group and one individual, who had enrolled in the unit of *Chemical Energetics and Kinetics* at Curtin University volunteered to attempt the remote laboratory located in the chemistry department at UNE. This process was conducted to test the applicability of the items in the pre-lab, post-lab survey forms and the laboratory observation sheet and thereby obtain a general overview of student behaviours in this remote laboratory.

Table 8.1 Pre-lab Survey Form Showing Possible Laboratory Interactions

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	
Reading the laboratory manual/notes you learn	About the procedures/ laboratory equipment	
	How to analyse your results	
	About the basic science theory behind the laboratory	
From the Internet, you learn about	The procedures/lab equipment	
	How to analyse your results	
	About the basic science theory behind the lab	
From the technician people you learn	About the procedures/lab equipment	

Table 8.2 Post-lab Survey Form Showing Possible Laboratory Interactions

Example Interaction	Frequency		
1. (Student-Student Interactions) Did you talk to another student about	Never	Sometimes	Many times,
1.1 The procedures, protocols or lab equipment?	1	2	3
1.2 The basic science concepts behind the lab?	1	2	3
1.3 Analysing your results?	1	2	3
1.4 Discipline topics not directly related to the lab?	1	2	3
1.5 Topics not related to the lab?	1	2	3
2. (Student-Interface Interactions) Did you communicate with the software (computer- interface) about...			
2.1 The procedures, protocols or lab equipment?	1	2	3
2.2 The basic science concepts behind the lab?	1	2	3
2.3 Analysing your results?	1	2	3
2.4 Discipline topics not directly related to the lab?	1	2	3
2.5 Topics not related to the lab?	1	2	3
3. Did you ...			
3.1 Read the lab manual/instructions associated with this lab?	1	2	3
3.2 Use the Internet for technical assistance, data analysis or for concepts behind this lab?	1	2	3
3.3 Ask for technical assistance			
3.4 Use the help option on the screen			

Pre-lab Survey Volunteer_2017_for Remote Labs

Q1 Below is a list of 10 possible interactions that may happen during this laboratory class. Please rank them from 1-10 (where #1 is the most important).

______ Talking to another student you learn about the procedures/lab equipment
______ Talking to another student you learn how to analyse your results
______ Talking to another student you learn about the basic science theory behind the lab
______ Reading the laboratory manual/notes you learn about the procedures/lab equipment
______ Reading the laboratory manual/notes you learn how to analyse your results
______ Reading the laboratory manual/notes you learn about the basic science theory behind the lab
______ From the internet you learn about the procedures/lab equipment
______ From the internet you learn how to analyse your results
______ From the internet you learn about the basic science theory behind the lab
______ From the technician people you learn about the procedures/lab equipment

Q2 In this experiment we will get gauge pressure data directly (in bar), and you need to convert it to absolute pressure. The equation to measure gauge pressure is as follows: gauge pressure = absolute pressure – atmospheric pressure. Calculate the absolute pressure (in mmHg) if the gauge pressure is -0.8000 bar, the Armidale atmospheric pressure is ca. 680.0 mmHg. (hint: 1 bar = 750.1 mmHg)

A) 1280 mmHg B) -79.92 mmHg C) 79.92 mmHg

Q3 if you are going to use pascal as the unit of pressure, how are you going to convert the pressure 79.92 mmHg into pa? (Hint: 1 mmHg = 133.3 pascal) A) 133.3 * 79.92 B) 133.3/79.92 C) 133.3+79.92

Q4 In the first step, you are going to open, evacuate and reseal the test tube following the instructions on the computer screen. To minimise the evaporation of n-octane during the evacuation process, what is the maximum time span to evacuate the sample? A) 1- 2 seconds B) 1-2 minutes C) 30 minutes

Q5 the reason of carefully heating is:

A) To ensure stabilised temperatures and pressures within a reasonable time frame

B) To give the sliders time to be heated C) Because it is chemistry experiment, we are supposed to be careful

Q6 which of the following statements correctly apply to vapour pressures? Please select all that apply

A) A plot of ln PC_8H_{18} against T^{-1} will have a negative slope B) A plot of ln P C_8H_{18} against T^{-1} will have a positive slope C) Vaporisation is an exothermic process and ΔS_{vap} is negative

D) Vaporisation is an endothermic process and ΔS_{vap} is positive

Q7 A bar of copper is heated to 30 °C and then placed into a Styrofoam cup of water. Thermal equilibrium between the copper bar and water is reached at 40 °C. What was the temperature of the water before the copper bar was dropped into it? Why?

A) Less than 40 °C because copper can hold more heat than water B) Less than 40 °C because the copper bar heated the water C) Greater than 40 °C because water can hold more heat than copper

B) Greater than 40 °C because the water heated the copper bar

C) Greater than 40 °C because the water and copper bar would cool down on their own without interacting with each other or anything else

Figure 8.2 the pre-lab survey used in the pilot study

Part 1 Frequency of interactions

1. (Student-Student Interactions) Did you talk to another student about	Never	Sometimes	Many times
1.1 the procedures, protocols or lab equipment?	1	2	3
1.2 the basic science concepts behind the lab?	1	2	3
1.3 analysing your results?	1	2	3
1.4 discipline topics not directly related to the lab?	1	2	3
1.5 topics not related to the lab?	1	2	3
2. (Student-Interface Interactions) Did you communicate with the software (computer- interface) about...			
2.1 the procedures, protocols or lab equipment?	1	2	3
2.2 the basic science concepts behind the lab?	1	2	3
2.3 analysing your results?	1	2	3
2.4 discipline topics not directly related to the lab?	1	2	3
2.5 topics not related to the lab?	1	2	3
3. (Student-Equipment Interactions) Did you ...			
3.1 read the lab manual/instructions associated with this lab?	1	2	3
3.2 use the Internet for technical assistance, data analysis or for concepts behind this lab?	1	2	3
3.3 ask for technical assistance	1	2	3
3.4 Use the help option on the screen	1	2	3

Part 2 Importance of interactions

Please choose only 5 of those 15 items (from 1.1 to 3.4) that you think are most important relating to the laboratory that you just finished and rank them

Part 3 Satisfaction and student opinions	Strongly disagree	Somewhat disagree	Neither nor	Somewhat agree	Strongly agree
The quality of this laboratory experiment compared favourably to my other face-to-face laboratory experiments					
If I had an opportunity to do another laboratory experiment via the Internet, I would gladly do so					
My choice to take this unit via the Internet was a wise one					
I gained more interest in the subject matter of this unit					
I was very satisfied with the unit					
I feel that this unit served my needs well					
I felt I have done a real laboratory					
The communication with students is as much as that in face-to-face laboratories					
The communication with instructors is as much as that in face-to-face laboratories					
I feel I was totally immersed into the lab process					
I think the technology is ease to use					
Overall satisfaction					

Figure 8.3 the post-lab survey used in the pilot study

One goal of the pilot study was to assess the applicability of the items about interactions and the student satisfaction levels (Table 8.1 and Table 8.2) in the survey forms and the laboratory observation sheet (Figure 3.2, Chapter 3), which was designed by two of our research group members. The criteria for the design was based on several resources: the literature review from this thesis (See Section 2.4, Chapter 2), the pre-lab survey used for face-to-face laboratories (See Table 4.2, Chapter 4), the IULC instrument (See Figure 5.1, Chapter 5), and the laboratory observation sheet used in the face-to-face laboratories (See Section 3.1, Chapter 3), as well as the remote laboratory manual provided by UNE. Eventually, preliminary versions of the pre-lab (Figure 8.2) and the post-lab survey (Figure 8.3) were designed. Further details will be introduced in Section 8.4.1. The options were also changed to *Never*, *Sometimes* and *Many Times* (Figure 8.3). Once was removed as the goal of this study was to investigate the general trend of frequency of interactions.

Another goal of the pilot study was to understand student behaviours; therefore, two of the volunteer students were videotaped and audiotaped as they worked as a pair. The individual student was not recorded because there were not many conversations in the laboratory process. Data from the video and audio recordings were analysed to develop the design and the improvement of the items in the survey forms, using the method developed by Knoblauch and Schnettler (2012). The transcript of the audio recordings is shown in Appendix C. The video recordings lasted two hours.

Based on the observations in the remote laboratory, the typical process was as follows. The website of the remote laboratory was opened, and the interactive platform illustrated in Figure 8.1 was shown to be available. After logging in using their specific account information, the apparatus located at UNE automatically began to work, as depicted by the changing of the temperature scales on the right side of the screen. Initial instructions appeared on screen to guide the student directions; a next-step instruction appeared after the button 'next' was clicked. The instructions were procedures to manipulate the equipment, including warnings on risks. The two students were mostly reading the on-screen instructions and discussing the phenomena that they saw or the manipulation technique, making comments such as 'the pressures are changing, the heat is...' and 'we need to make these two to be equal'. Occasionally, the students referred to the laboratory manual to confirm a procedure.

For this experiment, it is required that the user endeavours to keep the two temperatures similar. The same temperature numbers meant that equivalence had been achieved. The two values of temperature and the pressure value resulted from the changes in temperatures were then recorded. The students mostly met a problem at this stage because the sensors to assess temperatures were extremely sensitive and changed very quickly. It was almost impossible for the students to attain exactly the same temperature values. The students felt frustrated if their attempts to hold the same values failed.

After this first trial, the students only needed to increase the temperature slightly and wait for the new equilibrium to be achieved before recording the new data. The arrival at equilibrium mostly lasted several minutes and there was nothing special to do, so the students tended to talk about non-related topics or carry out other activities. It was compulsory for the students to record at least five data points and make further data analysis. The students were required to carry out two trials and they took turns to manipulate the apparatus. Before the commencement of the second attempt, they waited for the equipment to cool down. Even though there was a fan to help with the cooling, it took at least ten minutes to finish this task. In the second trial, the students were more relaxed and more unrelated conversations happened. However, the students met problems in the data analysis step, and after failing to find the answers by the Internet, they asked me for help with the unit conversions. This question about the unit conversion was designed for next-step manipulation as one of the pre-lab questions in Study 4, 2018. The students' behaviours that occurred frequently were categorised and listed in Table 8.3.

Table 8.3 Examples of Student Behaviours and the Corresponding Categorisation of Interaction Types

Interaction Type	Student Activities/Discussions
Student-Lab Manual	To read the laboratory manual
S-S Procedures	Follow the instructions on the screen and click the buttons
S-S Results	'It (the temperature) is getting high.'
S-S Theory	'Why do the two temperatures need to be equivalent?'
S-S Unrelated	'I ended up doing my Japanese exam.'
S-I Procedures	To ask the observer whether to wait longer before the second trial
S-I Results	'Are the data reasonable?'
S-I Theory	'Why do the two temperatures need to be the same?'

Results from the pilot study showed that the pre-designed items (see Figure 8.2 and Figure 8.3) were applicable to future studies. After this, pre- and post-lab surveys were then modified for use with subsequent cohorts.

8.4 Research Methods

8.4.1 Design of the Instruments

After the pilot study, the design of instruments was refined, and systematic procedures were conducted to improve them. Three types of item were included in the post-lab surveys, namely student interactions, the satisfaction and the student opinions about the remote laboratory. Similar to the post-lab survey in face-to-face laboratories (see Figure 5.1, Chapter 5), the frequency of interactions were classed into four types – 'never', 'once', 'a few', and 'many times'; the satisfaction and student opinions were divided into 5 Likert scales (Strongly Disagree to Strongly Agree). Details were illustrated in Appendix A7.

Student Interactions: The frequency of student interactions was measured by a 4-item scale, ranging from 'never' to 'many times'. The importance of student interactions was investigated by requiring the students to choose the five most important ones, exactly the same as the requirement in the post-lab surveys used for the face-to-face laboratories. However, there were several differences in the design of the items of interactions. In face-to-face laboratories, four types of interactions, namely S-S, S-I, S-E and I-I, were investigated. However, in the remote laboratory used in the present study, some of these interactions did not exist or the characteristics of interactions were different. Firstly, there are no indirect interactions because the students were manipulating the equipment without other groups present. In addition, there were no instructors with the students in the laboratory process. Even though, when the focus groups were conducting the remote laboratory, the researcher was present but was not intended to be an instructor but an observer. Therefore, for the other groups of students at Curtin and for all the UNE students, S-I interactions did not exist.

In the remote laboratories, the students could ask for help from the technicians and instruction was completed partly by the technician. Consequently, an item called 'S-I interactions' was still included in the pre- and post-lab surveys for the remote laboratories, with the focus being on the role of technicians and online help. Thirdly, S-S interactions were complex. For the Curtin students who were working in pairs, the S-S interactions were similar to the face-to-face laboratories. The UNE students who were doing the remote laboratory individually could still interact with their peers in the online group chatrooms. Nevertheless, the UNE students were provided with the same instruments as the Curtin students and the S-I interactions were retained as one item. Lastly, for the S-E interactions in the remote laboratory, the students more easily had access to the Internet and the Internet was assumed to play a more important role in the learning process than in the face-to-face laboratory. Consequently, Student-Internet interactions were expanded, and more sub-items were included. Similarly, the function of the laboratory manual was more important, and this introduction was made explicit. Details about the connections and differences between items of interactions for the remote laboratory and those used for face-to-face laboratories are shown in Table 8.4.

Table 8.4 Changes of Items of Interactions in the Remote Laboratory

Interactions in Face-to-face Laboratories	In the Remote Laboratory
Student-Student (S-S)	Kept
Student-Instructor (S-I)	Kept
Student-Equipment (S-E)	More items within Student-Internet and Student-Lab manual were included
Indirect Interactions (I-I)	Not included

Except for the changes in the items of interactions, the satisfaction variables that were unique for remote laboratories were added in the remote laboratory surveys.

Student Opinions: Two types of students' feelings about the remote laboratory were incorporated in the survey, namely the feeling of authenticity and flexibility. Authenticity and flexibility were chosen as they were two of the main significant beneficial characteristics that a remote laboratory conveys (Bright et al., 2008; Sauter et al., 2013), and compared with other characteristics, like cost efficiency, enables distance education, these two factors were more closely related to student opinions about a remote laboratory.

Student Satisfaction: Student satisfaction was measured by a 5-Likert validated and reliable scale adapted from Arbaugh (2000a) and the thesis of Ma (2008).

The internal reliability of the measure from Arbaugh (2000a) was validated by factor analysis as 0.92 in Arbaugh (2000b). This scale focused on the measurement of student satisfaction with online courses, the students' perception of the quality of the course, and their intention of taking future courses distantly. The details of the items are listed in Table 8.5.

The design and development of the survey forms used in the remote laboratory also went through two versions, for the pilot study and Study 4, respectively. Initially, the first version of the pre- and post-laboratory surveys were designed by two members from our research team. This version was implemented in the pilot study with three volunteer students. Considering the fact that the remote laboratory was not integrated into the curriculum for the volunteer students, some questions about key concepts and laboratory procedures were designed to assist the learning process. These questions were included in the pre-lab survey. Face validity of the survey forms was established through interviews with the three volunteer students. These interviews confirmed that the items in the pre- and post-laboratory surveys were comprehensive.

Based on the on-site laboratory observation, and the interview feedback from the students, the items were believed by both the researchers and the students to be suitable for the remote laboratory. Therefore, only slight changes of terms were made to adjust to the online learning environment. The pre-designed questions about concepts and procedures were kept in the unit of *Chemical Energetics and Kinetics* in Study 4, 2018 as pre-lab questions. The pre- and post-lab survey for in the remote laboratory are included in Appendix A. The survey forms were transformed into an online platform called *Qualtrics* to fit the necessity of students working on the remote laboratory. The development of the laboratory observation sheet was based on the one used in face-to-face laboratories, as shown in Section 3.1.2, Chapter 3.

Table 8.5 Interaction and Satisfaction Variables Included in the Pre- and Post-lab Surveys for the Remote Laboratory

Item Types	Item Category	Sources
Student-Student	Laboratory procedures/equipment	Modified from the classification of interactions from (Moore, 1989)
	Analysing data	
	Basic concepts	
Student-Instructor	Ask the technician/instructor for help	
	Use the online help function	
Student-Internet	Lab procedures/equipment	
	Basic concepts	
	Analysing data	
Student-Lab Manual	Lab procedures/equipment	
	Basic concepts	
	Analysing data	
Student opinions	Authenticity: I felt I have done a real laboratory.	(Sauter et al., 2013)
	Flexibility: the flexibility of doing a remote laboratory anytime anywhere is important to me.	
Satisfaction	Immersion: I feel I was totally immersed in the laboratory process.	Modified based on the student survey from (Arbaugh, 2000a) and the student survey in the thesis of Ma (2008)
	Ease of Use: I think the technology is easy to use.	
	Quality: the quality of this laboratory experiment compared favourably to my other face-to-face laboratory experiments.	
	Retry: if I had an opportunity to do another laboratory experiment via the Internet, I would gladly do so.	
Overall satisfaction	Overall, I'm very satisfied with this laboratory experience.	N/A

8.4.2 Participants and Description of the Laboratory

There were two cohorts of students included in Study 4. In July of 2018, all of the second-year Chemistry students from Curtin University enrolled in the unit *Chemical Energetics and Kinetics*, undertook the remote laboratory as a mandatory part of the course. The students were required to undertake the laboratory in pairs. Among the participants, five groups including ten students in total voluntarily completed the laboratory as a focus group. For these students, their behaviours were observed by the researcher during the laboratory process and some of them were interviewed immediately after finishing the laboratory activity. As much as possible the researcher endeavoured not to interrupt the students. The other students who were not part of a focus group completed the remote laboratory more freely, choosing the location and without the researcher being present. For the focus group students and those who had conducted the laboratory by themselves, a pre-lab survey before the conduction of the laboratory was circulated to introduce the project, ethical issues and to inform that their participation were completely voluntary. To help the students tackle the problems they might encounter, several pre-lab questions were also designed to guide their understanding of the procedures in the laboratory manual, and questions about concepts related to the specific laboratory. After the completion of the laboratory, a link leading to the post-lab survey was sent to the students. To avoid a potential problem of more than one group choosing the same time period, the available time sessions were circulated via Doodle, an online time-scheduling website. In this platform, the students could see what sessions were available and the name of other students who had chosen the time period. Considering the students were from the same Chemistry unit and they had known each other for one and a half years, the Doodle link was not designed as anonymous. A maximum of two students were able to choose a one-time session.

Meanwhile, earlier in June 2018, a similar process was conducted with the second-year students of UNE enrolled in the unit *Quantum and Thermal Structure*. The UNE students included both on-campus and distance learners. However, all of the UNE students were required to perform the remote laboratory individually without an instructor or researcher present. The unit focuses on an understanding of quantum and thermal structure and the relationship to chemical reactivity and physical processes. The remote laboratory was one main component of the laboratory part.

8.4.3 Data Collection

In Study 4, both pre- and post-lab surveys, direct observation and interviews with focus groups were implemented to provide a multi-aspect description of the students' behaviours and experiences with the remote laboratory. Similar items were included in both survey and laboratory observation sheets.

Surveys were used as one of the main data-collection strategies in all of the remote laboratories. A pre-lab survey before the commencement of the remote laboratory and a post-lab survey after the completion of the remote laboratory activity was completed. Similar to Study 2 and Study 3, the pre-lab survey focused on the analysis of the importance of interactions, while the post-lab survey focused on the frequency of interactions, as well as the overall satisfaction. Different from the previous studies, the survey was conducted via the online platform *Qualtrics*, instead of the paper-and-pencil based form, because most of the students undertook the laboratory by themselves, not in the traditional classroom and were not present in person. The other type of data collection method was on-site observations, which was conducted to provide multiple views of the learning process and only conducted with the focus groups when the participants were doing the remote laboratory with the researcher present. The observations were conducted through the GORP online platform https://gorp.ucdavis.edu/, using version 2 of the laboratory observation sheet (see Section 3.1.2, Chapter 3). Observation notes and pre-designed observation codes were used in the observation process. Meanwhile, the students were encouraged to articulate their opinions and their conversations were recorded. At the end of the laboratory, two groups of students were interviewed with questions based on their feedback to the post-lab survey to understand students' perceptions of the experience of remote laboratory manipulation.

