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# e-Laboratory for Automation Technology Course in UniMAP: Effective for Distance Education?

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## Abstract

With the high cost of traditional or hands-on laboratory classes, and the need for distance learning in many university institutions, there has been a trend towards providing online laboratory classes through remote or simulated access. An online laboratory class can offer cost savings compared to a hands-on laboratory, and has been made possible by advancements in software and communication technologies. The increase of e-laboratory or (remote laboratory) applications calls for an in-depth evaluation on its effectiveness. The results show that performing an experiment away from the physical equipment can have a significant effect on the student's learning experience while not negatively affecting learning outcomes. The physical separation allows students to learn and interact freely and creates a good opportunity for knowledge transfer. Furthermore, the freedom offered by e-laboratories has also allowed for a student's participation to be more involved with the laboratory experiment. Results also suggest that e-laboratories are comparable in effectiveness to hands-on laboratories, at least in teaching basic applications of course content, and are sufficient on their own.

Keywords: e-laboratory, practical intelligence, hands-on laboratory, remote laboratory, laboratory exercise

## Introduction

### *Laboratory Class in Engineering Course*

In the engineering profession, the main task is to manipulate material and energy for the benefit of humankind (Feisel and Rosa, 2005). This task will successfully be achieved if the engineers, technicians and others have knowledge and experience related to the specific engineering field. Therefore, at university or college level, engineering education plays important roles to produce related knowledge and experience for engineering students (Chen and Chen, 2013).

One of the most important factors in forming professional engineering qualities is the practical component of the engineering curriculum. To achieve these qualities, laboratory classes are valuable learning tools, which can effectively be used in an attempt to teach the link between practical skills and theory (Zol Bahri and Trevelyan, 2007). Work in the engineering laboratory environment provides students with opportunities to validate conceptual knowledge, to work collaboratively, to interact with equipment, to learn by trial and error and to perform analysis on experimental data (Su, 2006). According to Webb (2003) the underlying value of laboratory classes is that they provide a fundamentally different context for the students' learning. In a laboratory class, their environment is different compared to other learning modes, such as lectures or tutorials. They engage with the real hardware, components and materials; they embed their learning into a different context, and construct different knowledge as a result.

***From Real to Virtual to e-Laboratory (or Remote Laboratory)***

Work in a real laboratory imposes scheduling and physical restrictions both for students and academic staff. It requires significant scheduling effort and financial investments. Therefore, virtual or simulation and remote laboratories are becoming increasingly common alternatives in current undergraduate engineering courses (Trevelyan, 2013). The virtual laboratory provides a simulated environment. Many software packages have been developed for the simulation of real experiments. The simulators proved themselves to be beneficial for effective explanations of theoretical concepts; for conducting experiments step-by-step; as an interactive medium; as flexible, easy-to-use tools; and as a low cost alternative because of the lack of time and physical restrictions (Nedic, Machotka and Nafalski, 2003).

Although well-designed virtual laboratories can be very useful and simulations are indispensable in deepening students' conceptual understanding, they are generally considered to be a poor replacement for the practical work performed in a real laboratory. e-Laboratories (e-labs) are a relatively new development concept, but their numbers are exponentially increasing due to recent technological progress and availability of tools for their design. They represent the best alternative to working in a real laboratory because, if properly designed, they can offer students the opportunity to perform experiments on real equipment, to collaborate, to learn by trial and error, and to perform analysis on real experimental data. Additionally, e-laboratories can provide a tele-presence in the laboratory as well as the flexibility to choose the time and place to perform experiments (Nedic, Machotka and Nafalski (2003).

According to Trevelyan (2013), some incentives for implementing e-laboratories include:

1. Widely available laboratory experience outside the universities in which they are developed;
2. The provision of worldwide access for students and researchers in poor and developing countries;
3. Flexible delivery, allowing students to work on the laboratory at times that best suit them; and
4. Improved learning effectiveness by allowing better sequencing with lecture material. Often timetabling restrictions mean that a laboratory is run over several weeks; therefore, the completion of a laboratory may not coincide with lectures pertaining to the relevant material. Online laboratories can be completed as a series of short tasks, tied closely to tutorial questions and lecture material. This longer-term learning strategy gives a student time to digest information and has the potential to significantly improve learning effectiveness.

