المحور الرابع: الابتكار والمشاركة من أجل تعلم أفضل.

Theme IV: Creativity and Engagement for a Better Learning.

e-Laboratory for Mechatronics Engineering Courses: An Innovative Laboratory for Distance Learning

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Abstract: High cost of traditional or hands-on laboratory classes and the need for distance learning in many university institutions has been a trend towards providing online laboratory classes through electronics access. Aligned to this trend, Universiti Malaysia Perlis started a project to develop and test new technologies for student learning using the internet, including a substantial effort in electronics access laboratories (e-Lab). The e-Lab class can offer cost savings compared to a hands-on laboratory and has been made possible by advancements in software and communication technologies. However, some significant limiting factors have become apparent. The technology has not been widely adopted elsewhere. Nearly all engineering laboratory classes still follow traditional patterns, as do lecture and tutorial classes. Therefore it is worth asking why the adoption of such an attractive technology has been so much slower than expected. To answer this question we started a project to understand more about the practical learning outcomes from traditional and e-Lab classes. When we measure practical intelligence (experience) in e-Lab classes, we not only found we could measure a significant gain in e-Lab practical intelligence, but also predict students' ability to diagnose equipment faults. For the first time, therefore, we can demonstrate that there are real advantages inherent in e-Lab classes and we can measure this advantage. It is possible that measurements of practical intelligence may reveal novel and more powerful ways for students to acquire practical knowledge and skills. Results show that performing an experiment by e-Lab or away from the physical equipment can have significant effect on the student's practical intelligence (learning experience) while not affecting learning outcomes. The physical separation allows students to learn and interact freely and creates a good opportunity for knowledge transfer.

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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, 2003).

One of the most important factors in forming engineering graduate qualities is the practical component of the engineering curriculum. To achieve these qualities, laboratory classes are valuable learning tools, which can be used in an attempt to teach the link between practical skills and theory effectively (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). Regarding to (Webb, 2003) the underlying reason for the value of laboratory classes is that they are 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 laboratory to remote or e-Laboratory (e-Lab)

Work in a real laboratory imposes time and physical boundaries both for students and academic staff. It requires significant scheduling effort and financial investments. Therefore, remote and simulation laboratories are becoming increasingly common in the teaching of undergraduate engineering courses (Trevelyan, 2003). With all the focus on hands-on learning, learning by doing and the practical and personal skills a student can learn in the laboratory, it seems strange to remove the student again by implementing an online laboratory (Webb, 2003). However, a number of motivations are cited for the development of e-Lab. According to (Trevelyan, 2003) some incentives for implementing e-Labs include:

- Distance learning can make laboratory experiences more widely available outside the universities in which they are developed.
- It provides worldwide access for students and researchers in poor and developing countries.
- Flexible delivery, allowing students to work on the laboratory at times, which best suit them.
- Improving 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 improve learning effectiveness significantly.

Pedagogical issue in online delivery method

Although there is a slow trend to shift from real to e-Lab 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-Lab 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 learners constructtheir reality from the situations and scenarios that they encounter; their understanding is based on their experience. Different experiences will lead to different constructions; two learners who encounter different material will learn different things, but for some instance, based on their past experiences two learners who encounter the same material will assimilate it differently.

Concerning about current technology of delivering laboratory classes

There has been a long debate on whether current technology can replace conventional method of delivering laboratory classes. It is clear that the choice of laboratory technologies, i.e simulation or e-Lab, could change the economics of engineering education, and it is also clear that changing the technology could change the effectiveness of education (Nickerson, Corter et al., 2004). Referring to Corter, Nickerson et al. (2004), researchers on hands-on mode think that engineer needs to have contact with the apparatus and that labs 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, 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 e-Labs in distance education. In particular, aspects of an e-Lab are compared to a hands-on laboratory. Strong emphasis is placed on the experience gain by the students from performing the laboratory. The comparison is carried out through the analysis of students 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 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 from each other to provide an independent evaluation of each laboratory outcome. More specifically, this study aims to provide comparisons – e-laboratory vs. hands on laboratory.