Before the commencement of the laboratory, the students were informed that the study was voluntary, and it was not compulsory to complete the survey forms or to participate in the focus groups. The observer endeavoured to be unobtrusive and not to influence the students' behaviours. The students who agreed to be observed were informed that the observer did not intend to provide instructions, and would only answer questions, during the laboratory process. When observing, the observer sat away from the students at a distance and kept quiet as much as possible. The students were not concerned about being observed and did not behave differently. As an example, conversations about a large number of unrelated topics still occurred even though the students knew that they were being observed.

8.4.4 Data Analysis

To provide a general picture of interactions that occurred in the remote laboratory, figures were used to show (1) the ranking of interactions in the pre-lab survey; (2) the frequency of interactions in the post-lab survey, resulting from the pre- and post-lab survey; (3) the distribution of importance of interactions in the post-lab survey; and (4) the distribution of student opinions and satisfaction in the post-lab survey.

To investigate the relationship between the strength of interactions, student opinions, the satisfaction variables, and the overall satisfaction item, Spearman's rank-order correlation coefficients were calculated using SPSS.

One of the foci of this chapter is on the description and understanding of student behaviours in remote laboratories, not on the difference between students at Curtin and UNE. There exist differences in the characteristics of Curtin and the UNE students and the variances might influence their behaviours. However, both students from Curtin and UNE were conducting the laboratory with same laboratory equipment which was located at the same campus, and they were performing the laboratory at a distance. The similarity was believed to mainly influence the learning process not the difference of the institutions. Therefore, the results from Curtin and UNE students were combined in the data analysis. Similarly, results from the focus groups were analysed to provide detailed information about student behaviours, not on the comparison between the focus groups and the other students. The results of the focus groups were combined with other results in the survey forms. Results from laboratory observation and interview transcripts are illustrated in the results (see Section 8.5).

As mentioned in Section 3.1.2, Chapter 3, data with the focus groups from the laboratory observation was used to validate the results from the post-lab surveys. Because of the different features of remote laboratories, the items in the pre- and post-lab surveys varied from the face-to-face laboratories. Consequently, the analysis was not based on the five scales, but on the different types of interactions that happened in the remote laboratory. To provide detailed information, the interviews were transcribed and analysed.

8.5 Results:

8.5.1 Importance of Interactions - Results from the Pre-lab Survey

To address RQ 2.1. "What do undergraduate students consider to be important interactions before the conduct of the chemistry laboratory?", results in students' expectations of the importance of interactions are shown in Figure 8.4. Students expected that to interact with a laboratory manual would be important for their learning and also expected that to interact with the technician was important. To interact with peers about analysing the results and finding information about basic concepts through the Internet were the most important in the three task types in student-student and student-Internet interactions.

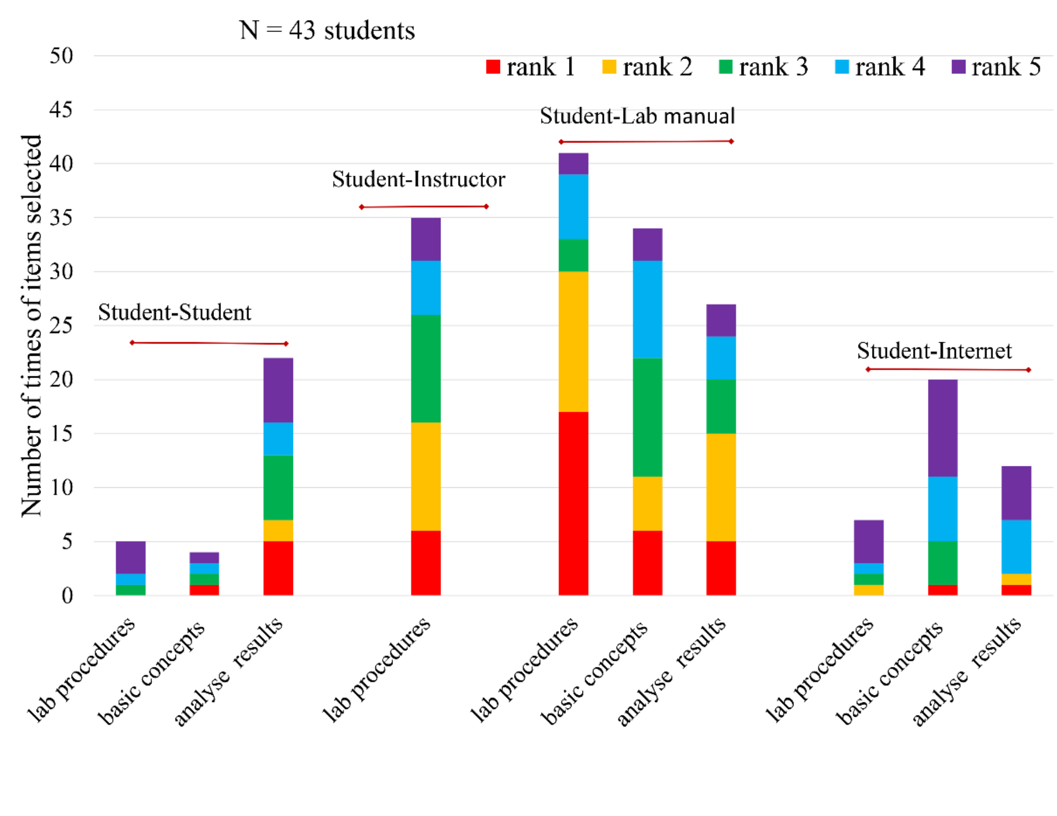


Figure 8.4 Students' expectations (number of times of items selected) of the importance of the potential interactions sorted by task types before undertaking the remote laboratory

Note: Data obtained from the pre-lab survey, Study 4 (total number of selections = 43 x 5 = 215)

8.5.2 Frequency of Interactions - Results from the Post-lab Survey and Laboratory Observation

To address RQ 2.2. "What type and range of frequency of interactions do students engage in during the chemistry laboratory?", results from the post-lab survey and the laboratory observation sheet were analysed and shown in Figure 8.4. The students conducting the remote laboratories were the same as those in Study 3, namely the second-year undergraduates majoring in Chemistry at Curtin. However, the frequency of interactions was significantly different. Firstly, the percentage of interactions that occurred many times was much less than in the previous studies. The laboratory manual provided the most frequent interactions among all the four types of interactions. This is reasonable because the students were working without the instructors present, so the laboratory manual was the main resource for them to use.

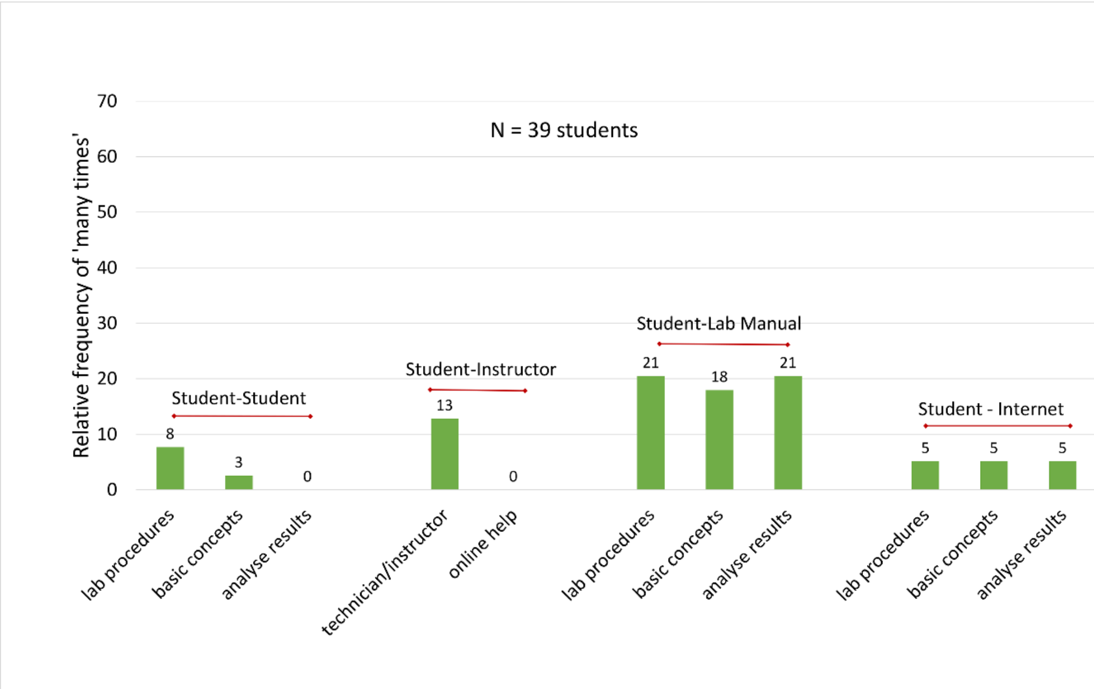


Figure 8.5 Relative percentage frequency of the interactions, sorted by task types, as reported to be 'many times' by students after undertaking the remote laboratory work

Note: Data obtained from the post-lab survey, Study 4. The percentage of each item is not equal to 100% as only data of 'many times' are illustrated, not including data of 'never', 'once' and 'a few times'.

After the completion of the laboratory, the students reported that they had interacted more frequently with the laboratory manual in all of the three aspects, namely, laboratory procedures, basic concepts and analyse results. The students also responded that they had had more interactions with their peers about procedures than about concepts or results. For online help, the interactions arising from the analysis of results had the same frequency as those for procedures and concepts.

For the focus groups, an on-site observation was performed via the online GORP platform and data about the frequency of interactions from the laboratory observation sheet were analysed. Firstly, more unrelated behaviours happened in the remote laboratory, especially in the second trial. For example, one group of students set up a gap time of ten minutes and began to read a psychology book while they were waiting. Another group was talking about hockey games, and some others were discussing the instructors and the courses that they had chosen. These students knew the process of the laboratory and understood that they only needed to record the results in a fixed time. They seemed to be less concerned and more confident with the laboratory procedure, while other students reported that the laboratory activity was boring and that the waiting time was too long.

The percentage of each type of interaction (i.e., the raw number of types of interactions divided by the total number of all interactions) is presented in Figure 8.6, to provide another viewpoint about the learning process. Compared with the students' self-reports, fewer student-laboratory manual interactions were observed. For the remote laboratory, two types of guidance about procedures were included. One type was from the laboratory manual; the other type was from the procedural guidance embedded within the website, received from the computer screen. The researcher only recorded behaviours as student-laboratory manual interactions that included directly reading or writing on the laboratory manual. However, from observation the students did spend a large amount of time following the directions on the computer screen to manipulate the equipment. This type of interactions was recorded as S-S interactions about procedures. However, one could consider that the students following directions about procedures was interactions with laboratory manual, not S-S, as in the process they mostly only needed to follow the guidance, no discussions were required between them. This type of classification was typical in face-to-face laboratories where procedures came from only the laboratory manual, so all interactions of procedures were likely to be assigned as student-laboratory manual interactions. If the laboratory activities of following the guidance from the computer screen were assigned as interactions with the laboratory manual, not as procedures, then the results from the observation align well with the results from the students' self-reports. Further study was required to test this assumption. This mismatch provided guidance for the future design of the instruments used for remote laboratories. Student-computer interactions should be allocated as an individual item in the instruments. This mismatch also provided a hint for researchers that validation was always needed for a newly developed instrument before wide application.

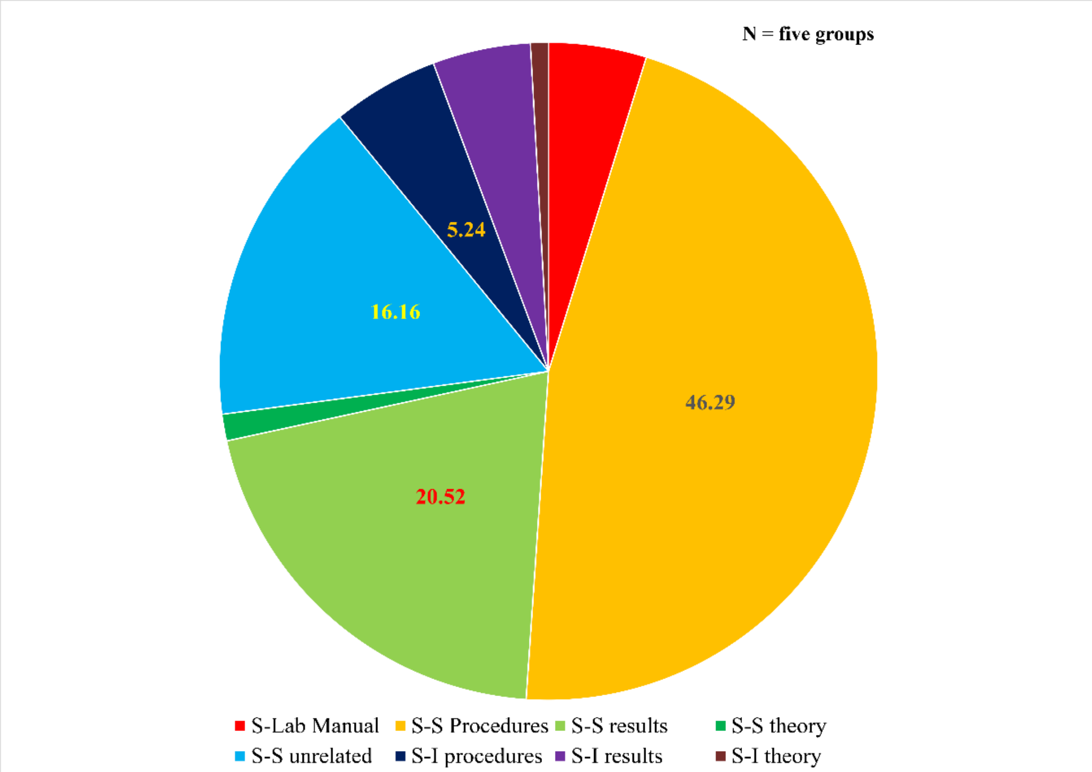


Figure 8.6 the proportion of each type of interactions observed in the remote laboratory work

Note: S-Lab Manual: student interacting with the laboratory manual, S-S Procedures: interactions about procedures among students, S-S results: interactions about results among students, S-S theory: interactions about theories among students, S-S unrelated: unrelated topics among students, S-I procedures: interactions about procedures between students and instructors, S-I results: interactions about results between students and instructors, S-I theory: interactions about theories between students and instructors,

8.5.3 Importance of Interactions - Results from the Post-lab Survey

To address RQ 2.3. "What do undergraduate students consider to have been important interactions after the completion of the chemistry laboratory?", the results of the post-lab survey were graphed as shown in Figure 8.7. The students reported that to refer to the laboratory manual for procedures, concepts and results was important. The fourth most important interaction was to talk about results with their peers and to ask for help from the technician/instructor. It is, therefore, necessary to point out the indispensable role of the laboratory manual when the students are working in a remote laboratory. In the process of conducting the laboratories, the instructors from whom the students were accustomed to request information in face-to-face laboratories were either physically absent or were not as conveniently available. The laboratory manual is the most directly-related source for the specific laboratory.

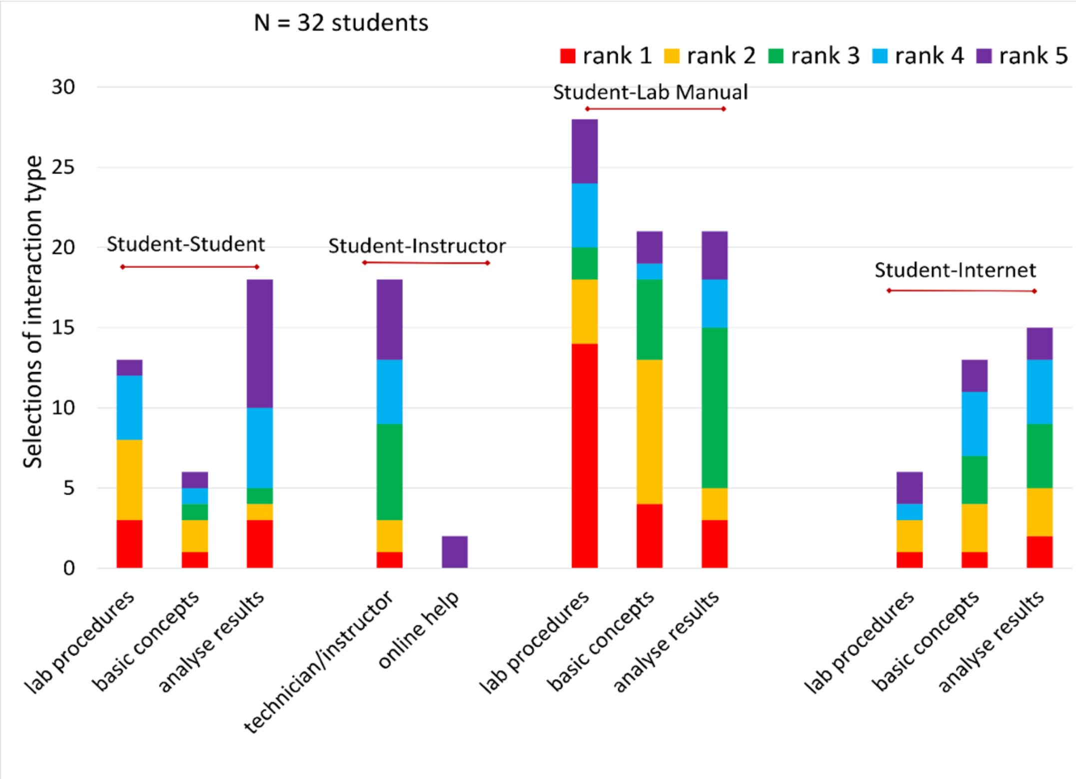


Figure 8.7 Raw number of importance of the interactions, sorted by task types, reported by students of Curtin and UNE after undertaking the remote laboratory work

Note: Data obtained from the post-lab survey, Study 4 (total number of responses =32)

8.5.4 Student Satisfaction

To address RQ 2.4. "How do the undergraduates describe their satisfaction with the chemistry laboratory?", the overall experience using the remote laboratory was collected in two ways, namely the post-lab surveys (all students) and the interviews (focus groups). The items about student opinions (Figure 8.8), satisfaction variables (Figure 8.9), and the overall satisfaction item (Figure 8.10) were included in the post-lab survey.