***Pedagogical Issue in the Electronic Delivery Method***

Although there is a slow trend to shift from real to e-laboratory classes, little attention has been paid to the pedagogical differences caused by this shift. In a recent study by Lindsay (2005), he showed that e-laboratory classes are introducing distance and technology-mediated interfaces into the laboratory environment. Each of these factors has been shown to have an impact upon learning outcomes. He insisted that the learner constructs their reality from the situations and scenarios that they encounter; their understanding is based on their experiences. Different experiences will lead to different constructions; two learners who encounter different material will learn different things, but, based on their past experiences, two learners who encounter the same material will assimilate it differently.

### *Concerning Current Technology of Delivering Laboratory Classes*

There has been a long debate on whether current technology can replace the conventional method of delivering laboratory classes. It is clear that the choice of laboratory technologies, i.e., simulation or e-laboratory, could change the economics of engineering education, and it is also clear that changing the technology could change the effectiveness of education (Nickerson et al., 2007). According to Corter et al. (2004), researchers on the hands-on mode think that engineers need to have contact with the apparatus and that laboratory should include the possibility of unexpected data occurring as the result of apparatus problems, noise or uncontrollable real-world variables. While simulation researchers often begin by invoking the spectre of cost, hands-on laboratories take up space and impose time and location constraints. Many educators claim that simulation is not only cheaper, but it is also better in that more laboratories can be conducted than with hands-on laboratories.

## Research Objective

The aim of this research is to evaluate the effectiveness of remote laboratories in distance education. In particular, aspects of an e-laboratory are compared to a hands-on laboratory. Strong emphasis is placed on the experience gained by the students from performing the laboratory. The comparison is carried out through the analysis of student feedback and their observations.

## Research Methodology

### *Selection of Experiments*

Two experiments from the Mechatronics course were chosen for comparison and analysis. Both experiments are independent of each other – students are not required to complete the two experiments in a particular order, hence their knowledge is assumed to be independent. This independence is important, especially when analysing the data from each experiment. Thus, it is necessary to select other experiments that are different in concepts and approach of laboratory to provide an independent evaluation of each laboratory outcome. More specifically, this study aims to provide comparisons – remote (e-laboratory) vs. hands-on laboratory.

*Samples*

The main e-laboratory exercise studied in this research is part of Mechatronics Systems syllabus, a second year Mechatronics course at The University of Western Australia. Therefore, the sample population for this research is students of second-year Mechatronics Engineering.

*e-Laboratory vs. hands on laboratory*

The comparison between a purely e-laboratory and a hands-on laboratory aims to reveal any possible difference in student outcomes due to the lack of physical proximity and interaction with the real equipment. This includes exploring the important aspects that students forego during the physical separation.

### ***e-Laboratory Experiment***

*Aim of the e-laboratory*

The aim of this e-experiment is to introduce the idea of implementing a finite state machine on an online control system. The objective of this laboratory exercise is to design an automated control system for the process of filling, measuring and dumping sand. This e-laboratory exercise incorporates concepts like discrete control, program timing and delay, remote access control of equipment and further practice for programming in LabVIEW.

Students complete the laboratory experiment individually without direct assistance from tutors. There are no appointed laboratory sessions, but one tutorial session was arranged for students to seek help with programming. Students were also given an introduction to the machine during a lecture, an opportunity to experiment with the machine during a tutorial session and a recorded list of questions and answers for reference on the unit webpage.

*e-laboratory software setup - clients*

An e-laboratory experiment is created for students to design an automated control system using the sand-weighing machine. The laboratory experiment aims to provide students with a practical experience from theories and concepts introduced in lectures and tutorials. Guidelines and handy tips were included in the laboratory sheet to assist students in getting started. A new Hardware Client and Remote Client are designed for this e-experiment as Figure 1 and Figure 2.

