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The Effects of Remote Laboratory Implementation on Freshman Engineering Students' Experience

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

Abstract

Today, learning in the engineering laboratory takes place via face-to-face and distance modes, the latter via the internet. Learning of laboratory skills in any mode of laboratory is influenced by the interactions that occur between the students, instructors and the equipment in the laboratory. Recent innovations have focused on developing new remotely controlled laboratories for various disciplines in engineering studies. These laboratories focus purely on technical aspects and may struggle to provide an environment for the development of personal and professional skills that are also a critical part of an engineering student's education. In this research, quantitative and qualitative surveys were conducted at two Australian institutions to measure first-year students' interactions and capturing their experience in these two contrasting laboratory modes. Quantitative survey data showed that students were more satisfied and valued social interactions more in the remotely controlled laboratory than in the face-to-face laboratory. By contrast qualitative responses revealed that their first preference was still face-to-face laboratories because they valued the importance of gaining hands-on experience of the experiment, working in teams and under an instructor's guidance as an engineering student. Students also preferred remote laboratory work to be introduced at a later stage in their engineering studies when they are conceptually more capable and experienced.

Introduction

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

There are basically three types of interactions in the laboratory: student-student, student-instructor and student-equipment [1]–[4]. The level of these interactions determines the student satisfaction and their engagement in the laboratory. In remote laboratories, students interact with their peers, instruments, and instructors through a platform which is technology-mediated, but in the face-to-face laboratory, all of the interactions take place on-site. Each interaction type contributes to the achievement of specific laboratory skills. For instance, the interaction of students with their peers leads to the development of teamwork and collaboration skills [5], [6], the interaction between students with their instructors results in a better understanding of the concepts and also the ability to follow instructions and finally, interaction with the equipment leads to expertise in engineering instrumentation and experimentation skills [1].

Students learning is strongly directed by the expectations and outcomes set by the society, universities and the accrediting bodies [7], [8]. An engineering student is expected to be aware of technical advancements but at the same time acquire hands-on and social skills that characterize a professional engineer [9]. Engineering laboratories are designed so as to prepare students with all the necessary personal and professional skills through properly planned layered instructions designed for each year or semester. Of all the years of engineering studies at undergraduate level, the first-year is often the most crucial. At this level, students build their foundation of engineering concepts which are later built upon in subsequent years of their degree. The concepts and skills that students are expected to learn in the first-year also greatly influence the retention (or attrition) rates of students in engineering degrees [10]–[12].

Education researchers in the field of remote laboratories have mostly focused on studying the viability of this laboratory mode for educating and preparing students for the future workforce [13],[14]. Remote laboratories have been tested and studied for their effectiveness in meeting their desired goals [15] but only a few studies have focused on the actual learning processes that are involved in reaching those goals [16].

Today, many engineering disciplines are benefitting from significant developments in terms of the technology used in remote laboratories [17]–[20]. Despite this fact, the use of remote laboratories has not been able to reach its anticipated level. This field is still struggling to be widely accepted by students and the institutions where they study [21], [22]. Students are generally found to be excited about working in a technology integrated environment [23], but their main preference still remains to manipulate equipment in person and get direct experience [24] of handling equipment. However, studies have shown that remote laboratories do provide similar learning outcomes as face-to-face laboratories [25], [26] and, on occasions, comparatively better learning outcomes for students and with better reflective ability [27].

Our study is focused on assessing the appropriateness of remote laboratories for first-year engineering students. It is based on a comparison made between students' experience and perception about the interaction possibilities and their relation to the expected learning outcomes from their work in both remote and face-to-face laboratories. We also consider how remote laboratories can be integrated into engineering courses from the students' viewpoint, in order to preserve the essential learning of practical skills and also to make students better prepared for future engineering practices.