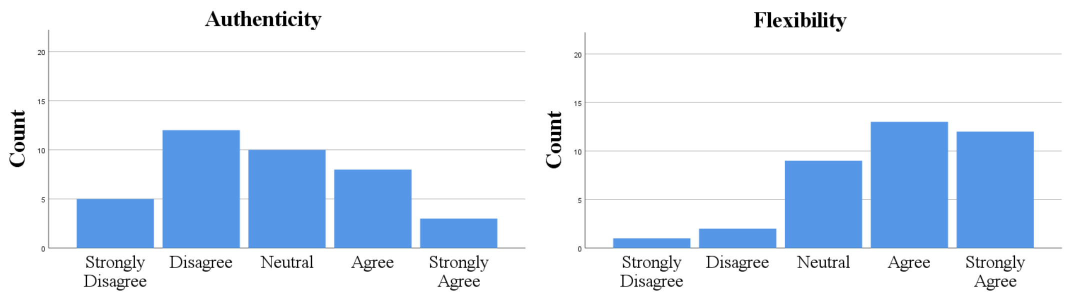


Figure 8.8 Raw number of selections of student opinions after undertaking the remote laboratory work: Authenticity and Flexibility

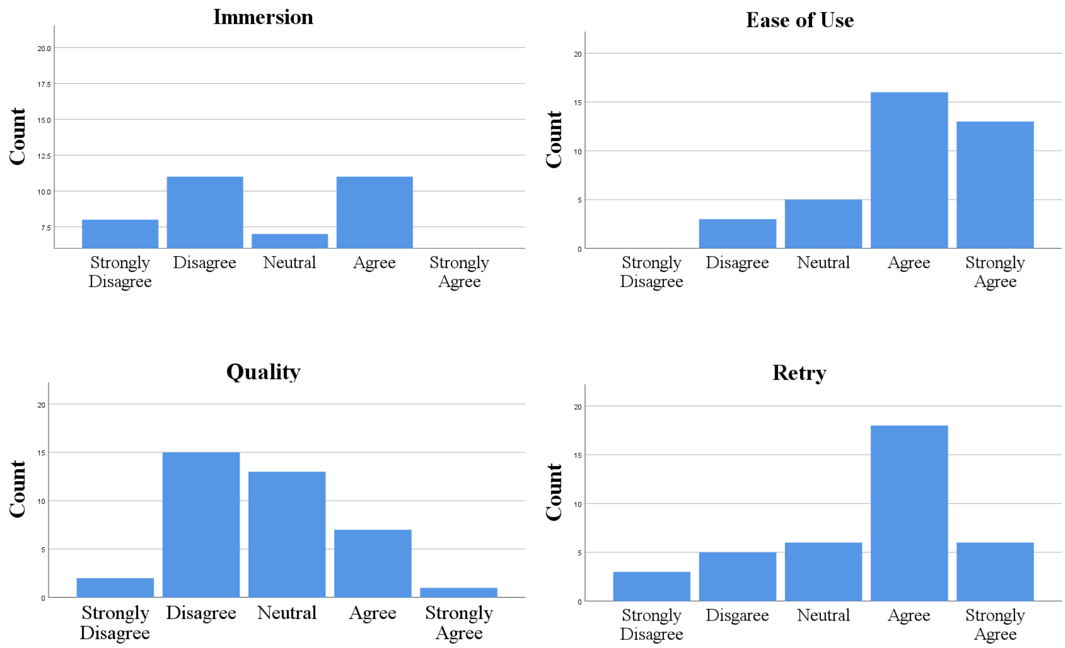


Figure 8.9 Raw number of selections of satisfaction variables after undertaking the remote laboratory work: Immersion, Ease of Use, Quality and Retry

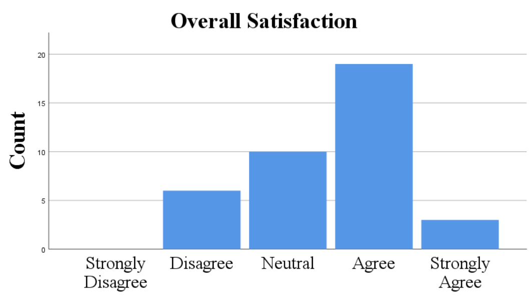


Figure 8.10 Raw number of selections of the overall satisfaction item after undertaking the remote laboratory work

Note: Data of Figure 8.7, Figure 8.8, and Figure 8.9 all obtained from the post-lab survey, Study 4 (total number of responses =39)

The subscale of student opinions, satisfaction variables and the overall satisfaction item consisted of seven items and the internal consistency was α = .85, meaning the variables were reliable (Taber, 2018). Overall, the students exhibited satisfaction with the remote laboratory, although they did not believe that they had performed an authentic laboratory they did not feel immersed in the process, and reported that the quality of the laboratory was not very high compared with the face-to-face laboratories. On the positive side, the characteristics of the flexible and easy-to-manipulate apparatus may lead to their preference to carry out another remote laboratory and their overall positive satisfaction.

Further interviews were carried out for three groups, the transcripts from the interviews are in Appendix D. In group 1, the students preferred to work with instructors being present, because '*the lab demonstrator can correct their problem before making mistakes*'. They did not mind conducting another remote laboratory if '*it's explained better, the step-by-step clearer*'. In group 2, the two students' confidence when they were manipulating the laboratory may be due to the fact that one of them was enrolled in a double degree programme in chemical engineering and chemistry. One of the students also stated that he was familiar with the remote laboratory experience because it was like some laboratories in engineering. Generally, the two students reported that the laboratory was not hard, however, it was a boring experience, because '*the waiting time was far too long*'. However, they affirmed that they would rather '*…wait longer to get the proper values*.' In the remote laboratory, there was no clear guidance about the expected waiting time. This uncertainty lowered the learning experience for the students who believed that if this were clearly identified, they would not think the long waiting time was a negative factor.

The third group of students interviewed presented more detailed information about the laboratory itself. Overall, they preferred to conduct the laboratory with an instructor present, instead of finishing it at home. This is because '*if I was doing this at home as I would probably get failed because I would not get what I will do'*. They would not be afraid of making mistakes and would like to try hard with an instructor at present. Both of the two students were concerned with making mistakes even though in the remote laboratory they were provided with the opportunity to attempt it several times and they could learn from their mistakes. For the equipment, they thought the guidance about the two temperature bars '*don't clearly label'* and they did not realise they needed to stop heating, prior to waiting for the completion of equilibrium. The students did not like smelly odours and the necessity to clean up that was present in the face-to-face laboratories but not in the remote laboratory. However, they would like to have another attempt for one more remote laboratory. Firstly, they believed that doing laboratories online was reasonable, '*it's still interactive'*, and they did learn something during the process. However, they insisted the guidance should be planned carefully, especially for the learners who were manipulating the equipment by themselves. They acknowledged the positive side of the flexibility of a remote laboratory. One student said she preferred to work in a group, with peers, if it was possible.

8.5.5 Interaction Types and Satisfaction

To address RQ 2.5. "How do the frequency of interactions and student satisfaction correlate in the chemistry laboratory?", statistical analyses were made between the 18 Item Categories (the second column in Table 8.5) and the last item (overall satisfaction) in the satisfaction part of the post-lab survey. Results from Spearman's rank-order correlation coefficients (Table 8.6) illustrated that among the interactions types, only the interactions with the technician (within the Student-Instructor type) were reported to be significantly related to the overall satisfaction levels. Furthermore, among the other features of satisfaction, the quality of the remote laboratory, the preference of trying another remote laboratory, the easy-to-use equipment, the feeling of immersion during the laboratory process, and feeling of having done a real laboratory all showed a significant positive correlation with the overall satisfaction. However, flexibility did not have significant strength with overall satisfaction.

Table 8.6 Spearman's Rank-Order Correlation Coefficient for the Frequency of Interactions, Student Opinions, and Other Satisfaction Variables with Overall Satisfaction

Student-Technician	Authenticity	Immersion	Ease of Use	Quality	Retry
.457**	.397*	.469**	.588**	.652**	.675**

*Note. *p < .05, **p < .01, N=39, Only statistically significant values were illustrated*

To sum up, based on the students' reports, the more interactions with technicians, the more they were satisfied with the laboratory. The frequency of other interaction types, namely S-S, Student-Lab Manual, Student-Internet, did not show significant correlations with the overall satisfaction level. In addition, the more the students felt that they had done a real laboratory, the more they feel immersed in the laboratory activity, the easier to use the equipment, the higher quality of the remote laboratory, and the higher willingness to try another remote laboratory, all significantly related to the higher level of satisfaction with the remote laboratory activity. By contrast, the flexibility of the remote laboratory did not correlate with the overall satisfaction level. Unlike the UNE students, the Curtin students who participated in the remote laboratory could not choose any time that suited them but conducted the remote laboratory based on the pre-designed time schedules through Doodle. This decrease in flexibility might have caused a lack of correlation between flexibility and satisfaction. Nevertheless, from the interview, the students showed that the flexibility of a remote laboratory might be beneficial for some students.

8.6 Discussion

8.6.1 Perceptions Variation about the Importance of Interactions

The perception change about the importance of interactions between pre-lab to post-lab was conducted by comparing the first five items in Figure 8.4 and Figure 8.7. The same five items were expected and self-reported by the students, only with a slight ranking sequence difference. Firstly, the laboratory manual interaction for procedures, concepts, and results, was the most important medium for the students to interact with. Secondly, interacting with the technician/instructor and talking about results with their group partner was important.

8.6.2 Frequency and Importance of Interactions

For the frequency and importance of interactions, overall, much less frequent interactions occurred in the remote laboratory, which were consistent with previous findings (Cooper & Ferreira, 2009).

Among the four types of interactions, S-S did not happen as much as those in face-to-face laboratories and played much less important roles too. This finding aligns well with one prediction made by Wei et al. (2019), which stated that '*This finding may imply that in remote laboratories, the S-S interactions did not play as many important roles in the learning process as in the face-to-face ones*'. The frequency and the importance of interactions were compared between the first five items in Figure 8.5 and Figure 8.7. In the remote laboratory, the laboratory manual was both frequently used and was regarded as important by the students, for all of referring to procedures, trying to find some concepts, and analysing results. By contrast, even though S-S talking about procedures happened frequently, to discuss results was more important.

Even though asking for help from instructors was not so frequent, the students thought this type of interaction was important. From the interview results, some students mentioned that they would prefer to have an instructor present. Some of the students in the focus groups stated that the instructors could help them to check their process and ensure the validity of the procedures, while others were afraid that they might not finish the laboratory if no guidance with some procedures was provided. This finding aligned well with previous findings about the importance of a synchronous human instructor in addressing some problems (Böhne et al., 2004). The first group, on the contrary, showed themselves more confident and believed that they could complete the laboratory without a physically-present instructor. When asked whether they could implement the remote laboratory without laboratory pairs, they were confident that individual work was not a problem. These comments suggest that at least part of the roles of an instructor could be supplemented by the meticulous design of remote laboratories, mostly in the form of S-E interactions (Wei et al., 2019). These comments are also supported by another of our findings: All of the students believed that a clear guidance and goals setting were indispensable components in the remote laboratory progress.

8.7 Chapter 8 Summary

In this chapter, the studies of remote laboratories were presented. The development of the items in the instrument and the laboratory observation sheet was listed first, followed by the detailed introduction of the studies in the two cohorts. The results about the frequency and importance of interactions, the satisfaction levels and results from interviews were examined. The main findings are summarised in Table 8.7. In the next chapter, the results from Face-to-face (Study 2 and 3, Chapter 6 and 7), and remote laboratories (Study 4, Chapter 8) will be compared and analysed.

Table 8.7 Research Questions and the Main Findings in Study 4

Research Questions	Main Findings
RQ2.1: What do undergraduate students consider to be important interactions before the conduct of the chemistry laboratory?	Interactions with laboratory manual were reported to be important before the commencement of the remote laboratory
RQ2.2: What type and range of frequency of interactions do students engage in during the chemistry laboratory?	Interactions with laboratory manual were reported to occur frequently after the completion of the remote laboratory.
RQ2.3: What do undergraduate students consider to have been important interactions after the completion of the chemistry laboratory?	Interactions with laboratory manual were reported to be important after the completion of the remote laboratory.
RQ2.4: How do the undergraduates describe their satisfaction with the chemistry laboratory?	Overall, the students were satisfied with the remote laboratory and felt that clear guidance would help with the laboratory activity.
RQ2.5: How do the frequency of interactions and student satisfaction correlate in the chemistry laboratory?	Interactions with technician, Authenticity, Immersion, Ease of Use, Quality, and Retry all had a significantly positive correlation with the overall satisfaction.

CHAPTER 9: DISCUSSIONS, CONCLUSIONS, LIMITATIONS, AND DIRECTIONS

9.0 Chapter Outline

The final chapter of this thesis presents a summarised description of the conceptual and theoretical framework used for the guidance of the thesis in Section 9.1. A general summary of the four studies involved in the whole thesis were explained in Section 9.2, followed by a summary in Section 9.3 of the findings related to the research questions. In Section 9.4, discussions on key findings were analysed and consequent conclusions were generated. Section 9.5 provides the limitations of this research; the implications are presented in Section 9.6.

9.1 Conceptual and Theoretical Frameworks Guiding the Research

This research was guided by the theoretical framework of distributed cognition where, in this study, individual actions are contextualised within the laboratory setting and the conceptual framework of the Model of Educational Reconstruction (MER) (Komorek & Kattmann, 2008) which has three main elements, namely, the design of the learning environment, the students' perceptions, and the science content. Figure 9.1 (a repeat of Figure 1.1) shows how these elements interconnect and the two types of laboratories - face-to-face and remote – in which the undergraduate students participated.

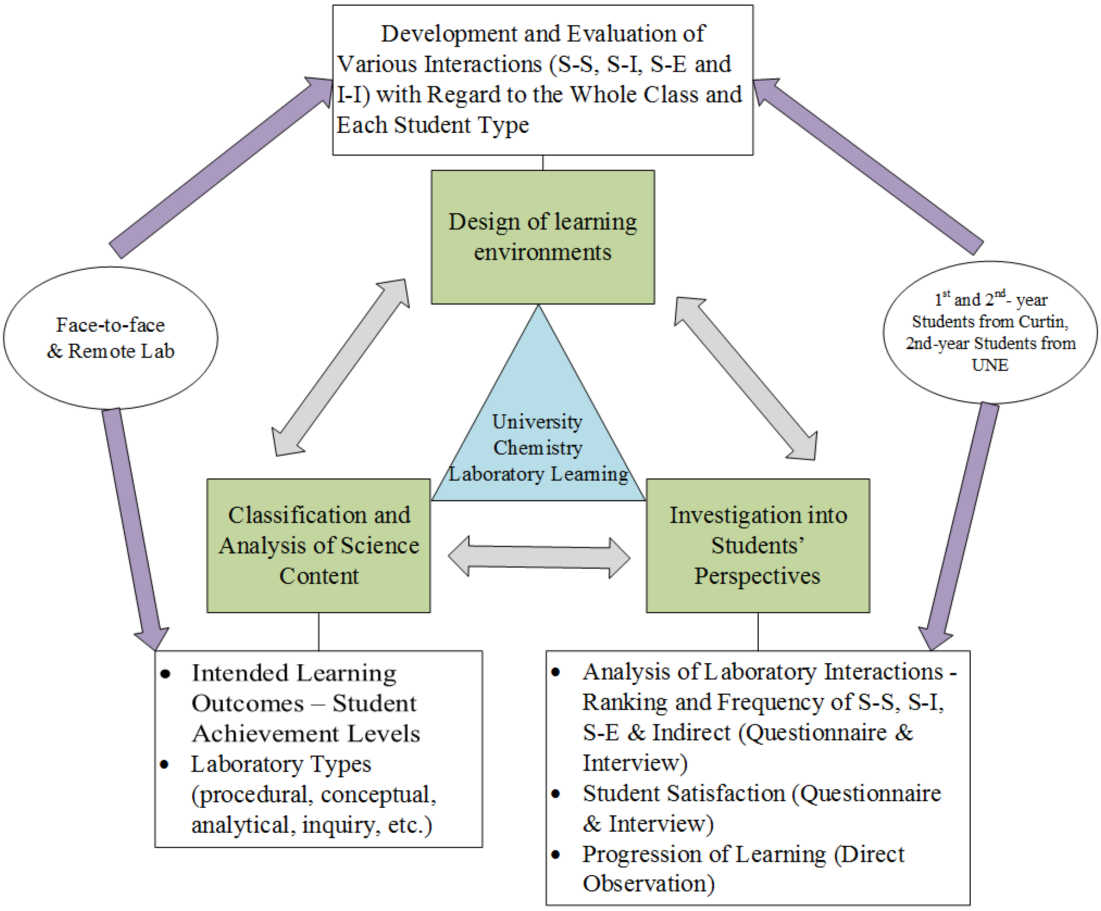


Figure 9.1 The conceptual framework for this thesis, derived from the Model of Educational Reconstruction (MER)

Note: S-S = Student-Student, S-I = Student-Instructor, S-E = Student-Equipment, and I-I = Indirect

The MER provided direction for the design of the research which involved the learning environment, the students' perceptions within different laboratory types, and different content areas. The Learning Environment where the research was conducted is the face-to-face and remote laboratories within which there are different types of interactions between students and students, students and instructor, students and equipment and those interactions that are indirect. Four studies were included in these two main types of laboratories. The way chosen to measure the different types of interactions within the laboratory was by students' perspectives or experiences on the frequency and ranking of different identified interactions and their satisfaction of working in the laboratories. The different laboratory types such as being procedural, procedural/analytical or conceptual, and having different content areas such as *Principles of measurement* or *Identification of common ions in solution* enabled the research to be multi-focussed in terms of variety of laboratories.

An investigation of interactions within the laboratory clearly cannot refer to one individual but must involve more than one individual in the experiences. Consequently, students' perspectives and experiences as influenced by the interactions between the learner and the learning environment can best be understood by the theory of distributed cognition (Cole & Engeström, 1993; Nakhleh, Polles, & Malina, 2002). The design of the pre-, post-lab surveys and the laboratory observation sheet took into account the nature of these interactions.

9.2 Description of the Research Studies

This thesis presents a broader view of the interactions that occurred in both face-to-face and remote laboratories and the assessment of student experiences when engaged in the laboratory process.

The research was conducted through several stages. The first stage in face-to-face laboratories was the design of the preliminary data collection methods, namely the Pilot Study shown in Section 4.4.4, Chapter 4. Following this, the second stage was conducted to develop, improve, assess, and validate the data collection methods, namely Study 1 introduced in Chapter 4. The third stage in face-to-face laboratories was the application of the data collection methods to wider participants, to provide statistical results in face-to-face laboratories. The results of the third stage from Study 2 and Study 3 are included in Chapter 5, Chapter 6 and Chapter 7. For the study of the remote laboratory, a pilot study was an initial design of data collection methods (Stage 1), which was explained in Section 8.3, Chapter 8. Stage 2 involved the application of the data collection methods to provide detailed information in the remote laboratory; details are introduced in Chapter 8.

Firstly, to achieve the goals of the research, instruments were developed to measure the student behaviours and their learning experiences in chemistry laboratories. Theory of distributed cognition was used as guiding the design of the pre-, post-lab surveys and the laboratory observation sheet. For face-to-face laboratories, a pilot study was carried out to test the applicability of the items in the survey forms. Details can be found in Section 1.2, Chapter 1, and 4.4.3, Chapter 4. After the pilot study, Study 1 was conducted to explore the first version of the survey forms, with laboratory observation being implemented to validate the results from the post-lab survey. Details were illustrated in Section 4.5.2, Chapter 4. Subsequently, the post-lab survey was shown to be reliable as the main data collection method, so data were collected from a broader range of students with both first-year (Study 2) and second-year (Study 3) undergraduates using the validated survey. At the same time, statistical analysis methods were employed to assess the reliability and the validity of data resulting from the survey; details were presented in Chapter 5.

For the remote laboratory, guided by the results from the face-to-face laboratories, the theory of distributed cognition, and the volunteer students' feedback, pre- and post-lab surveys, direct observation and interviews were designed specifically for the remote laboratory. Research methods (Study 4) were undertaken to understand deeply the student behaviours and the students' opinions about the remote laboratory, by integrating various data collection methods. Among the methods, data from the pre- and post-lab surveys were used to provide general results about interactions that happened in the laboratory, on-site observations with focus groups were designed to understand the student behaviours from the viewpoint of the observer. Interviews with two selected groups of students followed the observations and the manipulation of the remote laboratory to understand the participants' detailed personal perceptions.

Secondly, interactions and satisfaction in both face-to-face and remote laboratories were analysed. In the analysis of interactions and satisfaction, visual descriptions about the importance of interactions before the commencement of the laboratory, the frequency and importance of interactions after the completion of the laboratory, as well as the satisfaction were initially presented. In the face-to-face laboratories, results were divided into two chapters. Considering that only five factors, namely, Indirect Interactions, Student-Instructor Lab-related, Student-Instructor Lab-unrelated, Student-Student Lab-related, and Student-Student Lab-unrelated Interactions, emerged from the results of factor analysis; and Student-Equipment was not one of the five scales. Responses from face-to-face laboratories among the first-year (Study 2) and second-year (Study 3) students were analysed and presented in Chapter 6. Results about Student-Equipment Interactions in face-to-face laboratories, from both Study 2 (large-scale first-year non-major F2F) and Study 3 (second-year chemistry-major F2F) were analysed and presented in a separate chapter, namely Chapter 7. For remote laboratories, the focus was on the detailed description and analysis of student behaviours and was presented in Chapter 8.