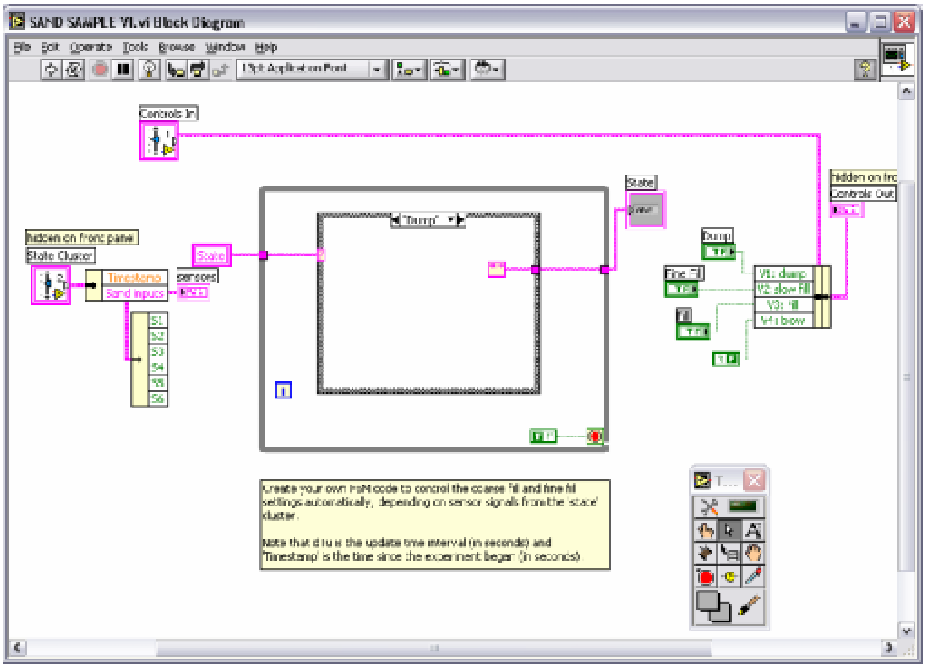


**Figure 1**: Screen of LabView Remote Client (e-Laboratory Software).

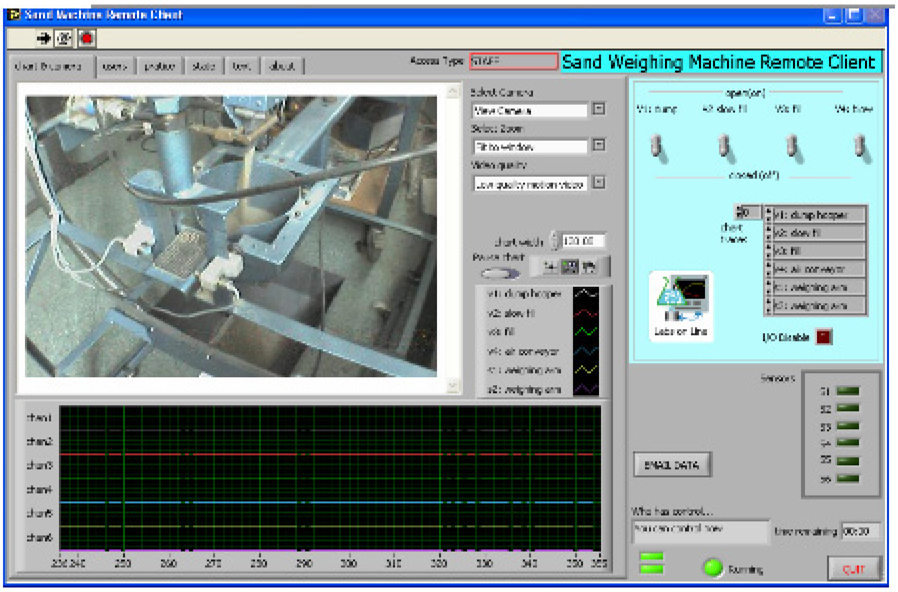


**Figure 2**: Screen of LabView Hardware Client (e-Laboratory Software).

*e-laboratory hardware setup – sand-weighing machine*

In this research, the sand-weighing machine (Figure 3) is used as Mechatronics e-laboratory setup. Its basic function and operation is to measure an amount of sand and dump it into a bag. The sand-weighing machine consists of 4 independently controlled pneumatic actuators – coarse fill, fine fill, dump and blow (compressed air). These actuators are controlled via the interface in the Mechatronics laboratory. There are six sensors attached to the machine – 4 motion sensors and an ultrasonic gage providing two output signals.

*Methods of e-experiment*

The aim of this experiment is to run the sand-weighing machine (Figure 3) remotely by using the e-laboratory software (through Internet). The hardware of the sand-weighing machine is in another laboratory or university (potentially thousands of kilometres away). Once student (or user) turns ON the Hardware Client (Figure 2) in the e-laboratory software, remotely the sand-weighing machine is turned ON and the e-laboratory experiment begins. Then, the student continues the experiment by following the e-lab hand-out and collecting the real data from the sand-weighing machine equipment. All the processes and sensors are controlled by the e-laboratory Remote Client (Figure 1).

However, it is not easy to decide whether experiences in e-laboratory contribute towards a foundation for practical engineering. One cannot be sure about what students will miss or gain when moved from hands-on labs to e-labs or simulations (Gillet, Latchman et al., 2011; Colwell, Scanlon et al., 2012; Nedic, Machotka et al., 2003). Thus, in order to improve the learning experience of the students while performing the laboratory experiment, a camera was placed beside the sand-weighing machine to enable the students to view and feel the operation of the machine remotely as if they are doing it hands-on. Students are able to view the process of filling and dumping, and to view the increasing or decreasing level of sand in the bottom hopper from the view angle provided.