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

a. *Is the remotely controlled laboratory implementation appropriate for first-year engineering students*?
b. *Can remote laboratories help in learning essential personal and professional skills?*
c. *What is the best way to integrate a remote laboratory component into a conventional engineering laboratory program?*

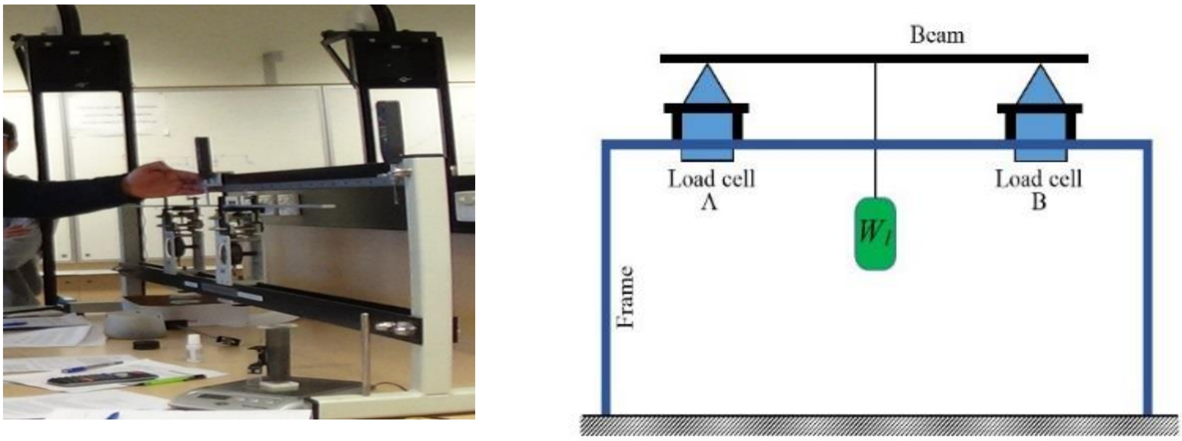
Laboratory activities used in the study

A similar laboratory experiment was identified for first-year students in face-to-face and remote laboratory modes. Both experiments involved two sets of the task to be attempted within 90 minutes of a laboratory session. The main objective of both laboratories was identical, that is, to allow students to investigate the effect of loading on the bending of a beam. Both laboratory modes included students working in a group under an instructor's supervision and a laboratory manual at hand. Students prepared a report after the completion of the experiment. Reports were assessed on the accuracy of data collected and arguments presented in response to discussion questions answered in the report.

Figures 1 (a) and 2 (a) show two different physical setups for the beam experiment; the former is in the face-to-face laboratory while the latter is that which is operated in the online remote laboratory.

Face-to-face laboratory experiment

In each session of the face-to-face laboratory, approximately 12 students in groups of three performed the experiment. One instructor was assigned for each session. In the face-to-face laboratory, shown in Figure 1 (a), students personally set up the beam by supporting it on two load cells. The students manually increase the load applied on the beam and the reaction forces are indicated at the supporting load cells. The arrangement is then used to confirm the equilibrium condition of the beam. This experiment involved two sets of an investigation where the loads were applied at two different positions. A schematic diagram of the experimental setup is shown in Figure 1 (b).



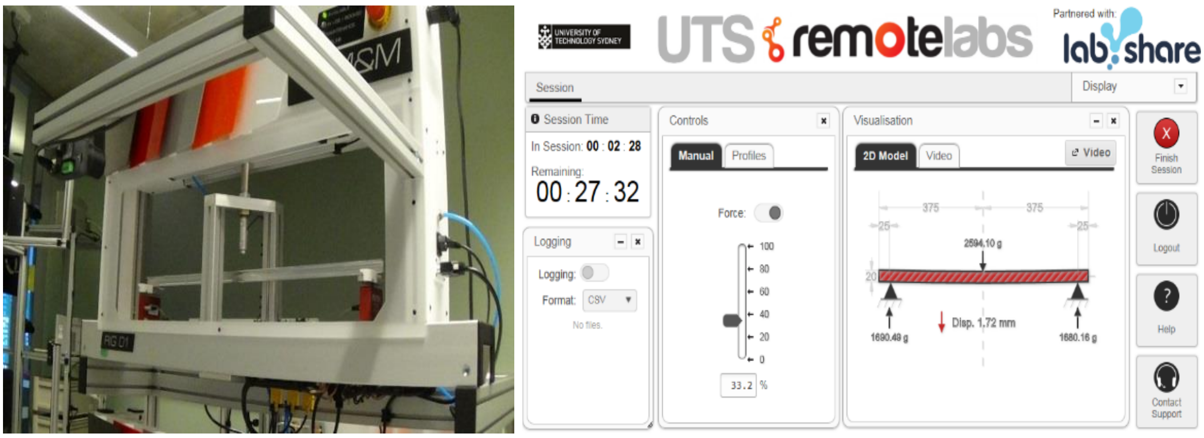
(a) (b)

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

In the face-to-face laboratory there is no fixed time allotted for data acquisition. The students are free to manage their laboratory time within the 90 minutes session.