9.3 Summary of the Findings

Based on the previous chapters, the following sections provide summaries of the major findings and discussions in terms of each research question. Findings from Study 1 (Chapter 4) will not be included here. The students from Study 1 and Study 2 were from the students enrolled in the same unit, in different years (the Year 2016 for Study 1 and Year 2018 for Study 2), and the findings from Study 2 were highly similar to those from Study 1. Therefore, the related data from Study 2, 3 and 4, gathered in Chapter 6, 7 and 8, are summarised to address each individual question.

The three descriptive research questions about the importance and frequency of interactions (RQ 1.1, 1.2, and 1.3 in face-to-face laboratories, and RQ 2.1, 2.2, and 2.3 in the remote laboratory) are summarised together in Section 9.2.1. The three correlational research questions about the interactions and student learning outcomes in face-to-face laboratories (RQ 1.4, 1.5, and 1.6) are summarised in Section 9.2.2. The remaining correlational research questions about the interactions and satisfaction (RQ 1.7 and 1.8 in face-to-face laboratories, and RQ 2.5 in the remote laboratory) are summarised in Section 9.2.3. The descriptive research question about satisfaction in the remote laboratory (RQ 2.4) is categorised in 9.2.3 as it is also related to students' reports about satisfactions.

9.3.1 Importance and Frequency of interactions in Face-to-face and Remote Laboratories

Research Question 1.1: What do undergraduate students consider to be important interactions before the conduct of *face-to-face* chemistry laboratories?

Research Question 2.1: What do undergraduate students consider to be important interactions before the conduct of the *remote* chemistry laboratory?

Before the commencement of the laboratory, the first-year students in face-to-face laboratories thought that interactions with the instructors about results and procedures would be the most important types for their laboratory learning, while the second-year students in face-to-face laboratories expected that the laboratory manual was more important even though the instructors were still assigned as one of the top three important interactions. Students in remote laboratories also thought the laboratory manual was the most important type of interaction.

Research Question 1.2: What type and range of frequency of interactions do students engage in during *face-to-face* chemistry laboratory work?

Research Question 2.2: What type and range of frequency of interactions do students engage in during the *remote* chemistry laboratory?

The research findings related to the type and range of interactions revealed that the first- and second-year students in face-to-face laboratories and the students in the remote laboratory had different perceptions about the frequency of interactions. In face-to-face laboratories, the first-year students reported that more interactions occurred between peers talking about results, while the second-year undergraduates reported that interactions with laboratory manual were more frequent. In remote laboratories, the students also reported the laboratory manual was the most frequently referred to materials.

Research Question 1.3: What do undergraduate students consider to have been important interactions after the completion of the *face-to-face* chemistry laboratories?

Research Question 2.3: What do undergraduate students consider to have been important interactions after the completion of the *remote* chemistry laboratory?

After the completion of the laboratory, the first-year students in face-to-face laboratories reported that the laboratory manual was the most important medium, while the second-year undergraduates thought that to talk about procedures with the instructors was more important than all the other types of interactions. In the remote laboratory, the laboratory manual was still reported to be the most important.

Table 9.1 summarises the frequency and importance of the interactions based on the students' self-reports.

Table 9.1 Summary of the Results Related to Research Question 1.1, 1.2, 1.3, 2.1, 2.2, and 2.3

Items	**First-year F2F**	**Second-year F2F**	**Second-year Remote**
Importance (Pre-)	S-I results, S-I procedures	Lab manual, S-I procedures	Lab manual about procedures, technician
Frequency (Post-)	S-S results, S-S procedures	Lab manual	Lab manual about procedures, results and concepts
Importance (Post-)	Lab manual, S-I procedures, S-S procedures and results	S-I procedures, S-S procedures, Lab manual	Lab manual about procedures, results and concepts

9.3.2 Interaction Types and Student Learning in Face-to-face Laboratories

Research Question 1.4: How do the frequency of interactions and student learning outcomes correlate in *face-to-face* chemistry laboratories?

Research Question 1.5: How do the frequency of interactions and laboratory types correlate in *face-to-face* chemistry laboratories?

Research Question 1.6: How do the importance of interactions and laboratory types correlate in *face-to-face* chemistry laboratories?

The student learning investigated in these research questions was divided into two main groups, one was about the laboratory types and the other was the final learning outcomes, from the aspect of achievement levels and course completion (pass/fail). The links between the interactions and student learning outcomes were only addressed in the face-to-face laboratories, as the number of laboratories analysed was different in the studies of the face-to-face and remote laboratories. In face-to-face laboratories, almost all of the laboratories included in the units were analysed in this research. However, the students involved in the remote laboratory carried out many face-to-face laboratories (no data collection made in these laboratories) and only one remote laboratory. It is, therefore, believed that the data obtained in these face-to-face laboratories can provide more general information with the students' learning outcomes than those of the remote laboratory.

No significant correlations were found between the frequency of interactions and student learning outcomes (laboratory marks and the completion rate) in both

Study 2 (large-scale first-year non-major F2F) and Study 3 (second-year chemistry-major F2F) (see Table 6.2 and Table 6.3, Chapter 7).

There were three types of laboratories in the first-year, namely procedural, conceptual and procedural/analytical (see Table 6.1, Chapter 7). Relatively, more procedural interactions happened in procedural and procedural/analytical laboratories, and more conceptual interactions existed in the conceptual laboratory (see Section 6.3.5, Chapter 7). Interactions between the student and the instructors about procedures were reported to be important even though the frequency of S-I interactions about concepts were not as high as S-S conceptual interactions (see Section 6.3.6, Chapter 7).

9.3.3 Interaction Types and Student Satisfaction in Face-to-face and Remote Laboratories

Research Question 1.7: How do the frequency of interactions and overall student satisfaction correlate in *face-to-face* chemistry laboratories?

Generally, in face-to-face laboratories, those students with more interactions (overall and by type) were satisfied with the laboratories, while those with fewer interactions were less satisfied in both Study 2 and Study 3 (see Section 6.3.7, Chapter 6).

Research Question 1.8: How do the importance of interactions and overall student satisfaction correlate in *face-to-face* chemistry laboratories?

The more satisfied students and less satisfied students had similar ratings on the importance of interactions in the first-year face-to-face laboratories. In the second-year face-to-face laboratories, the students with higher satisfaction levels considered interacting with their peers about concepts and listening to other people's conversations were important, while students with lower satisfaction levels chose interactions about concepts with the instructors as important (see Section 6.3.8, Chapter 6).

Research Question 2.4: How do the undergraduates describe their satisfaction with the *remote* chemistry laboratory?

Statistical analysis was conducted in face-to-face laboratories and the remote laboratory. Students were generally satisfied with the remote laboratory, although most of them reported that it was less satisfying compared with their other face-to-face laboratories (see Figure 8.9 and Figure 8.10, Chapter 8). The students also reported that they did not feel really immersed with the remote laboratory activity but they preferred the flexibility and easy-to-use equipment. Comparably, most students in face-to-face laboratories were satisfied with their face-to-face laboratory experience, with the second-year students being more satisfied (see Figure B1, Appendix B).

Research Question 2.5: How do the frequency of interactions, student opinions, satisfaction variables and overall student satisfaction correlate in the *remote* chemistry laboratory?

Statistical analysis of the correlation between the frequency of interactions, student opinions, satisfaction variables and the overall satisfaction for the remote laboratory item was conducted in the remote laboratory. Results illustrated that more frequent interactions between the students and the technician significantly correlated with the higher satisfaction levels. The authenticity of the laboratory activity, feelings of being immersed during the laboratory process, the ease of use of the equipment, the quality of the remote laboratory, and the willingness to try another remote laboratory all significantly related to the satisfaction level (see Section 8.5.5, Chapter 8).

9.4 Conclusions

9.4.1 Interactions of Students with Different Levels of Experience in Different Types of Laboratories

Based on the theoretical and conceptual framework of the research, the learning environment had impacts on the students' perceptions of interactions. It was found that when the students encountered an unfamiliar learning environment, they expected to rely on experienced instructors before the commencement of the laboratory. For example, for the first-year students with limited chemistry laboratory experience, the instructors were assigned much higher importance in the pre-lab survey. For the second-year students who had significant experience in face-to-face laboratories, the remote laboratory was new to them. Because the remote laboratory was designed to be finished without an instructor present, the students chose the technician as the second-highest important type to interact with in the pre-lab survey. In one of the face-to-face laboratory sessions, one student was so nervous in her first laboratory class that she even expressed her concerns with the laboratory to me, not an instructor, but an observer. Several students chose to perform the remote laboratory as a focus group because they were not confident conducting it on their own. These findings align well with those of previous studies in which it was reported that students regarded laboratory instructors as laboratory process guiders or conceptual provokers in a chemistry laboratory classroom (Rodriques & Bond-Robinson, 2006).

When the students became familiar with the laboratory process, the laboratory manual was regarded as more important for laboratory learning. For the first-year students, the laboratory manual was not assumed to be important before the commencement of the laboratory (pre-lab), but the function of the laboratory manual was reported to be the most important after the completion of the laboratory. Consequently, for the second-year students who had abundant experience in laboratory classes, the laboratory manual was chosen as the most important both before and after the laboratory, in face-to-face and remote laboratories. Direct observation in the remote laboratory also demonstrated that the students referred to the laboratory manual when they met problems.

9.4.2 Interpersonal Interactions (S-S and S-I) in Face-to-face and Remote Laboratories

In the first-year face-to-face laboratories, the students interacted with their peers about procedures more than with the instructors, while in the second-year laboratories the frequency of S-S talking about procedures was almost equal to the number of S-I on procedures. A previous study made with secondary school students also indicated that S-S interactions occurred more than S-I interactions (Högström et al., 2010). Considering the first-year undergraduates had a limited chemistry laboratory background, their behaviours may have similarities with secondary school students who tend to interact with their peers instead of with the instructors. In addition, the set-up of the laboratory may be the other influencing factor on the frequency of interpersonal interactions. The first-year laboratories were performed in groups, so it was reasonable that more interactions happened between students than with the instructors. However, even though the second-year laboratories were required to be finished individually, the students still interacted with their peers about procedures. This may be due to the fact that the second-years believed that S-S interactions about procedures played similarly important roles with S-I interactions about procedures. Alternatively, the second-year undergraduates have been familiar with each other and felt comfortable to ask for help from each other. The second-year students also responded that to observe other people setting up the equipment was frequent and important compared with first-year undergraduates. This result also implied that learning from their peers played a greater role in the second-year laboratories than the first-year ones. These findings match well with those of other studies, which revealed that in science laboratories, S-S interactions were more frequent than S-I interactions and student behaviours were independent of instructors' teaching styles (Jenkins, 2006; Velasco et al., 2016).

There were more Student-Student Lab-unrelated conversations in the second-year face-to-face laboratories. This finding is because, on the one hand, the students were more accustomed to the laboratory, on the other hand, the laboratory activity included a large number of gap times when the students had to wait for a long time period while the reagents were reacting. Even though the unrelated topics were not directly related to the laboratory itself, they were indispensable components for the laboratory activity. The second-year students were more independent; some were helping others solve problems, and others were working on the laboratory notes, during the waiting time. The second-year students acknowledged the existence of unrelated topics. One student consistently listed unrelated topics as important for his learning because he believed these topics motivated his interests.

In the remote laboratory, far fewer interactions directly relating to the laboratory occurred, with more unrelated topics happening during the waiting time. Even though most of the students carried out the laboratory in pairs, S-S interactions were much less frequent than those of face-to-face ones. From the interviews, the students also thought that they could complete the remote laboratory individually, although some of them preferred to work in pairs. Therefore, the role of the laboratory manual should be amplified more than interpersonal interactions in the remote laboratory.

9.4.3 Guidance through the Laboratory Manual

In both face-to-face and remote laboratories, interactions with the laboratory manual were chosen to be one of the most important types. Most of the students thought that the laboratory manual was helpful in their learning. However, from the interviews, several students emphasized that they felt frustrated when there were mistakes in the laboratory manual, even though most of them created only minor problems. An updated laboratory manual matching with the current curriculum was strongly recommended. For example, in Lab Session two, Study 2, if following the number of drops of reagents suggested by the laboratory manual, the reactants might flow to other charts and mix with other ingredients, thus influence the results. One student who was doing the unit for the second time identified this problem and said that he avoided making this mistake because he learned it from the previous year's mistake. In the remote laboratories, the students felt more frustrated with the guidance and both the two groups being interviewed cited the importance of clear guidance.

9.4.4 Relationship between Interactions and Learning in Face-to-face Laboratories

Firstly, there were unique differences between high and low satisfied students' perceptions of the frequency of interaction. Students' satisfaction with the laboratories generally increased if there were more interactions involved and vice versa. In other words, students who were more satisfied with the laboratory perceived greater interaction than their less satisfied peers. This finding supports the higher education research on the importance of interaction to retain engagement (Sadler et al., 2011).

In contrast to interactions impacting experience, there was no practical significant effect of interaction on the grade awarded or the course completion. However, this did not necessarily mean that there were no correlations between the student behaviours in the laboratory and their final learning outcomes. There may be several reasons for this outcome: 1) the grading criteria in the individual laboratory were about the concepts, such as balancing equations, doing calculations, etc. These standards were not related to the student behaviours, as in another study which showed that a laboratory report did not cover the laboratory skills in manipulating the equipment (Ottander & Grelsson, 2006). 2) The grades awarded had limited variation. The grades were biased towards the higher grades and there were far fewer students with lower grades. Thus, it would be difficult to detect differences in perceptions of respondents with a small range of grades. Still, the interaction was assumed to be a precursor of high performance and led to higher satisfaction. The assessment criteria in the current curriculum did not measure student performance or social factors, which is an issue that should be addressed. For example, student behaviours, such as the students' engagement levels during the laboratory process, can be tested as one criterion in the assessment sheets or both formative and final summative assessment can be conducted "…to enable students to understand and improve their own learning" (Chan & Van Aalst, 2004, p. 93).

It had been pointed out that the current school curriculum and instruction focused less on the students' abilities in collaboration and social skills and placed more emphasis on discipline and task-related knowledge (Fiore, Graesser, & Greiff, 2018). This may also be one of the reasons that the interactions analysed in the present research showed no correlation with the learning outcomes because social factors are not one of the learning objectives.

9.4.5 Interactions in the Remote Laboratory

In the remote laboratory, the interactions between the students and the instructor were far fewer because most of the students completed the experimental task without an instructor present. There were no indirect interactions because the students were doing a remote laboratory without other groups. It may be assumed that these limited types of interactions might impact learning experiences but the results did not fully support this assumption. From the interviews, this loss, especially the lack of S-I interactions did cause confusion to some students. However, the students also believed that they could complete the task without an instructor as long as there was guidance in the laboratory manual and that the platform was clear enough. This idea can also be affirmed by a study made by Böhne et al. (2007), in which the instructor was considered more as a tutor in solving technical problems by the students manipulating the remote laboratories than as a facilitator in learning. The students in this study were not as satisfied with the remote laboratory as their experience in the face-to-face laboratories. Complaints were more about the confusion caused by a procedure or one unit conversion during the calculation process, than about the technology itself. The students acknowledged that remote laboratories were interactive and that the equipment was not hard to manipulate. Students tended to look to the laboratory manual when they met problems. A well-designed laboratory manual with clear guidance can increase the students' learning experiences and can supplement part of the change in the type of interactions.

9.4.6 The Characteristics of Laboratory Types and Interactions

The student behaviours were influenced by laboratory types. This is confirmed by the following. Firstly, in Study 2, certain student behaviours were prominent in specific types of laboratories. For example, more interactions relating to procedures happened in the procedural and analytical/procedural laboratories, and interactions about concepts happened in the conceptual laboratory. Secondly, in Study 3 and Study 4 where the laboratories included many waiting times, the students engaged in more unrelated topics than the first-year undergraduates. The student behaviours being influenced by the laboratory characteristics were also shown by (Velasco et al., 2016); Xu and Talanquer (2013).

9.5 Limitations

There were several limitations to this research.

9.5.1 Design of the Instruments

In the instruments of this thesis, only several items relating to interactions were included. However, the learning environment is complex and other factors such as gestures, mechanical devices etc. also may have played significant roles in the learning process (Gorham, 1988). However, it is difficult to include all of the factors in one study, and the focus of this thesis is only on the impact of measurable interactions based on the selected types of interactions that were involved.

9.5.2 A limited Number of University of New England Participants in the Remote Laboratory

A small number of UNE students were involved in the analysis, which makes it hard to provide more meaningful findings of the students doing remote laboratories individually and distantly. Nonetheless, eight students out 20 students had completed the survey. One possible advantage of this circumstance was that the students represented a variety of characteristics of the participants of the students doing remote laboratories individually.

9.6 Implications for Future Work

Students relied more on laboratory manuals when they were more accustomed to the laboratory process. The design of the laboratory manual played inevitable roles in the laboratory process. From the results of interviews in face-to-face and remote laboratories, the lack of clarity or misguidance in the laboratory manual decreased the students' learning experience significantly. It is, therefore, recommended that the laboratory manual should be designed more carefully and updated according to the current curriculum, to make sure that simple mistakes are avoided. In addition, except for the overall goals, within some sub-topics, the related goals are suggested to be included. They can play the function of guiding students' behaviour and help them understand the value of manipulation, instead of merely following the procedures.

The second-year students assigned S-S interactions regarding procedures as almost the same frequency and importance as S-I topics about procedures. They also reported the indirect interactions of observing others' set-up as frequent and important. This implied that students learn from their peers about the manipulation of equipment, both directly and indirectly. Therefore, the current laboratory assignment format in the second-year face-to-face laboratory, with two students using the same fume hood and sharing some equipment, should be retained. This is because this way was supportive in assisting learning from their peers, at least in guiding the procedures. Other evidence is that the second-year undergraduates reported that an increase in the number of S-S interactions, even on unrelated contents, would positively increase their satisfaction with the laboratories.

The frequency of interaction had a significant impact on students' satisfaction with laboratories, but not on students' completion of the course and the final laboratory grade awarded. An increased number of interactions resulted in increased student satisfaction levels. Based on the results of this research, along with other findings from RQ 1 and RQ 2, two implications for practitioners can be made. First, interaction matters in terms of both frequency and importance. The more satisfied students perceived that to discuss results with the instructors were more important in the first-year laboratories and the less satisfied students in the second-year laboratories preferred to discuss with the instructors about procedures than with their colleagues. Instructors should continue to maintain a high frequency of interaction with students. One way to achieve this is to place more emphasis on interaction at the beginning of a course to provide clear guidance before the commencement of laboratory activities.

References

Agustian, H. Y., & Seery, M. K. (2017). Reasserting the role of pre-laboratory activities in chemistry education: A proposed framework for their design. *Chemistry Education Research and Practice, 18*(4), 518-532. doi:10.1039/C7RP00140A

American Association for the Advancement of Science. (2013). *Describing and measuring undergraduate STEM teaching practices* Retrieved September 25, 2019 from Washington, DC: https://cgsnet.org/describing-and-measuring-undergraduate-stem-teaching-practices

Arbaugh, J. B. (2000a). Virtual classroom characteristics and student satisfaction with Internet-based MBA courses. *Journal of Management Education, 24*(1), 32-54. doi:10.1177/105256290002400104

Arbaugh, J. B. (2000b). How classroom environment and student engagement affect learning in Internet-based MBA courses. *Business Communication Quarterly, 63*(4), 9-26.