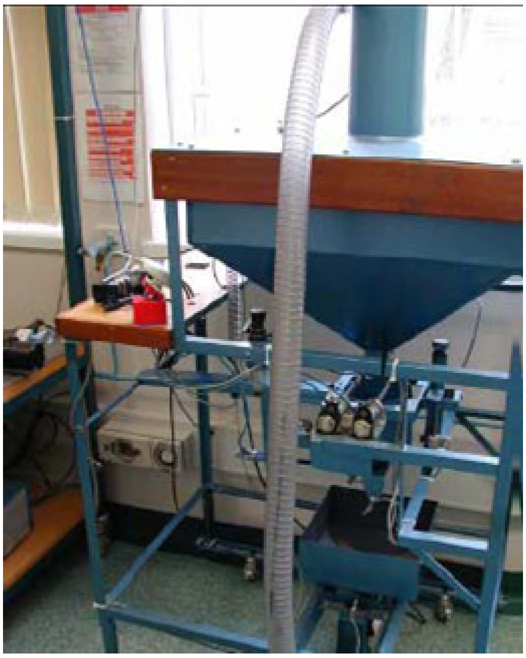

**Figure 3**: Sand-weighing machine (e-Laboratory Hardware).

***Hands-on Laboratory Experiment***

*Aim of the hands-on laboratory*

The objective of this laboratory experiment is to help students develop an understanding of theoretical concepts related to Fluid Mechanics and pumps. This laboratory is conducted in groups led by a demonstrator. Students interact with the pump system by identifying each component of the pump and its functions. They record data from the pump during operation in order to generate a system curve. Towards the end of the laboratory session, a short discussion was held between the students and the demonstrator to discuss possible sources of error and a short analysis on the curve.

*Laboratory setup - thermofluid pump rig*

The pump rig is installed in the Mechanical engineering laboratory and consists of a Gould's 3196 MTX model chemical process centrifugal pump (Figure 4).

**Figure 4**: Thermo fluid pump rig

## Results and Discussions

The objective is to gather information regarding student outcomes from their involvement in e-laboratory and to compare these outcomes with those from the hands-on laboratory. Three methods were devised to assess the student outcomes: student observations, interviews and surveys. The contents of the survey instrument were developed based on the transcript of the observation and interviews. Students' outcomes, learning experiences and feedback from the laboratories were compared for analysis. For the survey, there are two types of evaluation: PRE and POST evaluation. PRE evaluation is performed before the students run the laboratory, and the POST evaluation after performing the laboratory.

### *Method of Evaluation*

#### *Student observations and interviews*

Student observation and interview were designed to be complementary of each other. The aim of the student observation is to understand problems students encounter and the approaches taken. It is also aimed at picking up issues and observations that students might not be able to verbally explain or recall during the interview. For the sand-weighing machine, the author observed students while they were completing the exercise in the department computer laboratories, either individually or in groups. The students did not receive any direct assistance from the author during the observation, which would affect their learning behaviour, exploration and learning outcomes.

During the informal interview sessions, some students commented on the convenience provided by the remote access feature of the laboratory. Several of the participants interviewed said:

> …interesting and easily accessible.
> Remote labs provide no time constraint in completing the exercise and more opportunity to explore the equipment.
> The flexibility gave me more time to think about the concepts in the exercise.

Other students preferred a traditional laboratory setup.

> …second rate. You can’t truly get a feel for how a piece of equipment works without seeing it operate in real life. A camera image without any sound does not convey the same information.
> Students who had access to the laboratory itself found a solution to the problem above.
> I chose to work on the computer right next to the machine so that I can get a good view of the machine working.
> Although a camera image did not convey the same information as direct visual feedback, another student found it useful.
> Having the camera view helped a lot. I didn’t get a very detailed introduction to the physical machine

*Survey*

The custom-made surveys were a quick and relatively easy form of student feedback evaluation. They were designed to be as easy to complete as possible, comprised of quantitative and qualitative questions. Figure 5a and Figure 5b show samples of survey questions for e-labs and hands-on exercises, respectively.