Samples

The main e-Lab exercise studied in this research is part of Industrial Automation syllabus, a second year of Robotics and Automation Technology Programme, at Universiti Malaysia Perlis. Therefore, the samples for this research are students of second year Robotics and

Automation Technology.

e-laboratory (e-Lab) vs. hands on laboratory

The comparison between a purely e-Lab and 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 foregone during the physical separation.

e-Lab experiment

Aim of the e-Lab

The aim of this remote or electronically 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-Lab exercise incorporates concepts like discrete control, program timing and delay, remote access control of an 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 play around 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 setup

An e-Lab experiment was designed 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-Lab experiment as Figure 1 and Figure 2.

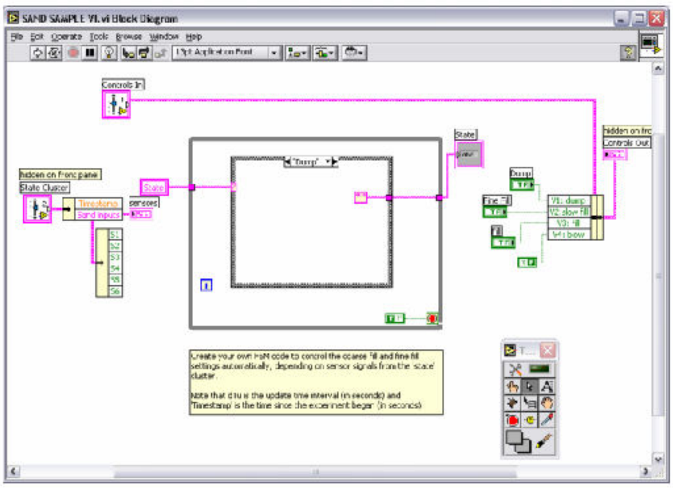


Figure 1: Hardware Client

e-Laboratory Hardware Setup - Sand Weighing Machine

In this research, the sand weighing machine (Figure 3) is used as Industrial Automation e-Lab 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 four (4) independent controlled pneumatic actuators – coarse fill, fine fill, dump and blow (compressed air). These actuators are controlled via the interface in the Industrial Automation laboratory. There are 6 sensors attached to the machine – 4 motion sensors and an ultrasonic gage providing two output signals.

Figure 2: Software Client

Figure 3: Sand Weighing Machine

In order to improve the learning experience of the students (Gillet, Latchman et al., 2001; Colwell, Scanlon et al., 2002; Nedic, Machotka et al. 2003), a camera was placed beside the sand weighing machine to enable the students to view the operation of the machine remotely. Students are able to view process of fill, dump and event of increasing or decreasing level of sand in the bottom hopper from the view angle provided.

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 of the pump in 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 about possible sources of error and a short analysis on the curve.

Laboratory Setup – Thermo-fluid pump rig

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

Figure 4: Thermo-fluid pump rig

Evaluation of the Both Experiments

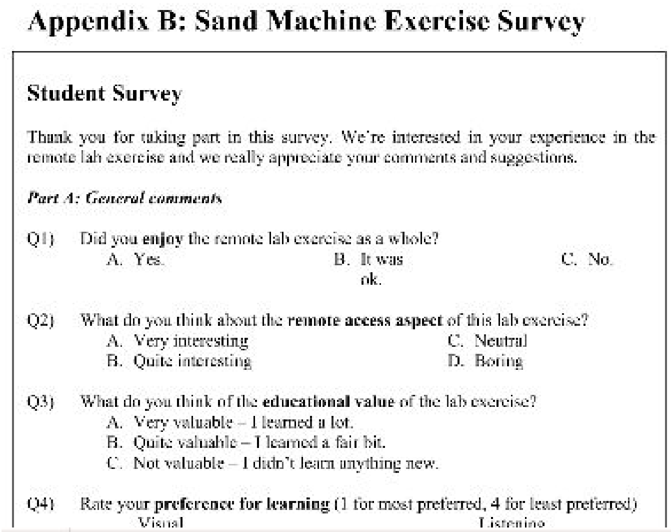
Method of evaluation

The objective is to gather information regarding student outcomes from their involvement in e-Labs and to compare them. Four methods were devised to assess the student outcomes; surveys, student observations, interviews and a personal experience report. Student's outcomes, learning experience and feedback from the laboratories were compared for analysis.