Austin, A. C., Hammond, N. B., Barrows, N., Gould, D. L., & Gould, I. R. (2018). Relating motivation and student outcomes in general organic chemistry. *Chemistry Education Research Practice, 19*, 331-341. doi:10.1039/c7rp00182g

Bandura, A., & Walters, R. H. (1977). *Social learning theory* (Vol. 1). Englewood Cliffs, NJ: Prentice-hall.

Barrie, S. C., Bucat, R. B., Buntine, M. A., Burke da Silva, K., Crisp, G. T., George, A. V., . . . Yeung, A. (2015). Development, evaluation and use of a student experience survey in undergraduate science laboratories: The advancing science by enhancing learning in the laboratory student laboratory learning experience survey. *International Journal of Science Education, 37*(11), 1795-1814. doi:10.1080/09500693.2015.1052585

Bernard, H. R., & Bernard, H. R. (2012). *Social research methods: Qualitative and quantitative approaches*. Thousand Oaks, CA: Sage Publications.

Berry, D. C., & Broadbent, D. E. (1984). On the relationship between task performance and associated verbalizable knowledge. *The Quarterly Journal of Experimental Psychology, 36*(2), 209-231.

Bloome, D. (1989). Locating the learning of reading and writing in classrooms: Beyond deficit, difference, and effectiveness models. In C. Emihovich (Ed.), *Locating learning: Ethnographic perspectives on classroom research* (pp. 87-114). Norwood: Ablex Pub. Corp.

Böhne, A., Faltin, N., & Wagner, B. (2007). Distributed group work in a remote programming laboratory-a comparative study. *International Journal of Engineering Education, 23*(1), 162-170.

Böhne, A., Rütters, K., & Wagner, B. (2004). *Evaluation of tele-tutorial support in a remote programming laboratory*. Paper presented at the 2004 American Society for Engineering Education Annual Conference and Exposition, Salt

Lake City, Utah. Retrieved September 25, 2019 from https://peer.asee.org/13115

Botero, M. L., Selmer, A., Watson, R., Bansal, M., & Kraft, M. (2016). Cambridge weblabs: A process control system using industrial standard SIMATIC PCS 7. *Education for Chemical Engineers, 16*, 1-8. doi:10.1016/j.ece.2016.04.001

Bowers, C. A., & Flinders, D. (1990). *Responsive teaching: An ecological approach to classroom patterns of language, culture*. New York: Teachers College Press.

Bright, C., Lindsay, E., Lowe, D., Murray, S., & Liu, D. (2008). *Factors that impact learning outcomes in remote laboratories.* Paper presented at the Ed-Media 2008: World Conference on Educational Multimedia, Hypermedia and Telecommunications, Vienna, Austria. Retrieved September 26, 2019 from https://www.learntechlib.org/primary/p/29248/.

Brinson, J. R. (2015). Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. *Computers & Education, 87*, 218-237.

Bromfield Lee, D. (2018). Implementation and student perceptions on Google Docs as an electronic laboratory notebook in organic chemistry. *Journal of Chemical Education, 95*(7), 1102-1111. doi:10.1021/acs.jchemed.7b00518

Brouwer, N., Fleerackers, G., Majcen, N. H., Maciejowska, I., McDonnell, C., & Mocerino, M. (2017). Online course to improve university laboratory teaching practice. *VIRT&L-COMM, 10*, 10-2016.2011.

Bryant, F. B., Yarnold, P. R., & Michelson, E. A. (1999). Statistical methodology: VIII. Using confirmatory factor analysis (CFA) in emergency medicine research. *Academic Emergency Medicine, 6*(1), 54-66. doi:10.1111/j.1553-2712.1999.tb00096.x

Bryman, A. (2015). *Social research methods* (5th ed.). Oxford: Oxford university press.

Carter, D. J., Lindsay, E. D., Lucey, A. D., Mocerino, M., Treagust, D. F., & Zadnik, M. G. (2015). *Identification of student learning processes in classroom and remote laboratory settings.* Paper presented at the Australasian Science Education Research Association Conference, Perth, Western Australia. Retrieved September 26, 2019 from https://www.asera.org.au/sites/default/files/2017-04/ASERA-2015-program-and-abstracts.pdf

Chan, C. K. K., & Van Aalst, J. (2004). Learning, assessment and collaboration in computer-supported environments. In J. W. Strijbos, P. A. Kirschner, & R. L. Martens (Eds.), *What we know about CSCL* (pp. 87-112). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Cheng, K.-H., & Tsai, C.-C. (2013). Affordances of augmented reality in science learning: Suggestions for future research. *Journal of Science Education and Technology, 22*(4), 449-462.

Childers, G., & Jones, M. G. (2017). Learning from a distance: High school students' perceptions of virtual presence, motivation, and science identity during a remote microscopy investigation. *International Journal of Science Education, 39*(3), 257-273. doi:10.1080/09500693.2016.1278483

Cho, E., & Kim, S. (2015). Cronbach's Coefficient Alpha: Well known but poorly understood. *Organizational Research Methods, 18*(2), 207-230. doi:10.1177/1094428114555994

Chopra, I., O'Connor, J., Pancho, R., Chrzanowski, M., & Sandi-Urena, S. (2017). Reform in a general chemistry laboratory: How do students experience change in the instructional approach? *Chemistry Education Research and Practice, 18*(1), 113-126. doi:10.1039/C6RP00082G

Cicchetti, D. V. (1994). Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychological assessment, 6*(4), 284.

Cohen, D. K., & Ball, D. L. (1999). *Instruction, capacity, and improvement* (CPRE-RR-43) Retrieved September 26, 2019 from Philadelphia: https://www.cpre.org/sites/default/files/researchreport/783_rr43.pdf

Cole, M., & Engeström, Y. (1993). A cultural-historical approach to distributed cognition. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 1-46). New York: Cambridge University Press.

Colella, V. (2000). Participatory simulations: Building collaborative understanding through immersive dynamic modeling. *The Journal of the Learning Sciences, 9*(4), 471-500. doi:10.1207/S15327809JLS0904_4

Cooper, M., & Ferreira, J. M. M. (2009). Remote laboratories extending access to science and engineering curricular. *IEEE Transactions on Learning Technologies, 2*(4), 342-353. doi:10.1109/tlt.2009.43

Corter, J. E., Esche, S. K., Chassapis, C., Ma, J., & Nickerson, J. V. (2011). Process and learning outcomes from remotely-operated, simulated, and hands-on student laboratories. *Computers & Education, 57*(3), 2054-2067. doi:10.1016/j.compedu.2011.04.009

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.): Thousand Oaks, CA: Sage.

De Jong, T. (2006). Technological advances in inquiry learning. *Science, 312*(5773), 532-533. doi:10.1126/science.1127750

De Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science, 340*(6130), 305-308. doi:10.1126/science.1230579

De Jong, T., & Van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of educational research, 68*(2), 179-201. doi:10.3102/00346543068002179

de la Torre, L., Guinaldo, M., Heradio, R., & Dormido, S. (2015). The ball and beam system: A case study of virtual and remote lab enhancement with Moodle. *IEEE Transactions on Industrial Informatics, 11*(4), 934-945. doi:10.1109/tii.2015.2443721

DeKorver, B. K., & Towns, M. H. (2015). General chemistry students' goals for chemistry laboratory coursework. *Journal of Chemical Education, 92*(12), 2031-2037. doi:10.1021/acs.jchemed.5b00463

DiSessa, A. A. (2001). *Changing minds: Computers, learning, and literacy*. Cambridge, MA: MIT Press.

Domin, D. S. (1999). A Review of Laboratory Instruction Styles. *Journal of Chemical Education, 76*(4), 543. doi:10.1021/ed076p543

Dood, A. J., Johnson, L. M., & Shorb, J. M. (2018). Electronic laboratory notebooks allow for modifications in a general, organic, and biochemistry chemistry laboratory to increase authenticity of the student experience. *Journal of Chemical Education, 95*(11), 1922-1928. doi:10.1021/acs.jchemed.8b00140

Dourish, P. (2001). *Where the action is: The foundations of embodied interaction*. Cambridge, MA, USA: MIT Press.

Duit, R., Gropengießer, H., Kattmann, U., Komorek, M., & Parchmann, I. (2012). The model of educational reconstruction-A framework for improving teaching and learning science. In D. Jorde & J. Dillon (Eds.), *Science education research and practice in Europe* (pp. 13-37). Rotterdam, The Netherlands: Sense Publishers.

Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education, 25*(6), 671-688. doi:10.1080/09500690305016

Egbert, M. M. (1991). Scientists' orientation to an experimental apparatus in their interaction in a chemistry lab. *Issues in Applied Linguistics, 2*(2), 269-300.

Elawady, Y., & Tolba, A. (2009). Educational objectives of different laboratory types: A comparative study. *International Journal of Computer Science and Information Security, 6*(2), 89-96.

Elliott, M. J., Stewart, K. K., & Lagowski, J. J. (2008). The role of the laboratory in chemistry instruction. *Journal of Chemical Education, 85*(1), 145-149. doi:10.1021/ed085p145

Evertson, C., & Green, J. (1986). Observation as Inquiry and Method. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (3rd ed., pp. 162-213). New York: Macmillan.

Faulconer, E. K., & Gruss, A. B. (2018). A review to weigh the pros and cons of online, remote, and distance science laboratory experiences. *The International Review of Research in Open and Distributed Learning, 19*(2). doi:10.19173/irrodl.v19i2.3386

Field, A. P. (2009). *Discovering statistics using SPSS / Andy Field* (3rd ed.). London: SAGE.

Fiore, S. M., Graesser, A., & Greiff, S. (2018). Collaborative problem-solving education for the twenty-first-century workforce. *Nature Human Behaviour, 2*(6), 367-369. doi:10.1038/s41562-018-0363-y

Flaherty, A., O'Dwyer, A., Mannix-McNamara, P., & Leahy, J. J. (2017). Aligning perceptions of laboratory demonstrators' responsibilities to inform the design of a laboratory teacher development program. *Journal of Chemical Education, 94*(8), 1007-1018. doi:10.1021/acs.jchemed.7b00210

Gadermann, A. M., Guhn, M., & Zumbo, B. D. (2012). Estimating ordinal reliability for Likert-type and ordinal item response data: A conceptual, empirical, and practical guide. *Practical assessment, research & evaluation, 17*(3), 1-13.

Galloway, K. R., & Bretz, S. L. (2015). Development of an assessment tool to measure students' meaningful learning in the undergraduate chemistry laboratory. *Journal of Chemical Education, 92*(7), 1149-1158. doi:10.1021/ed500881y

Galloway, K. R., & Bretz, S. L. (2015b). Using cluster analysis to characterize meaningful learning in a first-year university chemistry laboratory course. *Chemistry Education Research and Practice, 16*(4), 879-892. doi:10.1039/C5RP00077G

Garcia, P. A. (2002). *Interaction, distributed cognition and web-based learning*. Paper presented at the E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2002, Montreal, Canada. Retrieved September 26, 2019 from https://www.learntechlib.org/p/9371.

George-Williams, S. R., Soo, J. T., Ziebell, A. L., Thompson, C. D., & Overton, T. L. (2018). Inquiry and industry inspired laboratories: The impact on students' perceptions of skill development and engagements. *Chemistry Education Research and Practice, 19*, 583-596. doi:10.1039/c7rp00233e

Giere, R. N. (2011). Distributed cognition in the lab. [Science as Psychology Sense-Making and Identity in Science Practice, Lisa M. Osbeck, Nancy J. Nersessian, Kareen R. Malone, Wendy C. Newsletter]. *Science, 333*(6039), 159-160. doi:10.1126/science.1207754

Glaser, B. G. (1965). The constant comparative method of qualitative analysis. *Social Problems, 12*(4), 436-445. doi:10.2307/798843

Goldstone, R. L., & Son, J. Y. (2005). The transfer of scientific principles using concrete and idealized simulations. *The Journal of the Learning Sciences, 14*(1), 69-110. doi:10.1207/s15327809jls1401_4

Gomes, L., & Bogosyan, S. (2009). Current trends in remote laboratories. *IEEE Transactions on Industrial Electronics, 56*(12), 4744-4756. doi:10.1109/TIE.2009.2033293

Gorham, J. (1988). The relationship between verbal teacher immediacy behaviors and student learning. *Communication Education, 37*(1), 40-53. doi:10.1080/03634528809378702

Gosling, S. D., Rentfrow, P. J., & Swann, W. B. (2003). A very brief measure of the Big-Five personality domains. *Journal of Research in Personality, 37*(6), 504-528. doi:10.1016/S0092-6566(03)00046-1

Graesser, A. C., Fiore, S. M., Greiff, S., Andrews-Todd, J., Foltz, P. W., & Hesse, F. W. (2018). Advancing the science of collaborative problem solving. *Psychological Science in the Public Interest, 19*(2), 59-92. doi:10.1177/1529100618808244

Graham, J. M. (2006). Congeneric and (essentially) tau-equivalent estimates of score reliability: what they are and how to use them. *Educational and Psychological Measurement, 66*(6), 930-944. doi:10.1177/0013164406288165

Grant, A. (1995). The effective use of laboratories in undergraduate courses. *International Journal of Mechanical Engineering Education, 23*(2), 95-101.

Gresser, P. W. (2006). *A study of social interaction and teamwork in reformed physics laboratories.* (Doctoral dissertation), University of Maryland, Retrieved September 26, 2019 from https://drum.lib.umd.edu/handle/1903/3362 Available from ProQuest Dissertations & Theses Global

Hallgren, K. A. (2012). Computing inter-rater reliability for observational data: An overview and tutorial. *Tutorials in Quantitative Methods for Psychology, 8*(1), 23.

Harshman, J., & Stains, M. (2017). A review and evaluation of the internal structure and consistency of the approaches to teaching inventory. *International Journal of Science Education, 39*(7), 918-936. doi:10.1080/09500693.2017.1310411

Henry, J. (2000). *24× 7: Lab experiments access on the web all the time*. Paper presented at the ASEE Annual Conference Proceedings, St. Louis, Missouri. Retrieved September 26, 2019 from https://peer.asee.org/8147

Herrington, D. G., & Daubenmire, P. L. (2014). Using interviews in CER projects: Options, considerations, and limitations. In *Tools of Chemistry Education Research* (Vol. 1166, pp. 31-59): American Chemical Society.

Herrington, D. G., & Nakhleh, M. B. (2003). What defines effective chemistry laboratory instruction? Teaching assistant and student perspectives. *Journal of Chemical Education, 80*(10), 1197. doi:10.1021/ed080p1197

Hillman, D. C. A., Willis, D. J., & Gunawardena, C. N. (1994). Learner ‐ interface interaction in distance education: An extension of contemporary models and strategies for practitioners. *American Journal of Distance Education, 8*(2), 30-42. doi:10.1080/08923649409526853

Hilosky, A., Sutman, F., & Schmuckler, J. (1998). Is laboratory based instruction in beginning college-level chemistry worth the effort and expense? *Journal of Chemical Education, 75*(1), 100. doi:10.1021/ed075p100

Hodson, D. (1991). Practical work in science: Time for a reappraisal. *Studies in Science Education, 19*(1), 175-184. doi:10.1080/03057269108559998

Hodson, D. (1993). Re-thinking old ways: Towards a more critical approach to practical work in school science. *Studies in Science Education, 22*(1), 85-142. doi:10.1080/03057269308560022

Hofstein, A., & Lunetta, V. N. (1982). The role of the laboratory in science teaching: Neglected aspects of research. *Review of educational research, 52*(2), 201-217. doi:10.2307/1170311

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education, 88*(1), 28-54. doi:10.1002/sce.10106

Högström, P., Ottander, C., & Benckert, S. (2010). Lab work and learning in secondary school chemistry: The importance of teacher and student interaction. *Research in Science Education, 40*(4), 505-523. doi:10.1007/s11165-009-9131-3

Hsieh, Y.-Z., Su, M.-C., Wu, C.-T., Chou, C.-H., Lu, C.-H., Zhao, Y.-X., . . . Chu, Y.-L. (2013). *To develop the virtual physics laboratory by integrating kinect with gesture classification algorithm.* Paper presented at the 2013 International Conference on Signal-Image Technology & Internet-Based Systems (SITIS). Retrieved September 26, 2019 from https://ieeexplore.ieee.org/document/6727314

Hu, L. t., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6*(1), 1-55. doi:10.1080/10705519909540118

Hurley, A. E., Scandura, T. A., Schriesheim, C. A., Brannick, M. T., Seers, A., Vandenberg, R. J., & Williams, L. J. (1997). Exploratory and confirmatory factor analysis: Guidelines, issues, and alternatives. *Journal of Organizational Behavior, 18*(6), 667-683. doi:10.1002/(SICI)1099-1379(199711)18:6<667::AID-JOB874>3.0.CO;2-T

Jenkins, E. W. (2006). The student voice and school science education. *Studies in Science Education, 42*(1), 49-88. doi:10.1080/03057260608560220

Johnson, D. W. (1981). Student-student interaction: The neglected variable in education. *Educational researcher, 10*(1), 5-10. doi:10.3102/0013189X010001005

Johnson, D. W., & Johnson, R. T. (1987). *Learning together and alone: Cooperative, Competitive, and Individualistic Learning* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall, Inc.

Johnson, D. W., & Johnson, R. T. (2002). Learning together and alone: Overview and meta‐analysis. *Asia Pacific Journal of Education, 22*(1), 95-105.

Johnstone, A., & Al-Shuaili, A. (2001). Learning in the laboratory: Some thoughts from the literature. *University Chemistry Education, 5*(2), 42-51.

Kawachi, P. (2003). Vicarious interaction and the achieved quality of learning. *International Journal on E-Learning, 2*(4), 39-45. Retrieved September 26, 2019 from https://www.learntechlib.org/primary/p/2114/

Kiboss, J. K. (1997). An evaluation of teacher/student verbal and non-verbal behaviours in computer augmented physics laboratory classrooms in Kenya. *African Journal of Research in Mathematics, Science and Technology Education, 1*(1), 65-76. doi:10.1080/10288457.1997.10756089

Kim, H., Ku, B., Kim, J. Y., Park, Y. J., & Park, Y. B. (2016). Confirmatory and exploratory factor analysis for validating the phlegm pattern questionnaire for healthy subjects. *Evidence-Based Complementary and Alternative Medicine*. doi:10.1155/2016/2696019

Knoblauch, H., & Schnettler, B. (2012). Videography: Analysing video data as a 'focused' ethnographic and hermeneutical exercise. *Qualitative Research, 12*(3), 334-356. doi:10.1177/1468794111436147

Kolb, D. A. (1984). *Experiential learning : Experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice-Hall.

Kolk, K. v. d., Beldman, G., Hartog, R., & Gruppen, H. (2012). Students using a novel web-based laboratory class support system: A case study in food chemistry education. *Journal of Chemical Education, 89*(1), 103-108. doi:10.1021/ed1005294

Komorek, M., & Kattmann, U. (2008). The model of educational reconstruction. In U. R. Silke Mikelskis-Seifert, Maja Brückmann (Ed.), *Four decades of research in science education–from curriculum development to quality improvement* (pp. 171-188). Münster: Waxmann.

Komperda, R., Hosbein, K. N., & Barbera, J. (2018). Evaluation of the influence of wording changes and course type on motivation instrument functioning in chemistry. *Chemistry Education Research and Practice, 19*(1), 184-198. doi:10.1039/C7RP00181A

Komperda, R., Pentecost, T. C., & Barbera, J. (2018). Moving beyond alpha: A primer on alternative sources of single-administration reliability evidence for quantitative chemistry education research. *Journal of Chemical Education, 95*(9), 1477-1491. doi:10.1021/acs.jchemed.8b00220

Kousa, P., Kavonius, R., & Aksela, M. K. (2018). Low-achieving students' attitudes towards learning chemistry and its teaching methods. *Chemistry Education Research and Practice, 19*, 431-441. doi:10.1039/C7RP00226B

Krbecek, M., Das, S., Schauer, F., Ozvoldova, M., & Lustig, F. (2018). Poster: "Radiation Remote Laboratory" with two level diagnostics. In M. Auer & R. Langmann (Eds.), *Smart Industry & Smart Education. REV 2018. Lecture Notes in Networks and Systems* (Vol. 47, pp. 312-320). Cham: Springer.