**Sand Machine**

| | Strongly disagree | | | | Strongly agree |
|---|---|---|---|---|---|
| 1. I understand the behaviour of the sand weighing machine. | 1 | 2 | 3 | 4 | 5 |
| 2. I feel confident modeling the sand weighing machine as a more exhaustive (detailed) finite state machine. | 1 | 2 | 3 | 4 | 5 |
| 3. I feel confident modeling another mechatronics system as a finite state machine. | 1 | 2 | 3 | 4 | 5 |
| 4. Given any finite state machine, I can implement it in LabVIEW. | 1 | 2 | 3 | 4 | 5 |
| 5. I now understand how to design a discrete control system. | 1 | 2 | 3 | 4 | 5 |
| 6. I feel confident to suggest and discuss reasons why the sand machine might fail mechanically. | 1 | 2 | 3 | 4 | 5 |
| 7. I feel confident to suggest and discuss timing and delay issues. | 1 | 2 | 3 | 4 | 5 |

**Figure 5a**: Sample of sand machine exercise survey.

**ASSESSMENT OF STUDENT LEARNING FOR THE PUMP COURSE**

The aim of this survey is to assess if changes made to the pump course (TF306) in 2005 have improved the student learning experience and achievement of specific outcomes. This assessment will be made through graded answers to specific questions and written work allowing students to reflect on the course.

The survey will be used to:

a. Gather feedback from the students related to specific course outcomes.
b. Assess the success or otherwise of the revised course.

NAME: ____________________________ STUDENT NO: ___________

1. Given a pipework system I would be confident in determining the system curve.

| Strongly Agree | | | | Strongly Disagree |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

2. Given a pipework system I would be confident in selecting an appropriate pump.

| Strongly Agree | | | | Strongly Disagree |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

3. I feel confident in contacting pump suppliers for technical information.

| Strongly Agree | | | | Strongly Disagree |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

4. I feel confident to suggest reasons for low-flow problems within a pump system

Strongly Agree — Strongly Disagree

**Figure 5b**: Sample of hands-on exercise survey.

## *Result of the Evaluation*

### *Analysis for e-experiment*

Based on the observations and interviews, the survey instruments were developed. Students were asked to answer the experiment objectives component of the survey before (PRE) and after (POST) performing the laboratory, by rating each question with a number from a scale of one (Strongly Disagree) to five (Strongly Agree). Only ratings above four were considered to be a significant achievement of the student. For example, Figure 5a and Figure 5b show the samples of the survey question given to the students before and after performing the e-Laboratory and hands-on laboratory, respectively.

There were 24 surveys collected and analysed for the Sand-Weighing Machine laboratory experiment. Results from the sand experiment indicated a positive learning experience from students. An almost perfect achievement was obtained for equipment understanding – 96% of the students rated that question with at least a scale four. Table 1 shows the relationship between the PRE-test and POST-test score for the achievement of Sand-Weighing Machine experiment. Additional results of the experiment objectives of the exercise obtained can be seen in Figure 6.

**Table 1**: Relative participation in e-experiment

| Relative Participation in e-Experiment | Percentage |
|---|---|
| Participated more in e-exercise | 50% |
| Participated equal amount | 40% |
| Participated less in e-exercise | 10% |

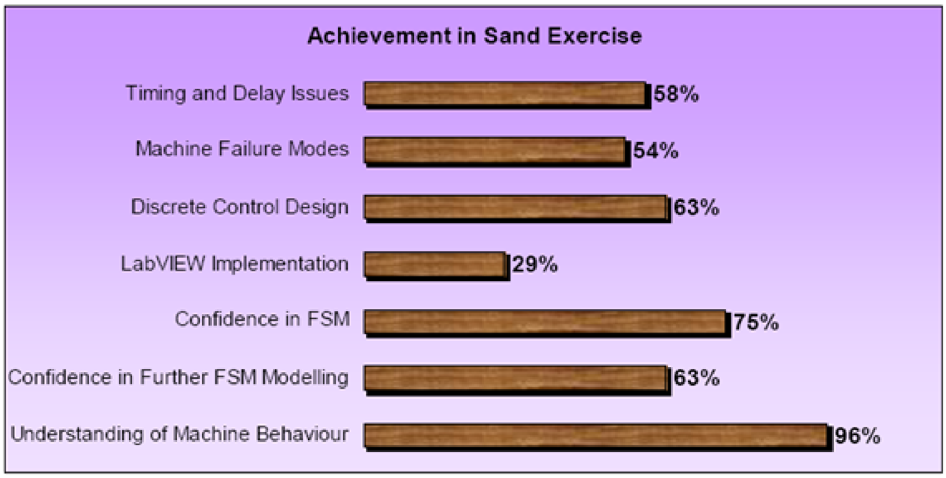


**Figure 6**: Achievement in sand machine experiment.

A distinct disappointment from the remote experiment is the failure to develop the student's LabVIEW programming skills. Only 29% of students recognised an improvement in their LabVIEW skills, and more than half the class felt that the remote experiment contributed otherwise.