Remote laboratory experiment

In the remote laboratory, the real equipment, involving an aluminium beam, shown in Figure 2 (a), is situated in Sydney and is accessible over the internet [28]. Students log into the program using their University credentials and log out on completion of the task. Each session of this laboratory accommodated four students to work in two groups (i.e. in pairs) in the presence of an instructor. Figure 2 (b) shows the interface designed for the interaction between the students and the equipment in the remote laboratory.



(a) (b)

Figure 2: Remote laboratory set up (a): Apparatus for beam-bending experiment, (b) Remote interface for students' interaction with the equipment.

This experiment requires students to take recordings of the beam displacement for two types of loading conditions. So each group chose one loading condition at the start and later switched to other loading condition, when the equipment was free to use. The 90 minutes experiment is designed as a single log-in to the interface lasting for 30 minutes for each loading condition, which comprises only data collection. As part of the experimental procedure, students had to apply a force on the beam and record the displacement in the beam, changing force values between 0 and 100 (in %). The interface involved no other task to complete the work.

Research Participants and Methodology

A total of 198 students from the engineering first-year performing the face-to-face laboratory for Engineering Mechanics units were studied for their behaviours and perceptions. In addition, 37 students who conducted remote laboratories were studied to identify variations in their behavior and perceptions. The students were from two different Australian institutions. Students considered for the study comprised a multicultural cohort and came from multiple disciplines of a first-year engineering degree. The remote laboratory was a compulsory part of the laboratory program for 26 out of 37 students. The remaining 11 students were volunteer participants, who first completed the face-to-face laboratory and later undertook the remote laboratory. Students were randomly selected from the 37 participants for interviews.

In order to investigate the proposed research questions, data were obtained quantitatively through the use of survey questionnaires [29] and for triangulation of the quantitative data obtained, semi-structured interviews [29], [30] were conducted. Students who completed both remote and face-to-face laboratories were given a survey questionnaire to capture their actual experience of the interactions in the laboratory. Finally, a semi-structured interview was conducted to understand students' viewpoints regarding the laboratories they had conducted and also to gather their perceptions about effective ways of integrating the remote laboratories in the engineering degree program.

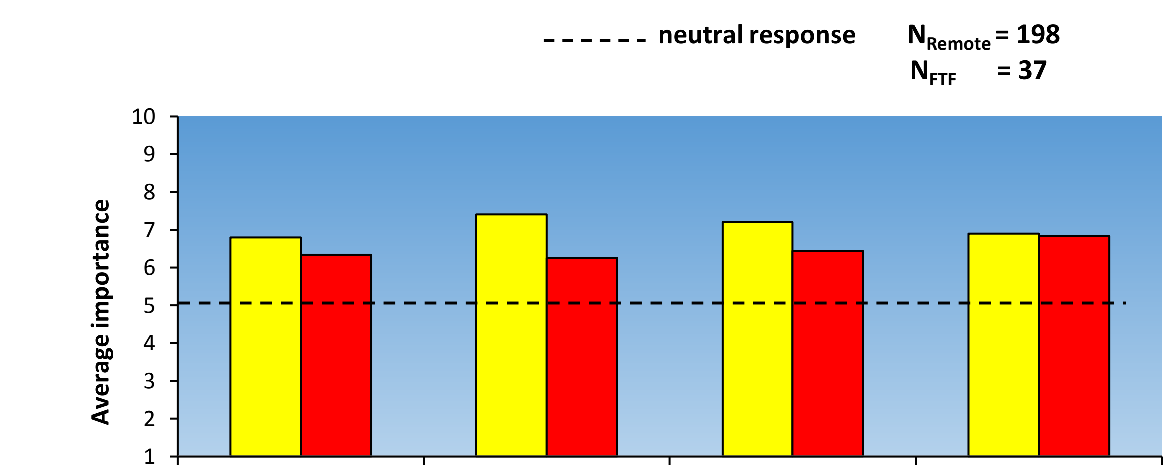
In all the surveys conducted, the focus was on aspects such as the interactions of students during their work in face-to-face and remote laboratories, their perceptions of the significance of the interactions in both laboratory modes and their satisfaction in terms of the interactions experienced in the respective laboratory modes. The survey questionnaire included questions about the various categories of each interaction type, that is, student-student, student-instructor, and student-equipment. The fourth type of interaction studied was an indirect interaction which occurs when a student observes other students' behavior in the laboratory, which may be between two students or between a student and an instructor. As students in both laboratory modes worked in groups, all four interaction types occurred in both laboratory modes. All questions relating to interactions were Likert type questions. Satisfaction and significance for all interactions were rated on the scale of 1 to 10, with 5 representing the neutral response. Appendix A presents the survey questionnaire used for obtaining quantitative data.