Krystyniak, R. A., & Heikkinen, H. W. (2007). Analysis of verbal interactions during an extended, open - inquiry general chemistry laboratory investigation. *Journal of Research in Science Teaching, 44*(8), 1160-1186. doi:10.1002/tea.20218

Kumpulainen, K., & Mutanen, M. (1999). The situated dynamics of peer group interaction: An introduction to an analytic framework. *Learning and Instruction, 9*(5), 449-473. doi:10.1016/S0959-4752(98)00038-3

Kuo, Y.-C., Walker, A. E., Schroder, K. E. E., & Belland, B. R. (2014). Interaction, Internet self-efficacy, and self-regulated learning as predictors of student satisfaction in online education courses. *The Internet and Higher Education, 20*, 35-50. doi:10.1016/j.iheduc.2013.10.001

Kyle, W. C., Penick, J. E., & Shymansky, J. A. (1979). Assessing and analyzing the performance of students in college science laboratories. *Journal of Research in Science Teaching, 16*(6), 545-551.

Lang, Q. C., Wong, A. F. L., & Fraser, B. J. (2005). Student perceptions of chemistry laboratory learning environments, student-teacher interactions and attitudes in secondary school gifted education classes in Singapore. *Research in Science Education, 35*(2-3), 299-321. doi:10.1007/s11165-005-0093-9

Laredo, T. (2013). Changing the first-year chemistry laboratory manual to implement a problem-based approach that improves student engagement. *Journal of Chemical Education, 90*(9), 1151-1154. doi:10.1021/ed300313m

Le Roux, G. A., Reis, G. B., de Jesus, C. D., Giordano, R. C., Cruz, A. J., Moreira, P. F., . . . Loureiro, L. V. (2009). Cooperative Weblab: A tool for cooperative learning in chemical engineering in a global environment. *Computer Aided Chemical Engineering, 27*, 2139-2144.

Lehman, J. R. (1990). Students' verbal interactions during chemistry laboratories. *School Science and Mathematics, 90*(2), 142-150.

Lin, T.-J., Liang, J.-C., & Tsai, C.-C. (2015). Identifying Taiwanese university students' physics learning profiles and their role in physics learning self-efficacy. *Research in Science Education, 45*(4), 605-624. doi:10.1007/s11165-014-9440-z

Lindgren, R., Tscholl, M., Wang, S., & Johnson, E. (2016). Enhancing learning and engagement through embodied interaction within a mixed reality simulation. *Computers & Education, 95*, 174-187. doi:10.1016/j.compedu.2016.01.001

Lindsay, E. D., & Good, M. C. (2005). Effects of laboratory access modes upon learning outcomes. *IEEE Transactions on Education, 48*(4), 619-631. doi:10.1109/TE.2005.852591

Lindsay, E. D., Naidu, S., & Good, M. C. (2007). A different kind of difference: Theoretical implications of using technology to overcome separation in remote laboratories. *International Journal of Engineering Education, 23*(4), 772-779. doi:10.3189/172756499781821562

Lowe, D., Newcombe, P., & Stumpers, B. (2012). Evaluation of the use of remote laboratories for secondary school science education. *Research in Science Education, 43*(3), 1197-1219. doi:10.1007/s11165-012-9304-3

Luckay, M. B., & Laugksch, R. C. (2015). The development and validation of an instrument to monitor the implementation of social constructivist learning environments in Grade 9 science classrooms in South Africa. *Research in Science Education, 45*(1), 1-22. doi:10.1007/s11165-014-9410-5

Luis de la Torre, Heradio, R., Jara, C. A., Sanchez, J., Dormido, S., Torres, F., & Candelas, F. A. (2013). Providing collaborative support to virtual and remote laboratories. *IEEE Transactions on Learning Technologies, 6*(4), 312-323. doi:10.1109/TLT.2013.20

Lund, T. J., Pilarz, M., Velasco, J. B., Chakraverty, D., Rosploch, K., Undersander, M., & Stains, M. (2015). The best of both worlds: Building on the COPUS and RTOP observation protocols to easily and reliably measure various levels of reformed instructional practice. *CBE-Life Sciences Education, 14*(2), ar18. doi:10.1187/cbe.14-10-0168

Ma, J. (2008). *Group collaborations in technology-mediated environments.* (Doctoral dissertation), Retrieved Spetember 27, 2019 from https://search-proquest-com.dbgw.lis.curtin.edu.au/docview/304371517?accountid=10382 Available from ProQuest Central; ProQuest Dissertations & Theses Global. (304371517)

MacCallum, R. C., Widaman, K. F., Zhang, S., & Hong, S. (1999). Sample size in factor analysis. *Psychological methods, 4*(1), 84-99. doi:10.1037/1082-989X.4.1.84

Maor, D., & Fraser, B. J. (2005). An online questionnaire for evaluating students' and teachers' perceptions of constructivist multimedia learning environments. *Research in Science Education, 35*(2), 221-244. doi:10.1007/s11165-005-2148-3

McGraw, K. O., & Wong, S. P. (1996). Forming inferences about some intraclass correlation coefficients. *Psychological methods, 1*(1), 30.

McMillan, J. H. (2012). *Educational research : Fundamentals for the consumer* (6th ed.). Boston: Pearson.

Mega, C., Ronconi, L., & De Beni, R. (2014). What makes a good student? How emotions, self-regulated learning, and motivation contribute to academic achievement. *Journal of Educational Psychology, 106*(1), 121. doi:10.1037/a0033546

Meir, E., Perry, J., Stal, D., Maruca, S., & Klopfer, E. (2005). How effective are simulated molecular-level experiments for teaching diffusion and osmosis? *Cell Biology Education, 4*(3), 235-248. doi:10.1187/cbe.04-09-0049

Mercer, N., Littleton, K., & Wegerif, R. (2004). Methods for studying the processes of interaction and collaborative activity in computer-based educational activities. *Technology, Pedagogy and Education, 13*(2), 195-212. doi:10.1080/14759390400200180

Millar, R. (2004). *The role of practical work in the teaching and learning of science.* Paper presented at the High school science laboratories: Role and vision, Washington D. C. Retrieved September 27, 2019 from https://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_073330.pdf

Miller, K., Brickman, P., & Oliver, J. S. (2014). Enhancing teaching assistants'(TAs') inquiry teaching by means of teaching observations and reflective discourse. *School Science and Mathematics, 114*(4), 178-190. doi:10.1111/ssm.12065

Mocerino, M., Yeo, S., & Zadnik, M. G. (2015). Enhancing students' learning in laboratories through Professional development of teaching assistants. *EC2E2N NewsLetter 2015 – Special Edition: Chemistry Teaching and Learning*. Retrieved September 27, 2019 from http://chemnet.edu.au/sites/default/files/u39/Mocerino2015EC2E2Nreport_demostratortraining.pdf

Moore, M. G. (1989). Editorial: Three types of interaction. *American Journal of Distance Education, 3*(2), 1-7. doi:10.1080/08923648909526659

Munro, A., Fehling, M. R., & Towne, D. M. (1985). Instruction intrusiveness in dynamic simulation training. *Journal of Computer-Based Instruction, 12*(2), 50-53.

Nakhleh, M. B., Polles, J., & Malina, E. (2002). Learning chemistry in a laboratory environment. In J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust, & J. H. Van Driel (Eds.), *Chemical education: Towards research-based practice* (pp. 69-94). New York: Springer.

National Research Council. (2012). Discipline-based education research: understanding and improving learning in undergraduate science and engineering. In S. R. Singer, N. R. Nielsen, & H. A. Schweingruber (Eds.), *Committee on the Status, Contributions, and Future Directions of Discipline-Based Education Research, Board on Science Education, Division of Behavioral and Social Sciences and Education*. Washington, DC: The National Academies Press.

O'Toole, P., Crampton, A., Rayner, G., Beavis, A., Beames, S., & Meier, P. (Writers). (2012). Demonstrator development: Preparing for the learning lab. In *The Australian Council of Deans of Science*.

Ocumpaugh, J. (2015). *Baker Rodrigo Ocumpaugh monitoring protocol (BROMP) 2.0 technical and training manual* Retrieved September 27, 2019 from http://penoy.admu.edu.ph/~alls/wp-content/uploads/2015/02/BROMP_2.0_Final-libre.pdf

Ogot, M., Elliott, G., & Glumac, N. (2003). An assessment of in-person and remotely operated laboratories. *Journal of Engineering education, 92*(1), 57. doi:10.1002/j.2168-9830.2003.tb00738.x

Ogunniyi, M., & Ramorogo, G. (1994). Relative effects of a micro-teaching programme on pre-service science teachers' classroom behaviours. *Southern African Journal of Mathematics and Science Education, 1*(2), 25-36.

Oh, S., So, H.-j., & Gaydos, M. (2017). Hybrid augmented reality for participatory learning: the hidden efficacy of the multi-user game-based simulation. *IEEE Transactions on Learning Technologies*. doi:10.1109/TLT.2017.2750673

Okebukola, P. A. (1984). In search of a more effective interaction pattern in biology laboratories. *Journal of Biological Education, 18*(4), 305-308. doi:10.1080/00219266.1984.9654661

Oliveira, A. W., & Sadler, T. D. (2008). Interactive patterns and conceptual convergence during student collaborations in science. *Journal of Research in Science Teaching, 45*(5), 634-658. doi:10.1002/tea.20211

Orduna, P., Garbi Zutin, D., Govaerts, S., Lequerica Zorrozua, I., Bailey, P. H., Sancristobal, E., . . . Garcia-Zubia, J. (2015). An extensible architecture for the integration of remote and virtual laboratories in public learning tools. *Tecnologias del Aprendizaje, IEEE Revista Iberoamericana de, 10*(4), 223-233. doi:10.1109/RITA.2015.2486338

Osbeck, L. M., Nersessian, N. J., Malone, K. R., & Newstetter, W. C. (2010). *Science as psychology: Sense-making and identity in science practice*: Cambridge University Press.

Osin, L., & Lesgold, A. (1996). A proposal for the reengineering of the educational system. *Review of educational research, 66*(4), 621-656.

Ottander, C., & Grelsson, G. (2006). Laboratory work: The teachers' perspective. *Journal of Biological Education, 40*(3), 113-118. doi:10.1080/00219266.2006.9656027

Patterson, D. A. (2011). Impact of a multimedia laboratory manual: Investigating the influence of student learning styles on laboratory preparation and performance over one semester. *Education for Chemical Engineers, 6*(1), e10-e30. doi:10.1016/j.ece.2010.10.001

Peters, G. J. Y. (2018). Userfriendlyscience: Quantitative analysis made accessible (Version R package version 0.7.2). Retrieved September 27, 2019 from https://userfriendlyscience.com

Phillips, D. C. (2000). *Constructivism in education: Opinions and second opinions on controversial issues*. Chicago, IL: University of Chicago Press.

Poulsen, C., Kouros, C., d'Apollonia, S., Abrami, P. C., Chambers, B., & Howe, N. (1995). A comparison of two approaches for observing cooperative group work. *Educational Research and Evaluation, 1*(2), 159-182. doi:10.1080/1380361950010203

Power, C. (1977). A critical review of science classroom interaction studies. *Studies in Science Education, 4*(1), 1-30. doi:10.1080/03057267708559844

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., . . . Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *Journal of the Learning Sciences, 13*(3), 337-386. doi:10.1207/s15327809jls1303_4

Ranjit, K. (2014). *Research methodology: A step-by-step guide for beginners* (4th ed.): Los Angeles SAGE.

Raubenheimer, J. (2004). An item selection procedure to maximise scale reliability and validity. *SA Journal of Industrial Psychology, 30*(4). doi:10.4102/sajip.v30i4.168

Ravenna, G., Foster, C., & Bishop, C. (2012). Increasing student interaction online: A review of the literature in teacher education programs. *Journal of Technology and Teacher Education, 20*(2), 177-203.

Richter, T., Boehringer, D., & Jeschke, S. (2011). Lila: A European project on networked experiments. In S. Jeschke, I. Isenhardt, & K. Henning (Eds.), *Automation, Communication and Cybernetics in Science and Engineering 2009/2010* (pp. 307-317). Berlin, Heidelberg: Springer.

Robbins, N. B. (2013). *Creating more effective graphs*. Hoboken, NJ: John Wiley & Sons, Inc.

Rodriques, R. A. B., & Bond-Robinson, J. (2006). Comparing faculty and student perspectives of graduate teaching assistants' teaching. *Journal of Chemical Education, 83*(2), 305. doi:10.1021/ed083p305

Roychoudhury, A., & Roth, W.-M. (1996). Interactions in an open-inquiry physics laboratory. *International Journal of Science Education, 18*(4), 423-445. doi:10.1080/0950069960180403

Rusek, M., Beneš, P., & Carroll, J. (2018). Unexpected discovery: A guided-inquiry experiment on the reaction kinetics of Zinc with sulfuric acid. *Journal of Chemical Education, 95*(6), 1018-1021. doi:10.1021/acs.jchemed.7b00110

Rutten, N., Van Joolingen, W. R., & Van der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education, 58*(1), 136-153. doi:10.1016/j.compedu.2011.07.017

Sadler, T. D., Puig, A., & Trutschel, B. K. (2011). Laboratory instructional practices inventory: A tool for assessing the transformation of undergraduate laboratory instruction. *Journal of College Science Teaching, 41*(1), 25-31.

Sandi-Urena, S., Cooper, M. M., Gatlin, T. A., & Bhattacharyya, G. (2011). Students' experience in a general chemistry cooperative problem based laboratory. *Chemistry Education Research and Practice, 12*(4), 434-442. doi:10.1039/C1RP90047A

Sauter, M., Uttal, D. H., Rapp, D. N., Downing, M., & Jona, K. (2013). Getting real: The authenticity of remote labs and simulations for science learning. *Distance Education, 34*(1), 37-47. doi:10.1080/01587919.2013.770431

Sawada, D., Piburn, M. D., Judson, E., Turley, J., Falconer, K., Benford, R., & Bloom, I. (2002). Measuring reform practices in science and mathematics classrooms: The reformed teaching observation protocol. *School Science and Mathematics, 102*(6), 245-253. doi:10.1111/j.1949-8594.2002.tb17883.x

Saxena, S., & Satsangee, S. P. (2014). Offering remotely triggered, real-time experiments in electrochemistry for distance learners. *Journal of Chemical Education, 91*(3), 368-373. doi:10.1021/ed300349t

Scanlon, E., Morris, E., di Paolo, T., & Cooper, M. (2002). Contemporary approaches to learning science: Technologically-mediated practical work. *Studies in Science Education, 38*(1), 73-114. doi:10.1080/03057260208560188

Scheucher, B., Bayley, P., Gütl, C., & Harward, J. (2009). Collaborative virtual 3D environment for Internet-accessible physics experiments. *International Journal of Online Engineering, 5*(REV 2009), 65-71. doi:10.3991/ijoe.v5s1.1014

Seery, M. K., Jones, A. B., Kew, W., & Mein, T. (2019). Unfinished recipes: Structuring upper-division laboratory work to scaffold experimental design skills. *Journal of Chemical Education, 96*(1), 53-59. doi:10.1021/acs.jchemed.8b00511

Sher, A. (2009). Assessing the relationship of student-instructor and student-student interaction to student learning and satisfaction in web-based online learning environment. *Journal of Interactive Online Learning, 8*(2), 102-120.

Shwartz, Y., & Katchevitch, D. (2013). Using wiki to create a learning community for chemistry teacher leaders. *Chemistry Education Research and Practice, 14*(3), 312-323. doi:10.1039/C3RP20180E

Smith, C. J. (2012). Improving the school-to-university transition: Using a problem-based approach to teach practical skills whilst simultaneously developing students' independent study skills. *Chemistry Education Research and Practice, 13*(4), 490-499. doi:10.1039/C2RP20096A

Southam, D. C., Shand, B., Buntine, M. A., Kable, S. H., Read, J. R., & Morris, J. C. (2013). The timing of an experiment in the laboratory program is crucial for the student laboratory experience: Acylation of ferrocene as a case study. *Chemistry Education Research and Practice, 14*(4), 476-484. doi:10.1039/C3RP00011G

Stang, J. B., & Roll, I. (2014). Interactions between teaching assistants and students boost engagement in physics labs. *Physical Review Special Topics - Physics Education Research, 10*(2), 020117. doi:10.1103/PhysRevSTPER.10.020117

Sutton, L. A. (2001). The principle of vicarious interaction in computer-mediated communications. *International Journal of Educational Telecommunications, 7*(3), 223-242.https://www.learntechlib.org/primary/p/9534/

Taber, K. (2018). The use of Cronbach's Alpha when developing and reporting research instruments in science education. *Research in Science Education, 48*(6), 1273-1296. doi:10.1007/s11165-016-9602-2

Taherdoost, H., Sahibuddin, S., & Jalaliyoon, N. (2014). Exploratory factor analysis: Concepts and theory. In J. Balicki (Ed.), *Advances in Applied and Pure Mathematics* (pp. 375-382). Gdansk, Poland: WSEAS Press.

Tallent-Runnels, M. K., Thomas, J. A., Lan, W. Y., Cooper, S., Ahern, T. C., Shaw, S. M., & Liu, X. (2006). Teaching courses online: A review of the research. *Review of educational research, 76*(1), 93-135. doi:10.3102/00346543076001093

Tamir, P., Nussinovitz, R., & Friedler, Y. (1982). The design and use of a practical tests assessment inventory. *Journal of Biological Education, 16*(1), 42-50. doi:10.1080/00219266.1982.9654417

Tirado-Morueta, R., Sánchez-Herrera, R., Márquez-Sánchez, M. A., Mejías-Borrero, A., & Andujar-Márquez, J. M. (2018). Exploratory study of the acceptance of two individual practical classes with remote labs. *European Journal of Engineering Education, 43*(2), 278-295. doi:10.1080/03043797.2017.1363719

Tofan, D. C. (2009). Software development for open-lab management. *Journal of Chemical Education, 86*(11), 1270. doi:10.1021/ed086p1270.1

Treagust, D. F., Carter, D. J., Lindsay, E. D., Zadnik, M. G., Mocerino, M., & Lucey, A. D. (2016). Student learning processes in classroom and remote laboratory settings. In I. Eilks, S. Markic, & B. Ralle (Eds.), *Science education research and practical work* (pp. 49-59). Aachen, Germany: Shaker Verlag.

Tsai, C.-C. (2003). Taiwanese science students' and teachers' perceptions of the laboratory learning environments: Exploring epistemological gaps. *International Journal of Science Education, 25*(7), 847-860. doi:10.1080/09500690305031

Uzuntiryaki, E., & Çapa Aydın, Y. (2009). Development and validation of Chemistry Self-Efficacy Scale for college students. *Research in Science Education, 39*(4), 539-551. doi:10.1007/s11165-008-9093-x

Vagias, W. M. (2006). Likert-type scale response anchors. *Clemson International Institute for Tourism & Research Development, Department of Parks, Recreation and Tourism Management. Clemson University*.

Velasco, J. B., Knedeisen, A., Xue, D., Vickrey, T. L., Abebe, M., & Stains, M. (2016). Characterizing instructional practices in the laboratory: The laboratory observation protocol for undergraduate STEM. *Journal of Chemical Education, 93*(7), 1191-1203. doi:10.1021/acs.jchemed.6b00062

Viegas, C., Pavani, A., Lima, N., Marques, A., Pozzo, I., Dobboletta, E., . . . Alves, G. (2018). Impact of a remote lab on teaching practices and student learning. *Computers & Education, 126*, 201-216. doi:10.1016/j.compedu.2018.07.012

Viskupic, K., Ryker, K., Teasdale, R., Manduca, C., Iverson, E., Farthing, D., . . . McFadden, R. (2019). Classroom observations indicate the positive impacts of discipline-based professional development. *Journal for STEM Education Research*. doi:10.1007/s41979-019-00015-w

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. In M. Cole, V. John-Steiner, & E. Souberman (Eds.). Cambridge MA: Harvard University Press.