*Relative participation score with e-Laboratories*

Students were asked to rate their relative participation score in the e-Labs experiment and the average participation in other conventional hands-on laboratories in their experience. The level of participation involves the time spent directly with the experiment and the level of interest towards completing the experiment. Participation scores can be found in Table 2, where the relative difference between student's score and experience and participating score are significant and where the significance level is 0.001 and 0.000, respectively. The results show that the students are proponents due to the experience gained and the e-Laboratory participation.

**Table 2**: Comparison of outcomes between e-Laboratories and Hands-on laboratories

| Average Weighted Outcome | % | Mean | Std Dev |
|---|---|---|---|
| Sand machine remote exercise | 63 | 0.7488 | 0.1158 |
| Pump hands-on laboratory | 57 | 0.7487 | 0.1262 |

*Analysis for hands-on experiment*

For the thermo-fluids pump experiment, course objectives of the laboratory obtained an average achievement of 57%. The pump laboratory seems to have failed to build a deep understanding of the pump system in the students. Only 22% felt confident (ratings of scale four and above) to perform further analysis on the pump. Apart from further analysis on the pump, the laboratory has quite successfully achieved its course objective outcomes with an average of 65%. The outcome of each objective is uniform across the entire class.

## Comparison of the Outcomes of the Experiments

With all the relevant literatures in mind and also in response to the student survey, two effective thermofluids laboratories have been designed. They incorporated the principles of student focussed teaching and will be something from which students can enjoy learning about fluid mechanics, pump theory and application. They are directly applicable to practical life, as the pump rig differs from an industrial pump system only in scale. This fact is clearly explained in the procedure notes and will be stressed by the demonstrator.

### *Sand Machine vs Pump Laboratory Experiment*

The average achievement from the e-Labs experiment is 63% and the average achievement from the hands-on is 44% (Table 3). Judging from this percentage alone, the remote experiment is more successful than the pump laboratory in achieving its laboratory objectives. From this alternative percentage, it can be concluded that students complete both laboratories with an equal sense of achievement.

**Table 3**: Results of comparisons (Hands-on vs. e-Lab)

| No | Analyses | Mean | Std. deviation | Sig. (2 tailed) |
|---|---|---|---|---|
| 1 | Pre-test<br>(e-Labs vs.<br>hands-on) | <br>56.65<br>64.00 | <br>15.97<br>18.07 | <br>p = 0.078 |
| 2 | e-Labs group<br>(pre-test vs.<br>post-test) | <br>56.65<br>44.15 | <br>15.97<br>11.48 | <br>p = 0.000** |
| 3 | Hands-on group<br>(pre-test vs.<br>post-test) | <br>64.00<br>62.65 | <br>18.07<br>16.90 | <br>p = 0.076 |
| 4 | Post-test<br>(e-Labs vs.<br>hands-on) | <br>44.15<br>62.65 | <br>11.48<br>16.90 | <br>p = 0.000** |

**Significant at the 0.01 level (2-tailed).

Referring back to Figure 6 and Figure 7, it is clear that the percentage outcomes from the sand experiment are more varied compared to the pump laboratory. Students from the e-Laboratory experiment achieve outcomes similar to each other and with greater success, despite the larger variation in the number of objectives achieved compared to the hands-on laboratory. Students from the hands-on laboratory complete the laboratory with more well-rounded skills compared to that of the e-Laboratory. Hence it can be concluded that the e-laboratory was more effective in emphasising certain course objectives than others, while the hands-on laboratory was effective in obtaining a uniform achievement from students. The e-Labs experiment was particularly successful in developing an understanding of the machine behaviour. Students were free to explore the functions of the machine and the controls on their own time schedule.