Result of the evaluation

Analysis for e-Lab experiment

Students were asked to answer the experiment objectives component of the survey (example Figure 5) by rating each question with a number from a scale of 1 (Strongly Disagree) to 5 (Strongly Agree). Only ratings above 4 were considered as a significant achievement by the student.



Appendix B: Sand Machine Exercise Survey

Student Survey

Thank you for taking part in this survey. We're interested in your experience in the remote lab exercise and we really appreciate your comments and suggestions.

Part A: General comments

Q1) Did you **enjoy** the remote lab exercise as a whole?
A. Yes. B. It was ok. C. No.

Q2) What do you think about the **remote access aspect** of this lab exercise?
A. Very interesting C. Neutral
B. Quite interesting D. Boring

Q3) What do you think of the **educational value** of the lab exercise?
A. Very valuable – I learned a lot.
B. Quite valuable – I learned a fair bit.
C. Not valuable – I didn't learn anything new.

Q4) Rate your **preference for learning** (1 for most preferred, 4 for least preferred)
Visual Listening

Figure 5: Sand Machine Exercise Survey

There are 24 surveys were 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 4. Other experiment objectives of the exercise obtained as Figure 6.

A distinct disappointment from the e-Lab 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 e-Lab experiment contributed otherwise.

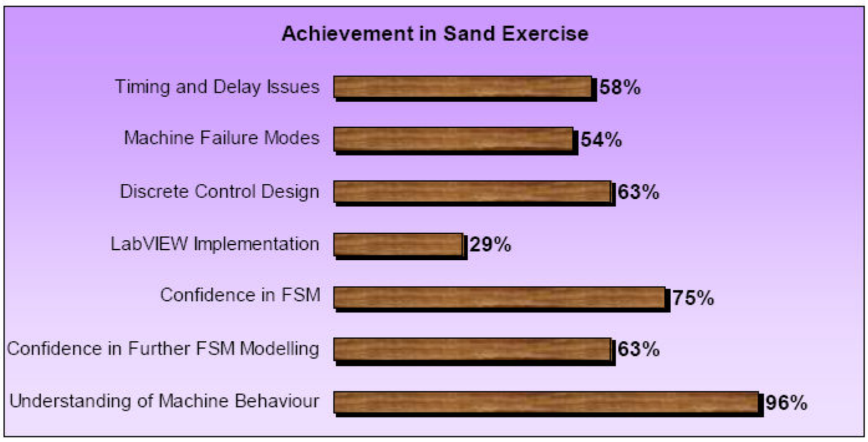


Figure 6: Achievement in Sand Machine experiment

First hand observation

Half (50%) of the students rate first-hand observation of the machine before starting the e-Lab experiment as very important. 45% of the students rated it as quite important, and 5% didn't think it was important to be able to see the machine and its behaviour before starting the exercise. However the students still found it helpful to see the physical machine operating while completing the experiment.

Relative participation with e-Labs

Students were asked to rate their relative participation levels in the sand e-Lab experiment and the average participation in other conventional hands-on laboratories in their experience. The level of participation involves the time spent involved directly with the experiment and the level of interest towards completing the experiment. The level of participating is as Table 1.

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 4 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 quite uniform across the whole class.

Table 1: Relative Participation in e-Lab experiment

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

Comparison of Outcomes

Sand Machine vs Pump Laboratory experiment

Referring to Figure 7, the average achievement from the sand experiment is 63% and the average achievement from the pump laboratory is 57%. Judging from this percentage alone, the e-Lab experiment is more successful than the pump laboratory in achieving its laboratory objectives. However, considering the weighted outcome of students – both scored a mean of 0.75. From this alternative percentage, it can be concluded that students complete both laboratories with an equal sense of achievement. The standard deviation is a bit smaller for the sand experiment compared to those of the pump laboratory (standard deviation 0.1262).