Results and Discussion

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

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

The average of responses reported by students for each item in each category of the interactions in the questionnaire was calculated in both modes of the laboratory. The results are shown in Figure 3.



	Student-Student	Student-Teacher	Student-Equipment	Indirect-interaction
Remote lab	6.80	7.40	7.20	6.90
FTF lab	6.34	6.26	6.45	6.83

Figure 3: Average importance perceived for each interaction type (FTF= face-to-face)

It is evident from Figure 3 that students' experiences of interactions were reported as more in the remote laboratory than in the face-to-face laboratory. Interaction between a student and an instructor substantially influenced the students' perception of their learning in the remote laboratory, while the most important interaction in the face-to-face laboratory were the indirect interactions that happened in the laboratory. Students' interactions with the equipment were the second most contributing factor for both the laboratory modes. In the remote laboratory interactions between students with their peers was the least important interaction while in the face-to-face laboratory it was the students and instructor interaction.

Students also expressed their satisfaction for each interaction type, as shown in Figure 4.

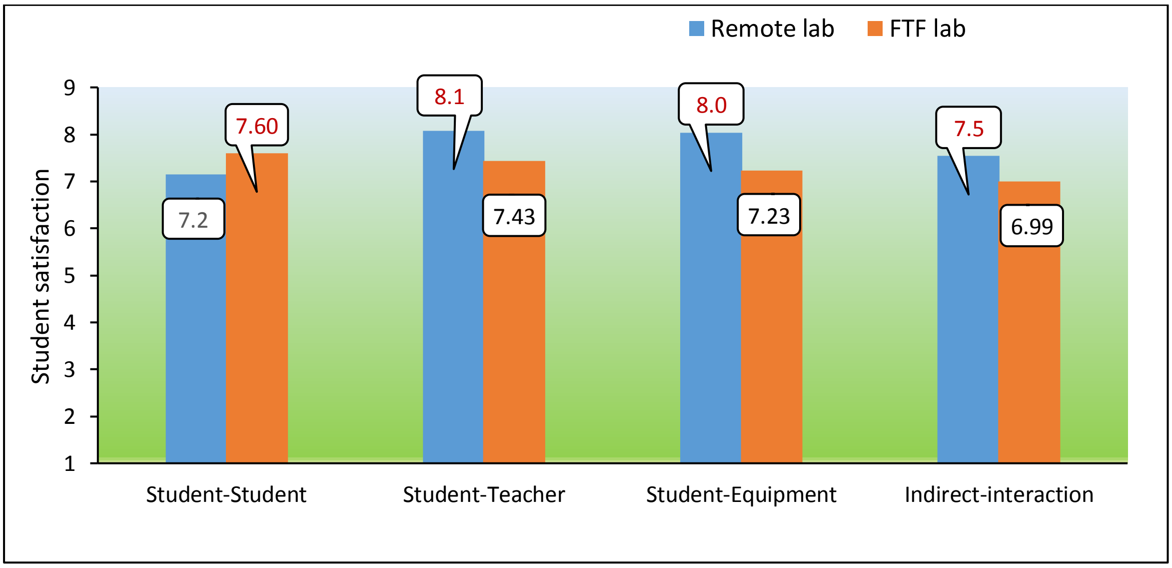


Figure 4: Satisfaction expressed for each interaction type (FTF= Face-to-face)

In Figure 4, students' satisfaction with the remote laboratory exceeds that for the face-to-face laboratory. The satisfaction for student-instructor interaction and student-equipment interaction in the remote laboratory has the highest values of 8.1 and 8.0 respectively.