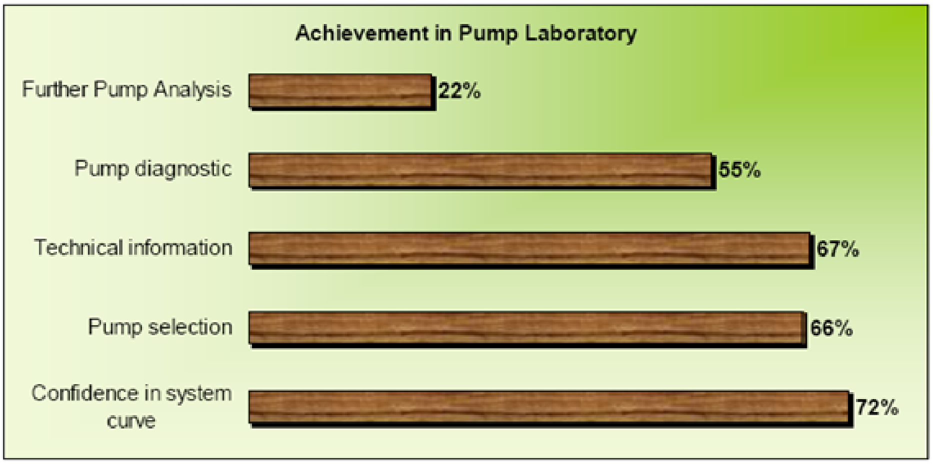


**Figure 7**: Achievement in pump laboratory experiment.

### *e-Laboratory Experience*

Students completing a remote experiment would not be able to experience the sound, feel and visual feedback of controlling equipment manually. The video feed will only be able to provide an image feedback of the equipment and if necessary, a microphone can be integrated into the remote client to provide audio feedback. Although students have commented about the lack of hands-on touch and direct visual feedback from an e-laboratory, the only impediment was the unsatisfactory view angle of the webcam. There was no evidence of any negative impact on learning outcomes due to the lack of a hands-on approach in the e-laboratory experiment.

For instance, during the e-laboratory approximately 70% of the students had the opportunity to control the robot using the teach-pendant. As the students controlled the robot, they observed the behaviour of the robot arm, felt the sensitivity of the robot speed with the joystick movement and developed an understanding of the robot's design. Some students have also taken the opportunity to test the robot's position limits and were able to observe errors that appear on the teach-pendant. Students who controlled the robot gained significant understanding and were observed to be capable of transferring their understanding to other students using verbal explanations. These experiences gained from the laboratory will not be an indication of a student's outcome from the laboratory, as traditional laboratories only aim to assess a student's academic outcome and formal knowledge. However, these practical and safe working experiences become important as students transition into the industry as engineers.

Students were also observed to be keen to complete the hands-on laboratory as soon as possible. A significant number of students were excited to finish the whole procedure and did not pay significant attention to the laboratory session. These students often required concepts and procedures to be repeated. Some of the students who were confused about certain concepts did not bother to pursue clarification from the tutor. They were quite happy to leave the laboratory in a semi-confused state as long as other group members had the data and understood the concepts. These students believed their questions could be clarified by their peers after the laboratory session because they felt constrained from asking for further explanations in the laboratory.

When finally implemented online, the focus will be on allowing remote control of the valves, fittings and the variable speed drive, with data logging from the pressure transducers and flowmeter. Web cams will establish visual contact with the experiment. By taking a particular interest in student learning, it is hoped that the resulting laboratories will be an enriching educational experience for both the thermofluids students and the staff who conduct them.

***Constrained Learning in Hands-on Laboratory***

One of the arguments for a traditional laboratory setup held in the laboratory itself is the real laboratory environment that students experience. This includes being able to observe and appreciate ergonomic placement of control panels, displays, and equipment, health and safety practices, and the basic ability to recognise and identify common symbols and displays. The aim was to introduce students to common issues and safe working practices likely to be found in the engineering industry. A simple and common example would be the need for enclosed footwear, safety glasses and occasionally, helmets. During the pump laboratory, students were specifically advised on a list of general safety guidelines and hazard identification involved with the laboratory. Students were instructed to follow a safety checklist throughout the operation of the pump system as they change controls and turn valves on and off. A significant laboratory experience would be the sound of the pumps and the pressure in the valves as students try to turn it to open or close.

However, student ignorance for general laboratory environment was observed for the e-laboratory. Before the start of the laboratory session, approximately 80% of the students triggered the optical sensor enclosing the robot area. The robot controls would be automatically turned off, an error message appeared on the teach-pendant and warning beeps sounded from the control unit. For the 80% of students who triggered the sensors, only 10% noticed the warning beep and then took notice of the optical sensors.

When the laboratory session was started, the laboratory demonstrator specifically highlighted various safe working practices of the robot to the students. Unless distinctively noted, students generally ignore the laboratory environment and safety practices. Supporting evidence to this conclusion would be the small number of students who turn up to the laboratory without enclosed footwear.

A structured group laboratory restricts individual learning and general communication between students. The pace of a hands-on laboratory is often determined by the laboratory demonstrator. Most students felt pressured to follow the flow of the laboratory session dominated by the average student and hence fall behind on the understanding of the concepts presented in the laboratory. This is where the benefits of remote access to the equipment become important – students who missed out on certain items during the laboratory are given a second chance to develop their understanding after the laboratory.