Wagner, E. D. (1994). In support of a functional definition of interaction. *American Journal of Distance Education, 8*(2), 6-29. doi:10.1080/08923649409526852

Wegner, P. (1997). Why interaction is more powerful than algorithms. *Communications of the ACM, 40*(5), 80-91.

Wei, J., Mocerino, M., Treagust, D. F., Lucey, A. D., Zadnik, M. G., Lindsay, E. D., & Carter, D. J. (2018). Developing an understanding of undergraduate student interactions in chemistry laboratories. *Chemistry Education Research and Practice, 19*(4), 1186-1198. doi:10.1039/C8RP00104A

Wei, J., Mocerino, M., Treagust, D. F., Zadnik, M. G., Lindsay, E. D., & Lucey, A. D (2017). *Evaluating the relationship between various interactions, student satisfaction and learning outcomes in face-to-face and remote-access chemistry laboratories*, American Chemical Society (ACS) Asia-Pacific International Chapters Conference.

Wei, J., Treagust, D. F., Mocerino, M., Lucey, A. D., Zadnik, M. G., & Lindsay, E. D (2019). Understanding interactions in face-to-face and remote undergraduate science laboratories: A literature review. *Disciplinary and Interdisciplinary Science Education Research, 1*(1), 14. doi:10.1186/s43031-019-0015-8

West, E. A., Paul, C. A., Webb, D., & Potter, W. H. (2013). Variation of instructor-student interactions in an introductory interactive physics course. *Physical Review Special Topics - Physics Education Research, 9*(1), 010109.

Wilensky, U., & Stroup, W. (2002). *Participatory Simulations: Envisioning the networked classroom as a way to support systems learning for all.* Paper presented at the Annual meeting of the American Research Education

Association, New Orleans, LA. Retrieved September 27, 2019 from https://ccl.northwestern.edu/papers/2002/ps-aera.pdf

Williams, B., Onsman, A., & Brown, T. (2010). Exploratory factor analysis: A five-step guide for novices. *Australasian Journal of Paramedicine, 8*(3).

Winberg, T. M., & Berg, C. A. R. (2007). Students' cognitive focus during a chemistry laboratory exercise: Effects of a computer‐simulated prelab. *Journal of Research in Science Teaching, 44*(8), 1108-1133. doi:10.1002/tea.20217

Wubbels, T. (1993). Teacher-student relationships in science and mathematics classes. In B. J. Fraser (Ed.), *Research implications for science and mathematics teachers* (Vol. 1, pp. 65-73). Perth, Australia: Curtin University of Technology.

Xu, H., & Talanquer, V. (2013). Effect of the level of inquiry on student interactions in chemistry laboratories. *Journal of Chemical Education, 90*(1), 29-36. doi:10.1021/ed3002946

Yang, S. C., & Liu, S. F. (2004). Case study of online workshop for the professional development of teachers. *Computers in Human Behavior, 20*(6), 733-761. doi:10.1016/j.chb.2004.02.005

Yezierski, E. J. (2014). Observation as a tool for investigating chemistry teaching and learning. In *Tools of Chemistry Education Research* (Vol. 1166, pp. 11-29): American Chemical Society.

Zacharia, Z. C., Manoli, C., Xenofontos, N., de Jong, T., Pedaste, M., van Riesen, S. A., . . . Tsourlidaki, E. (2015). Identifying potential types of guidance for supporting student inquiry when using virtual and remote labs in science: A literature review. *Educational Technology Research and Development, 63*(2), 257-302. doi:10.1007/s11423-015-9370-0

Zhao, N., & Wardeska, J. G. (2011). Mini-Journal inquiry laboratory: A case study in a general chemistry kinetics experiment. *Journal of Chemical Education, 88*(4), 452-456. doi:10.1021/ed100079t

APPENDICES

Appendix A

Pre- and Post-lab Survey Forms in Face-to-face and Remote Laboratories

A1 the First Version of Pre-lab Survey for Face-to-Face Science Laboratories

A2 the Second Version of Pre-lab Survey for Face-to-Face Science Laboratories

A3 the First Version of Post-lab Survey for Face-to-Face Science Laboratories

A4 the Second Version of Post-lab Survey for Face-to-Face Science Laboratories

A5 the Pre-lab Survey for the Remote Science Laboratory - Curtin

A6 the Pre-lab Survey for the Remote Science Laboratory - UNE

A7 the Post-lab Survey for the Remote Science Laboratory

A8 Participant Information Sheet

A1 the First Version of Pre-lab Survey for Face-to-face Science Laboratories

Participant Consent Form

Curtin University

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

- I have reviewed the participant information, or had it explained to me in language I understand and had an opportunity to ask questions. I believe I understand the purpose, extent and possible risks of my involvement in this project and I voluntarily consent to take part.
- I understand that this project has been approved by Curtin University Human Research Ethics Committee (approval number: RDSE-61-15) and will be carried out in line with the National Statement on Ethical Conduct in Human Research (2007) – updated March 2014.
- I understand that no personal identifying information will be used in any published materials.
- I understand that I am free to withdraw my participation at any time without affecting my relationship with Curtin University, or any staff member.
- I understand that all information will be stored securely for at least 7 years before a decision is made as to whether it should be destroyed.

1. We want to investigate if students with similar laboratory marks exhibit similar interaction patterns in laboratory classes.
   - ➢ I consent to allow the research team to access my laboratory mark for this unit: Y N
2. We also want to investigate if students with similar overall course marks exhibit similar interaction patterns in laboratory classes.
   - ➢ I consent to allow the research team to access to my course/semester weighted mark: Y N
3. In select laboratory classes we would like to study student interaction patterns using audio/video-recording, to compare with survey results and laboratory observations.
   - ➢ I consent to being video/audio-recorded in this class: Y N

Student ID								Family Name	Given Name(s)

Participant Signature: ____

Date: ____

Please turn this page over and complete the prelab survey questions

Participant Consent Form, version 1, 5/7/2016

Pre-Lab Survey Curtin University

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

- Gender: M F X (M=male, F=female, X=unspecified)
- Date: ______________________________
- Unit: ______________________________
- Degree: ______________________________
- Have you done laboratory classes at university before? Y N
- Is the primary language that you speak at home English? Y N If not, please specify: ____________________

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	Example
Talking to another student you learn	..... about the procedures/lab equipment		
	..... how to analyse your results		3
	..... about the basic science theory behind the lab		
Talking to a lab demonstrator you learn	..... about the procedures/lab equipment		4
	..... how to analyse your results		1
	..... about the basic science theory behind the lab		
During the prelab you learn	..... about the procedures/lab equipment		
	..... how to analyse your results		5
	..... 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			2

Thank you for your cooperation ☺

Pre-lab Survey, version 1, 25/7/2017

A2 the Second Version of Pre-lab for Face-to-face Science Laboratories

Participant Consent Form

Curtin University

Project Title: *The online future of Science and Engineering Education: The essential elements of laboratory-based learning for remote-access implementation*

- I have reviewed the participant information or had it explained to me in a language I understand and had an opportunity to ask questions. I believe I understand the purpose, extent and possible risks of my involvement in this project and I voluntarily consent to take part.
- I understand that this project has been approved by Curtin University Human Research Ethics Committee (approval number: RDSE-61-15) and will be carried out in line with the National Statement on Ethical Conduct in Human Research (2007) – updated March 2014.
- I understand that no personal identifying information will be used in any published materials.
- I understand that I am free to withdraw my participation at any time without affecting my relationship with Curtin University, or any staff member.
- I understand that all information will be stored securely for at least 7 years before a decision is made as to whether it should be destroyed.

Student ID								Family Name	Given Name(s)

- Gender: M F X (M=male, F=female, X=unspecified)
- Date: ______________________________
- Unit: ______________________________
- Degree: ______________________________
- Have you done laboratory classes at university before? Y N
- Is the primary language that you speak at home English? Y N If not, please specify: ____________________

1. We want to investigate if students with similar laboratory marks exhibit similar interaction patterns in laboratory classes.
   - I consent to allow the research team to access my laboratory mark for this unit: Y N
2. We also want to investigate if students with similar overall course marks exhibit similar interaction patterns in laboratory classes.
   - I consent to allow the research team to access my course/semester weighted mark: Y N
3. In select laboratory classes, we would like to study student interaction patterns using audio/video-recording, to compare with survey results and laboratory observations.
   - I consent to be video/audio-recorded in this class: Y N

Participant Signature: ____________________ Date: ____________________

Please turn this page over and complete the prelab survey questions

Participant Consent Form, version 2, 7/8/2017

Pre-Lab Survey

Curtin University

Project Title: *The online future of Science and Engineering Education: The essential elements of laboratory-based learning for remote-access implementation*

Below is a list of 16 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	Example
Talking to another student you learn	..... about the procedures/lab equipment		
	..... how to analyse your results		3
	..... about the basic science theory behind the lab		
Talking to a lab demonstrator you learn	..... about the procedures/lab equipment		4
	..... how to analyse your results		1
	..... about the basic science theory behind the lab		
During the prelab, you learn	..... about the procedures/lab equipment		
	..... how to analyse your results		5
	..... 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			2
You learn by observing or listening others to	..... setup the apparatus		
	.... ask another student for help/advice		
	.... Ask a teacher for help/advice		

Thank you for your cooperation ☺

Pre-lab Survey, version 2, 7/8/2017

A3 the First Version of Post-lab Survey for Face-to-face Science Laboratories

Post-lab survey | ***The online future of Science and Engineering education: The essential elements of laboratory-based learning for remote-access implementation*** | Curtin University

Date: ____________ Time: __________ Unit: ____

Student ID								Family Name	Given Name(s)
0	0	0	0	0	0	0	0		
1	1	1	1	1	1	1	1		
2	2	2	2	2	2	2	2		
3	3	3	3	3	3	3	3		
4	4	4	4	4	4	4	4		
5	5	5	5	5	5	5	5		
6	6	6	6	6	6	6	6		
7	7	7	7	7	7	7	7		
8	8	8	8	8	8	8	8		
9	9	9	9	9	9	9	9		

INSTRUCTIONS

- To register a response completely, fill the bubble with a blue or black ballpoint pen.
- Completely fill each bubble underneath each digit in your student ID.
- Completely fill a single bubble corresponding to your answers and reasons given on the survey.
- If you make an error, cross out the unwanted response and completely fill the circle corresponding to your wanted response.
- Do not make any other stray marks on the page.

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

5. Approximately how much time did you spend reading the lab manual ...			
... completing the pre-lab	... in the initial stages of the lab	... writing the lab report	... for the rest of the lab
mins	mins	mins	mins

Thank you for your cooperation ☺

Post-lab survey, version 1, 01/7/2016

A4 the Second Version of Post-lab Survey for Face-to-face Science Laboratories

Post-lab survey — ***The online future of Science and Engineering education: The essential elements of laboratory-based learning for remote-access implementation*** — Curtin University

Date: ____________ Time: __________ Unit: ________________________________

Student ID								Family Name	Given Name(s)

Reflecting on the laboratory class you just completed

1. (***Student-Student Interactions***) **Did you talk to another student about ...**	**Never**	**Only once**	**A few times**	**Many times**
1.1 the procedures, protocols or lab equipment?	0	1	2	3
1.2 the basic science concepts behind the lab?	0	1	2	3
1.3 analysing your results?	0	1	2	3
1.4 discipline topics not directly related to the lab?	0	1	2	3
1.5 topics not related to the lab?	0	1	2	3
2. (***Student-Teacher Interactions***) **Did you ask the teacher about ...**				
2.1 the procedures, protocols or lab equipment?	0	1	2	3
2.2 the basic science concepts behind the lab?	0	1	2	3
2.3 analysing your results?	0	1	2	3
2.4 discipline topics not directly related to the lab?	0	1	2	3
2.5 topics not related to the lab?	0	1	2	3
3. (***Student-Equipment Interactions***) **Did you ...**				
3.1 read the lab manual/instructions associated with this lab?	0	1	2	3
3.2 use the Internet for technical assistance, data analysis or for concepts behind this lab?	0	1	2	3
4. (***Indirect Interactions***) **Did you learn by observing someone else's interactions in the lab, such as ...**				
4.1 observing another students experimental setup or behaviour	0	1	2	3
4.2 listening to a student/group of students asking another student for help/advice	0	1	2	3
4.3 listening to a student/group of students asking a teacher for help/advice	0	1	2	3

Please **choose ONLY 5 of those 15 items (from 1.1 to 4.3)** that you think are most important in helping you successfully complete the lab that you just finished and **rank them.**

Rank	1	2	3	4	5
Item Name					
Example	*2.2*	*1.3*	*1.4*	*3.2*	*2.4*

(Student satisfaction) **Did you think…?**	**Strongly Disagree**	**Disagree**	**Neither Agree nor Disagree**	**Agree**	**Strongly Agree**
Did you think the quality of this experiment compared favourably with your other face-to-face laboratory experiments?	1	2	3	4	5

Post-lab survey, version 2, 4/7/2017

Pre-Lab Survey

Curtin University

3. In the first step, you are going to open, evacuate and reseal the test tube following the instructions on the computer screen. To escape the n-octane evaporating, what is the maximum time span to evacuate the sample?

A. 1- 2 seconds B. 1-2 minutes C. 30 minutes

4. The reason of carefully heating is:

A. To ensure stabilised temperatures and pressures within a reasonable time frame

B. To give the sliders time to be heated.

C. Because it is chemistry experiment, we are supposed to be careful.

5. Which of the following statements correctly apply to vapour pressures? Please select all that apply.

A. A plot of ln $P_{C_8H_{18}}$ against T^{-1} will have a negative slope

B. A plot of ln $P_{C_8H_{18}}$ against T^{-1} will have a positive slope

C. Vaporisation is an exothermic process and ΔS_{vap} is negative

D. Vaporisation is an endothermic process and ΔS_{vap} is positive

6. * (ChCl) A bar of copper is heated to 30 °C and then placed into a Styrofoam cup of water. Thermal equilibrium between the copper bar and water is reached at 40 °C. What was the temperature of the water before the copper bar was dropped into it? Why?

A) Less than 40 °C because copper can hold more heat than water.

B) Less than 40 °C because the copper bar heated the water.

C) Greater than 40 °C because water can hold more heat than copper.

D) Greater than 40 °C because the water heated the copper bar.

E) Greater than 40 °C because the water and copper bar would cool down on their own without interacting with each other or anything else.

**Retrieved from the Concept Inventory (ChCl) - (Krause, Birk, Bauer, Jenkins, & Pavelich, 2004)*

Thank you for your cooperation ☺

Pre-lab Survey, version 1, 25/8/2017

A6 the Pre-lab Survey for the Remote Science Laboratory - UNE

Pre-Lab Survey

Curtin University

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

Dear Participant,
As part of an ongoing research project on educational laboratories and in order to continuously improve our laboratory offerings at UNE, we would like to solicit constructive feedback for the remote lab. You have the option of completing the questionnaire on an anonymous basis but, if you prefer, you can give us your student ID so that we can make further analysations according to student learning outcomes.

- **I consent to allow the research team to access my laboratory mark for this unit:** **Y** **N**
- **I consent to allow the research team to access to my course/semester weighted mark:** **Y** **N**
- Gender: M F X (M=male, F=female, X=unspecified)
- Is the primary language that you speak at home English? Y N If not, please specify: ____________________

Please assume the importance of the following 7 possible interactions that may happen during this laboratory class and rank them (1 means the most important).

Example interaction		Rank	Example
Reading the laboratory manual/notes you learn	..... about the procedures/lab equipment		4
	..... how to analyse your results		1
	..... about the basic science theory behind the lab		3
From the internet you learn	..... about the procedures/lab equipment		6
	..... how to analyse your results		5
	..... about the basic science theory behind the lab		7
From the technician people	..... about the procedures/lab equipment		2

Student ID: ________________________

Curtin University Ethics Approval Number: RDSE-61-15 Pre-lab Survey, version 2, 20/2/2018

A7 the Post-lab Survey for the Remote Science Laboratory

Post-lab survey ***The online future of Science and Engineering education: The essential elements of laboratory-based learning for remote-access implementation*** Curtin University

Date: ____________ Time: __________ Unit: ______________________________________

Student ID								Family Name	Given Name(s)

- Gender: Ⓜ Ⓕ Ⓧ (M=male, F=female, X=unspecified)
- How many years of internet experience do you have? A. 1 year B. 2 years C. ≥ 2 years

Reflecting on the laboratory class you just completed:

1. How much have you talked with other students about…	**Never**	**Once**	**A few times**	**Many times**
1.1 the procedures, protocols or lab equipment?	0	1	2	3
1.2 the basic science concepts behind the lab?	0	1	2	3
1.3 analysing your results?	0	1	2	3
2. Did you use online searching tools such as google about …				
2.1 the procedures, protocols or lab equipment?	0	1	2	3
2.2 the basic science concepts behind the lab?	0	1	2	3
2.3 analysing your results?	0	1	2	3
3. Did you read the lab manual associated with this lab for …				
3.1 the procedures, protocols or lab equipment?	0	1	2	3
3.2 the basic science concepts behind the lab?	0	1	2	3
3.3 analysing your results?	0	1	2	3
4. Did you…				
4.1 Ask the technician/instructor for help	0	1	2	3
4.2 Use the online help function	0	1	2	3

Please **choose ONLY 5 of those 11 items (from 1.1 to 4.2)** that you think are most important relating to the lab that you just finished and **rank them (#1 is the most important).**.

Rank	1	2	3	4	5
Item Name					
Example	*2.2*	*1.3*	*1.4*	*3.2*	*2.4*

(Student satisfaction) **Do you think…**	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
The quality of this laboratory experiment compared favourably to my other face-to-face laboratory experiments	1	2	3	4	5
If I had an opportunity to do another laboratory experiment via the Internet, I would gladly do so	1	2	3	4	5
The flexibility of doing a remote laboratory anytime anywhere is important to me.	1	2	3	4	5
I felt I have done a real laboratory	1	2	3	4	5
The communication with students is as much as that in face-to-face laboratories	1	2	3	4	5
I feel I was totally immersed into the lab process	1	2	3	4	5
I think the technology is ease to use	1	2	3	4	5
Overall I'm very satisfied with this laboratory experience.	1	2	3	4	5

Post-lab survey, version 1, 29/4/2018

A8 Participant Information Sheet

Participant Information Sheet

Curtin University

Project Title:	The online future of Science and Engineering education: The essential elements of laboratory-based learning for remote-access implementation	
Principal Investigators:	Prof. David Treagust Prof. Euan Lindsay Prof. Anthony Lucey A/Prof. Mauro Mocerino	A/Prof. Marjan Zadnik A/Prof. Sven Esche Dr Damien Carter Jianye Wei Sulakshana Lal
HREC Project Number:	RDSE-61-15	

Invitation to participate

You are kindly invited to participate in this research project. Participation is voluntary and you are free to withdraw at any time, or from any particular aspect such as consent relating to video-recording or access to laboratory marks. There will be no costs to you and your time will be recognized by a voucher for use at the Curtin Guild. This research project is funded by the Australian Research Council Discovery Project DP140104189.

The purpose of the research project

Existing literature of remote laboratories has focused upon the learning outcomes of remote laboratories, but not upon the learning processes. This project aims determine the mechanisms through which students learn in a laboratory setting, by addressing:

1. With whom and with what do students interact, and what is the purpose of these interactions?
2. Correlating patterns of these interactions with students' learning and assessment outcomes?
3. Which of these interactions must be preserved in a shift to the remote access mode?
4. Can remote/online interfaces provide the essential interactions?

These questions will be answered by observing, recording and analysing students at work in physical laboratory classes, and by using this analysis to guide the development of the next generation of remote laboratory interfaces. Results of this research will be made available in the form of scholarly publications.