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

<u>*Students' perceptions about the importance of interactions with instructors and peers*</u>

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

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

"I realized how much I relied on the tutor"

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

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

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

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

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

<u>*Students' perceptions of the interaction with the equipment*</u>

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

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

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

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

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

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

<u>*Summarising students' responses*</u>

It was an interesting coincidence that the majority of the students in both groups had previous awareness of a remote laboratory. Those who did have some knowledge were unaware of the use of remote laboratories in the education sector. When they were asked to compare their experience in two laboratory modes, the majority of students were glad to have experienced the remote laboratory, while some appeared confounded. Students believed they were learning essential skills in the face-to-face laboratory and were more skeptical towards the remote laboratory in terms of skills attainable from the laboratory activity. Being first-year students, they considered that face-to-face laboratories were essential to acquire the basic skills and knowledge at their level. Some of the concerns and benefits of the remote laboratory as reported by students are tabulated in Table 1.

Table1: Benefits and concerns conveyed by students for the remote laboratory

Benefits of remote laboratory	
• Easy to operate • Flexibility in time and operation • Better human error analysis possible • No stress of safety hazards • Feel of real face-to-face experiment • Easy to record data from the experiment • Independent operation possible	• No need of physical co-location • Convenient to begin the experiment • Good for experiments with less setup • Technology enhances better result analysis • Glimpse of future engineering practice

Concerns for remote laboratory	
• No opportunity to set up experiment personally • Difficult for teamwork and lack of real-time instructor support • Assumption that machines are perfect and chances of working on erroneous data • Lack of safety knowledge, and support in emergency • Limited view of the equipment • Time delay between instruction and results	• Feel insecure working alone in remote lab • Physical separation from equipment • Difficulty in logging-in to the system due to internet problem • Not appropriate for experiments with significant setup • Lack of assurance for accurate results obtained • Better if implemented above first-year level studies

Students' opinions about integrating remote laboratories into engineering studies

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

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

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

".... midway through the second year, third year onwards, ... once those basic concepts have been cemented....then maybe remote labs would perhaps be best...."

An argument presented by another student in support of the above response was:

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

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

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

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

Discussion

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

Students' responses further indicated that internet-mediated interactions could also interfere with their acquiring some of the expected learning outcomes such as instrumentation, communication, experimentation, ethics and safety matters, and learning from failures [31].

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

Conclusion

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

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

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

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

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

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Appendix A- Sample of survey questionnaire used for capturing engineering students' perception of interactions in the laboratory

Date: ______________ Time: ____________ Unit: ____

Student ID								Family Name	Given Name(s)

Reflecting on the laboratory class you just completed:

- **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.**
- **Significance: 1= Insignificant; 10= Extremely significant**
- **Do not make any other stray marks on the page**

1. (*Student-Student Interactions*) How significant was talking to another student about…

the procedures, protocols or laboratory equipment?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
the basic theoretical concepts behind the laboratory?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
analysing and interpreting your results?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
engineering topics not directly related to the laboratory?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
general topics not related to the laboratory?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
What was your level of satisfaction with the above interactions?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩

2. (*Student-Instructor Interactions*) How significant was talking to the instructor about…

the procedures, protocols or laboratory equipment?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
the basic theoretical concepts behind the laboratory?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
analysing and interpreting your results?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
engineering topics not directly related to the laboratory?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
general topics not related to the laboratory?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
What was your level of satisfaction with the above interactions?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩

3. (*Student-Equipment Interactions*) At what level of significance, did you...

use laboratory manual/instructions for conducting the experiment?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
use the Internet for laboratory related tasks	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
feel you were operating a real equipment for collecting the data	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
feel difficulty in operating equipment via internet	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
What was your level of satisfaction with the above interactions?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩

4. (*Indirect Interactions*) How significant was your learning by…..

observing other students' operation of the remote laboratory	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
listening to other students discussion	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
listening to other students asking an instructor for help/advice	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
What was your level of satisfaction with the above interactions?	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩

Please provide any feedback/comments for this remotely controlled laboratory and also for the improvement of this laboratory at your study level?

Thank you for your cooperation ☺