### *Preference for Different Laboratory Modes*

Students were asked to comment on their experiences with both components of the laboratory – hands-on and electronics. Figure 8 shows 31% preferred a conventional hands-on laboratory where they can obtain 'immediate visual feedback'. This group of students found the video feed not very beneficial and the lack of an available laboratory demonstrator to answer any queries to be a major limitation of an e-access laboratory. A significant number of students have also highlighted their preference for direct contact with the equipment itself, describing the e-laboratory experience as “detached” compared to a hands-on laboratory.

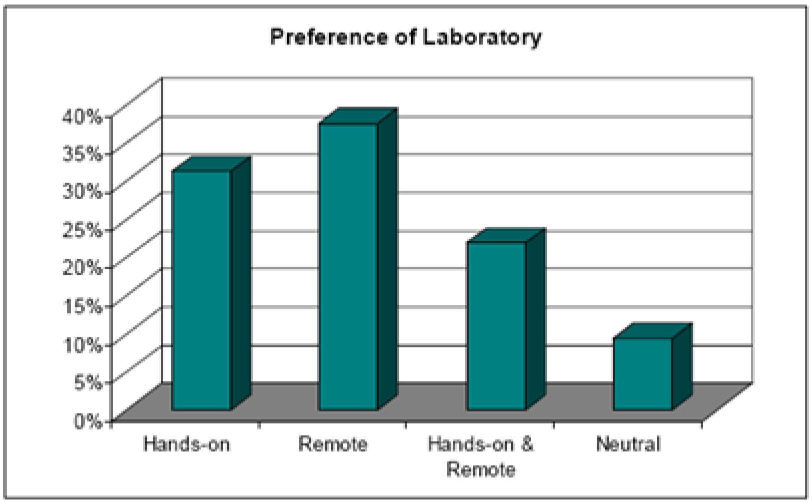


**Figure 8**: Preference for different laboratory modes.

On the other hand, 38% of students prefer the convenience offered by the e-laboratory. They enjoy the opportunity to work on the experiment at a remote location and at a convenient time. A few students found the remote access design an “excellent learning tool for control” and a good opportunity to allow further exploration. Some of them commented that the remote access allowed results to be checked after the laboratory session and the experiment has ended without the pressure of being in a laboratory situation where time contributes to pressure to follow the flow of the laboratory.

In order to assess the educational developments of the new laboratory classes, it is recommended that students be surveyed at the conclusion of the mode of laboratory for the course next year. The survey should ask students about their enjoyment of the laboratories and additionally whether they found them educationally beneficial. Most importantly, the survey should encourage students to make written suggestions for the designers.
The design of a laboratory class is an iterative process and findings from the follow-up survey should be implemented for the following class of students. Despite how carefully objectives are planned before the

laboratory is devised, student achievement can only really be seen once they have tried the laboratory.

## Conclusion

We have outlined a testing on the relative effectiveness of hands-on and e-laboratories, and we have discussed results from the assessment study that directly compared remote and hands-on laboratories in the context of a single course. This focused comparison, though limited in scope, allows for carefully controlled comparisons of the two laboratory formats because exactly the same students take part in both types of laboratories.

The results of this study were encouraging. More than 90% of the student respondents rated the effectiveness and impact of the e-laboratory to be comparable (or better) than the hands-on labs. The e-laboratory has effectively tested the students' conceptual knowledge, allowed them to work collaboratively on the problem, interact with the equipment, learn by trial and error and allowed the students to perform analysis on real experimental data.

Results of this study substantiated those of Corter, Nickerson et al. (2004) that e-laboratories have provided increased access to equipment for students. No longer are students constrained to learn within a group like in traditional hands-on laboratories. With e-laboratories students can perform and repeat the experiment at any time and any place convenient. Students have also found more freedom in exploring the equipment's behaviour and control as opposed to being spoon-fed with important information. Although some students feel a "detachment" from the physical machine, the learning outcomes have not been affected and the learning experience has improved. Students have also gained the experience of controlling equipment remotely.

The freedom offered by e-laboratories has also encouraged students to be more involved with the laboratory experiment. Although there is an effect of physical separation with the real equipment, the effect only presents when students are required to troubleshoot or diagnose errors from their design and the equipment itself. Results suggest that remote labs are comparable in effectiveness to hands-on labs, at least in teaching basic applications of course content and are sufficient to stand on their own, independently.

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