Why am I being asked to take part and what will I have to do?

An exhaustive list of interactions within a laboratory class will be constructed from surveys of academics and students, and direct observation of laboratories. In a limited number of cases video recording will be used to document the interactions within laboratory classes. What we ask participants to possibly do is:

- Fill out survey questionnaires
- Consent to be being observed in a laboratory class
- Consent to being video-recorded in a laboratory class
- Consent to allow the research team access to your laboratory mark

Apart from giving up a little of your time, we do not expect that there will be any risks or inconveniences associated with taking part in this study.

Data Collection

- Any information we collect and use during this research will be treated as confidential.
- The following people will have access to the information we collect in this research: the research team and the Curtin University Ethics Committee.
- The information we collect in this study will be kept under secure conditions at Curtin University for 7 years after the research has ended and then it will be destroyed.

What happens next and who can I contact about the research?

For more information please contact Prof. David Treagust.
Phone: +618 9266 7924 Email: d.treagust@curtin.edu.au

Thank you for your cooperation.

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number RDSE-61-15). Should you wish to discuss the study with someone not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Officer on (08) 9266 9223 or the Manager, Research Integrity on (08) 9266 7093 or email hrec@curtin.edu.au.

Participant Information Sheet, version 1b, 05/09/2017

Appendix B

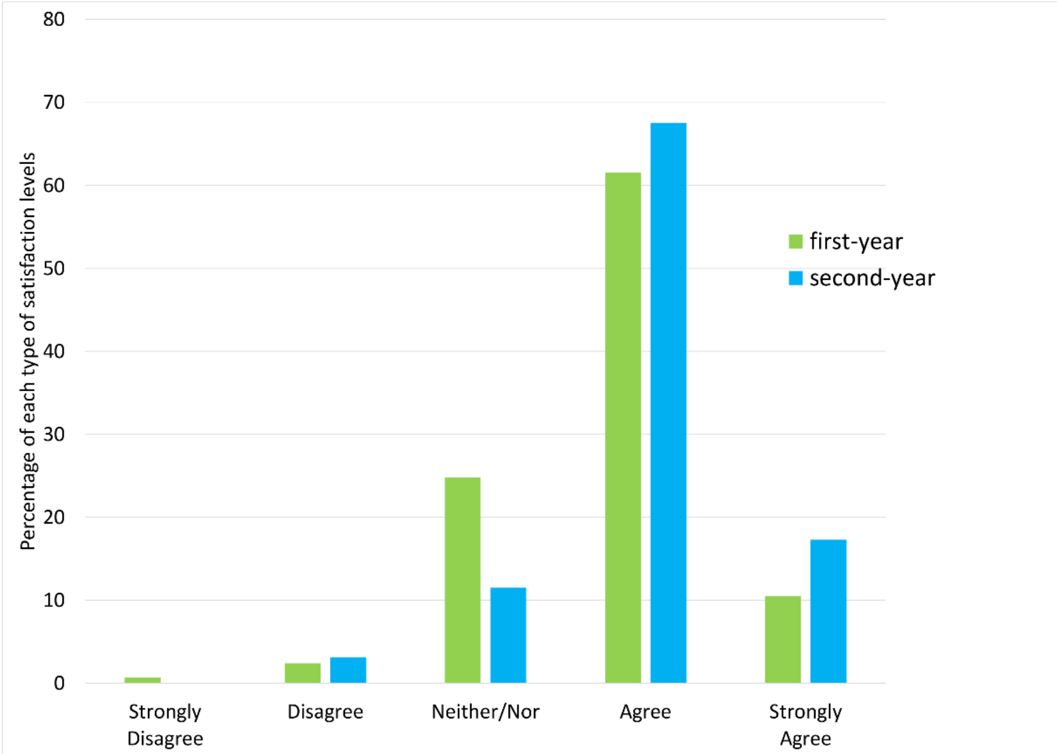


Figure B1 Student experiences of the satisfaction levels after undertaking the laboratory: Data obtained from the post-lab survey, Study 2 (total number of selections =656) and Study 3 (total number of selections =191)

One example of the results in comparing the relationship between the frequencies of interactions and learning achievements in Laboratory 1, Study 1.

Table B1. Pearson's product-moment correlation coefficient for the interactions with lab marks (Lab Session 1/Study 2)

	# of 'never' and lab marks	**# of 'once' and lab marks**	**# of 'a few' and lab marks**	**# of 'many' and lab marks**
Overall Interactions	.006	-.072	-.056	.107
Factor 1: S-S Lab-related (ss)	-.040	.009	-.095	.096
Factor 2: S-I Lab-related (si)	-.043	.069	-.075	.076
Factor 3: I-I (ii)	.085	-.126	-.012	.042
Factor 4: S-S Lab-unrelated (ssu)	-.011	.013	.025	-.064
Factor 5: S-I Lab-unrelated (siu)	.063	-.147*	.091	-.023

Table B2. Pearson's product-moment correlation coefficient for the interactions with course completion (Lab Session 1/Study 2)

	# of 'never' and lab marks	**# of 'once' and lab marks**	**# of 'a few' and lab marks**	**# of 'many' and**
Overall Interactions	.144*	-.092	-.100	.018
Factor 1: S-S Lab-related (ss)	.055	-.134*	.023	.030
Factor 2: S-I Lab-related (si)	.012	.021	-.050	.025
Factor 3: I-I (ii)	.155*	-.026	-.124	.025
Factor 4: S-S Lab-unrelated (ssu)	.132*	-.062	-.077	-.054
Factor 5: S-I Lab-unrelated (siu)	.051	-.039	.008	-.105

Table B3 The transcripts of the interviews and the key points

Transcripts of the Interview	Emphasis
Team one: *Interviewer (Int): Have you met any problems in today's lab?* *Student (Stu): no, we did this last year.* *Int: oh* *Stu: that' why we did it faster. Also, the transaction was really good.* *Int: do you have any suggestions to improve today's lab?* *Stu A: not really, it's pretty good.* *Stu B: maybe more step-by-step about the concentrations in the lab manual. (Stu A agreed)* *Int: ye. So you mean maybe in the concentration part was covered in the workshop more?* *Stu B: or even in the lab manual… just go how to do it.* *Int: give some directions…* *Stu A: yes.*	The two students presented that more clear guidance in the laboratory manual would be more helpful.
Team Two: *Stu ID: 18880698* *Int: any problems today?* *Stu: no, pretty good.* *Int: do u think any improvements, like the lab manual, from the instructor, or from your peers?* *Stu: the instructions from the instructor was clear.* *Int: so that's why it went fluently. Any suggestions?* *Stu: not yet.*	Instructors from the instructor were helpful.
Team Three: *Int: any problems in today's lab? You finish it really quickly.* *Stu: I finish quickly, but struggled with the calculations to the end. So just the … questions.* *Int: so that spent you more than half an hour. For the procedures, you are ok.* *Stu A: procedures are ok.* *Int: any suggestions?* *Stu: I think it's pretty well done because if we have any questions, Franca and the other lady (The instructors) were there to help us. It's good.* *Int: so the help from the demonstrators were helpful. Do u think in the future more stuff about the calculations should be included?* *Stu: I think that's on my behalf. I didn't do the reading beforehand. Everyone did the reading beforehand, then they won't struggle with the questions.*	The procedures were easy to follow and did not take long to complete. The instructors were really helpful. To do some pre-lab preparation will be useful. The workshop material contributed to the learning in the laboratories.

Int: do you mean from the lab manual or…?

Stu: it's from the workshop. We did the workshop the week before last. So.

Student Four:

Int: any problems?

Stu: in the lab, I don't think we meet any problem that can be solved eventually. Pretty good, so far.

Int: You mean that 'eventually', maybe in the process you have met some problems, then you solved it.

Stu: yes.

Int: How did you solve that?

Stu: we solved it like… as far as it's an actual lab work went, we went for ***the instructions*** *and the lab was done well. But the lab calculations, we had to ask some o****ther students and the lab demonstrators*** *and they sort of work it through. And we look back through our* ***notes*** *and stuff. And eventually, we worked it out.*

Int: I think the calculation is in the homework. So that means that in the lab process, you have no problem.

Stu: no, not yet. None in the lab, as far as the calculations were in the homework. I haven't done it yet, I only had my lab yesterday. So we'll find out.

Int: any suggestions?

Stu: maybe the addressing of the ***lab manual*** *can be changed every year? Like something in the middle is outdated instructions. So I think the staff can double-check the lab manuals each semester to make sure it still makes sense and coherence to the students at a basic level.*

Int: do you mean that some guidance in the lab manual was not clear? So it's better to make changes to the lab room…?

Stu: yes. Not much, but a little bit. Any other suggestions, like giving ***a model*** *answer for the homework…?*

Stu: yes. So for the homework, we discussed it on the board briefly, very quickly before we went home. But we did not get any examples, like a little bit more ***time*** *will be useful.*

The help from other students and the instructors were helpful for solving problems.

The contents in the laboratory manual should be updated timely.

To provide a modal answer to the homework will be more helpful.

Appendix C

Voluntary Students Audio Recordings for the Remote Laboratory

(P1: Participant 1 P2: Participant 2 I:Instructor)

Only the first four pages are shown here. The full transcription can be found in: https://www.dropbox.com/s/oznq5bv40kt6h0k/Transcription-Volunterr_2017_Remote.docx?dl=0

P1: [0:00:00.3] test tube. Cool. [0:00:11.1].

P2: Yeah, I think that's what that is, which [0:00:17.3].

P1: Yeah, but [0:00:19.9] instructions. I think we're meant to press next. I feel like that's the next logical option.

I: [0:00:33.2] steps will guide you [0:00:34.1].

P1: [0:00:36.2]. Next. System check [0:00:43.9] of the test tube. Power fault is off. The temperature should be reasonable and within tolerance. Pressure should be zero or less. Yes, it is at zero or less. [0:01:00.3] press next one complete. I don't really know exactly what's going on but I guess we just …

P2: It should just look like that anyway.

P1: But where exactly [0:01:16.6] if we want to [0:01:24.5].

P2: [0:01:29.9].

P1: [0:01:32.1]. Open new [0:01:37.4] new [0:01:40.4]. Okay. [0:01:47.0]. Cool. [0:01:51.5] pressure sensors means just add the temperatures from the table from the data [0:01:58.5].

P2: I think so.

P1: Cool. I don't know what this is supposed to do. I honestly don't think it really matters with this though.

P2: [0:02:17.7].

P1: Yeah. All good?

P2: Yep.

P1: Cool. Prepare for evacuation. System temperature must be below 35 degrees Celsius before evacuation [0:02:33.7].

P2: [0:02:37.0].

P1: Yeah, pretty much.

P2: [0:02:42.1] down but it's not so that's …

P1: [0:02:47.0] system. Turn what?

P2: [0:02:52.4].

P1: And turn it on.

P2: Yep.

P1: Yep. Turn that … oop, not that.

P2: [0:03:10.6].

P1: [0:03:18.7].

P2: [0:03:19.1].

P1: [0:03:23.4] system.

P2: [0:03:25.5].

P1: Turn [0:03:32.3] off. Turn [0:03:35.8] off. And oop. Turn heat on and control the rate using slider. Why [0:03:49.0]?

P2: I've done sliders before.

P1: I feel that's the slider they're talking about. Use the difference in the temperature sensors to [0:03:57.4] quality achieved. Maximum [0:03:59.1]. Oh, [0:04:02.7].

P2: That's where we [0:04:03.9]. That was [0:04:05.3] that one.

P1: Table?

P2: Yeah.

P1: The table.

P2: No, not the table.

P1: Temp?

P2: There we go. [0:04:24.7].

P1: Not until we know what we're looking at, but all right.

P2: [0:04:30.7]. It's going up slowly.

P1: So, yes, it is. [0:04:41.1] temperatures to ensure thermal equilibrium achieved, maximum a hundred, and then we use the slider.

P2: [0:04:49.9].

P1: Is that what the slider are meant to do?

P2: I think is the only difference between the two sensors.

P1: Okay. So, looking for a maximum of 100 difference. Okay. Where do you think you want to stop? 90 difference? Well, actually, if it's saying … what is it actually saying? [0:05:33.6] maximum a hundred degrees.

P2: I think we want them as close as possible.

P1: Yeah, but I don't know if we can get them as close as possible. It's a completely different story.

P2: See, what happens is we watch and wait for that one to get about a hundred and then we move the slider back down and that one should stabilise.

P1: Yeah, so [0:05:55.3].

P2: That should stabilise as well.

P1: Pressure seems to be pretty stable at the moment.

P2: [0:06:01.1] system [0:06:02.0] temperature [0:06:04.4] by increasing the slider bar a small step temperature and pressure to stabilise.

P1: Okay.

P2: [0:06:13.9]. So, it's [0:06:18.2].

P1: Sits here for five years. Come back [0:06:24.2]. [0:06:28.9] and some of us ended up with … the oil ended up actually forming soap at the bottom of our flask.

P2: I don't remember that.

P1: Okay, because mine formed a soap at the bottom of the flask when I left it alone for about five seconds. I had to heat it up again and just be like, "Excuse you? What are you doing?"

P2: My favourite was the [0:06:51.1] and watching stuff pass through [0:06:53.7] three hours.

P1: The [0:06:54.4]? Yeah. Oh, poor Helena. [0:07:00.2] at the back so she just went, "Screw this." Pauses [0:07:05.9] 100%. I was tempted to do that, actually. I didn't. Also, you know what's funny is they were complaining about how we had extra work to do when Tiara's just like, "Oh, yeah, we'll do both labs this week." And then everybody ended up pushing for a time while sitting there, like, "I told you this wasn't a good idea. We're all screwed." I'm so sad. I wanted to take samples home but Trace doesn't let us. They were shiny and pretty. I wanted to take them home.

P2: It's purple because most of them are toxic.

P1: Yeah. But they're pretty at the same time. So, have you decided what you're going to take as your elective next term?

P2: I'm not sure yet. I'm thinking actually [0:08:01.8] through the biochemistry and maybe taking what is it, analytical? It's probably not the core [0:08:12.6]. So, it probably isn't [0:08:15.1].

P1: Okay, because I'm thinking about taking biochem but if you look at the example of the schedule, it's absolutely hilarious.

P2: I think Wendy said if you take …

P1: [0:08:31.3].

P2: … the third year one …

P1: What do you mean third year one?

P2: Third-year biochem one, that has the biochem from this semester as its pre-req.

P1: It looks [0:08:43.8].

P2: Yeah, but no, it works better. You actually get a day off. You just have to miss one of the lectures [0:08:48.7] the lab.

P1: But can you take the third year one?

P2: If you meet the pre-requisites and I think the biochem here from this semester.

P1: Because I thought that you would take … oh, actually, I don't actually know [0:09:03.0]. What chemistry is it called? Is it med chem, because med chem actually is [0:09:11.1]? Hang on, I'm just trying to find it because of everything … Do we have a lot of shit clogging up this group chat? I'm not going to lie.

P2: Yeah, that's [0:09:26.6] I don't know if it's CHEM3003 I think.

P1: 3003?

P2: Yeah. So, you look at that and you get Thursdays off.

P1: Yeah, because the next one after biochem is actually CHEM2003, not 3003 and [0:09:44.4].

P2: Yeah, but I think 3003, the only pre req is the current biochem unit we're doing this semester.

P1: I'm going to check that right now because now I'm curious.

P2: Yeah, so am I. I didn't actually check in but it sounds like it's a possibility.

P1: 3003?

P2: Yep.

P1: What unit is it? 3003, Advanced Biological and Medicinal Chem. But what do I need to do in order … we actually can? But somehow, I feel like it's probably better to do …

P2: [0:10:27.3] good timetabling [0:10:29.9].

P1: Is it even a second sem unit? Can we take it second sem? Is that a thing?

P2: No, I'm pretty sure Wendy did [0:10:37.6] my timetable which we're doing in the second set, so.

P1: Yeah, so.

P2: I'd rather do it …

P1: So, these numbers don't look like they're getting any closer.

P2: Yeah, but, [0:10:47.2] the slider and I think it's going to probably increase a little bit more than the other one.

P1: Okay. I'll trust you on this one.

P2: We'll see.

P1: I think you might've had a bit more sleep than me so I trust you on this one.

P2: I don't know. I went to bed pretty late.

P1: I feel that.

P2: And I got up pretty early because of reflection.

P1: I don't feel that because I did mine in 15 minutes and said, "Here, [0:11:11.9]."

P2: Mine was like 20 minutes so I thought I'd get up early just in case.

P1: You know what I'll do? Because I know somebody who's probably done that unit, 3003. I'll go and message him and ask him what it's like and if he thinks it's better to do medicinal first.

Appendix D

Interview with Three Groups of Students Manipulating the Remote Laboratory

Group 1:

Student 1: If doing at home, they will fail because have no idea what to do. But here with the instructors, she can correct it. In the physical labs, the lab demonstrator can correct their problem before they make mistakes.

Jianye: what do you think of the possibility of trying the lab multiple times?

Student 2: at least we don't need to the clean-up.

Jianye: no unpleasant smells like in organic labs.

Jianye: you mentioned that you'd like to try another remote lab, what's your opinion?

Student 1: If it's implemented in the right way, it's explained better, the step-by-step more clear. Jianye: guidance more clear. Pre-instruction about the lab?

Student 1: yes. Flexible for some people.

Jianye: know the concepts. Any questions about data analysis?

Student 2: check the lab manual.

Student 1: I learn a lot more from talking from another person. Almost from you. If I could, if getting the same experiments, (not a different one).

Jianye: do you have any suggestions for the equipment?

Student 1: the colour of the on and off can be differentiated.

Can the two temperatures be signified more, like which one is the inside or outside?

Group 2

Student 1: the waiting time was far too long.

S2: It's probably better when we think it is chemist, while we think its chemical engineering.

S1: because I would like to wait longer to get the proper values. I'd rather wait for them to be stabilised completely so that we can get…

Student 2: but apparently there is no one instruction there. Considering its vaporisation, so it makes sense that it's a boring experiment.

Student 1: yes.

S 1: no, unfortunately, no.

Group 3 Two girls

S 1: I think the condition is that we don't understand much. If I was doing this at home as I would probably get failed because I would not get what I will do. If there is a lab demonstrator, like there, then you actually co.. Try harder because you've got the help right there, you can just use it.

Interviewer: also there's another thing about this lab is that you can do it multiple times,

S1: yes.

Jianye: so at first, you may fail, maybe you can learn from the mistakes.

S2: but the problem is you don't know what the mistake is.

S1: yes. When you are in the lab, you don't make mistakes because you can ask before you do it.

S2: don't think the temperature bar helps. They don't clearly label. I guess if we do it without you beside us, we would keep heating, like out of control. How fast to speeding.

Jianye: I think when they're designing the lab, they are asking you to learn from your mistakes.

S2: it's nice that there is no clean-up, no unpleasant like organic labs.

Jianye: you mentioned that you'd like to do it again.

S1: if it is implemented in the right way, yes. I don't see that there is anything wrong with doing it online, as long as it has to be implemented in the right way. So it’s still interactive, we actually learn something from it. It’s more planned better, I guess?

Jianye: so like the guidance, perhaps, can include more information?

S1: sort of like, just step-by-step, like to do it by yourself?

Jianye: like maybe a pre-lab instruction about …?

S1: I can certainly say that this like people working have a very constrictive timetable, we can say?

Jianye: more flexible?

S1: yes.

Jianye: from this lab, we can still know the concepts. Do u have any questions about data and submission?

S2: read the lab manual. Compare…

S1: also for me I learn a lot from talking to people around me, instead of just by myself. When I am doing by myself, I just like, not so confident. I am the kind of person who’d like to talk with people like you to get a deeper understanding.

Jianye: do you mean that you’d like to have partners in the lab?

S1: I mean if I could, results and the same quality of assignments, I’d like to work in a group or with peers.

S2: is this lab only for today or will end soon?

Jianye: no, it will last for the whole term. So you can try it one more time if you want.