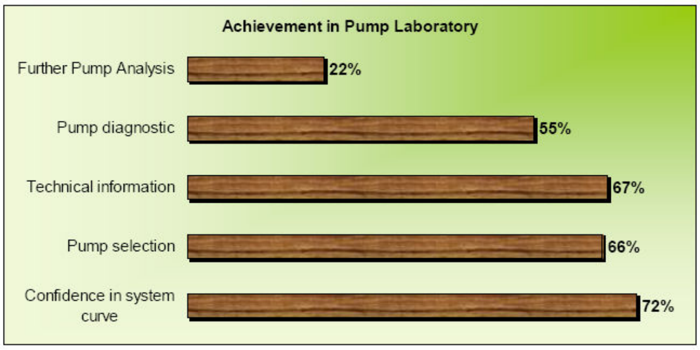


Figure 7: Achievement in Pump Laboratory experiment

Referring back to Figure 6 and Figure 7, it is clear that the percentage outcomes from the sand experiment is more varied compared to the pump laboratory. Students from the e-Lab 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 (Table 2).

Table 2: Comparison of outcomes between E-Lab and Hands-on laboratories

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

Students from the hands-on laboratory complete the laboratory with more well-rounded skills compared to that of an e-Lab. Hence it can be concluded that the e-Lab 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 sand machine e-Lab experiment was particularly successful in developing an understanding of the machine behaviour. Students were free to explore the functions of the machine and controls at their own time.

E-Lab experience

Students completing an e-Lab 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 e-Lab client to provide audio feedback. Although students have commented about the lack of hands-on touch and direct visual feedback from a e-Lab, the only impediment was the unsatisfactory view angle of the webcam. There was no evidence on any negative impact on learning outcomes due to the lack of a hands-on approach to the laboratory experiment.

Constrained learning in hands-on laboratory

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 e-Lab 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 respond on their experience with both components of the laboratory – hands-on and e-Lab. 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 a major limitation of an e-Lab access laboratory. A significant number of students have also highlighted their preference for direct contact with the equipment itself, describing the e-Lab experience as “detached” compared to a hands-on laboratory.

On the other hand, 38% of students prefer the convenience offered by the e-Lab. They enjoy the opportunity to work on the experiment at an e-Lab location and at a convenient time. A few students found the e-Lab access design an "excellent learning tool for control" and a good opportunity to allow further exploration. While some of them commented that the e-Lab 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.

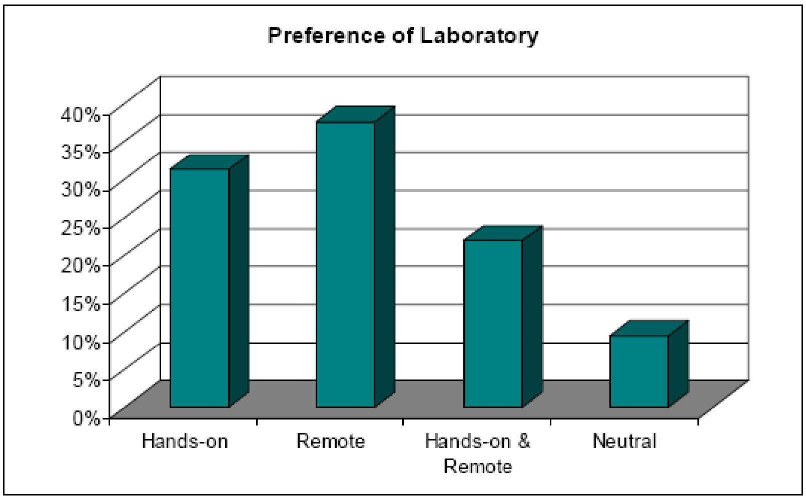


Figure 8: Preference for different laboratory modes

Conclusion

We have outlined a testing on the relative effectiveness of hands-on and e-Labs, and we have discussed results from the assessment study that directly compared e-Lab 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-Lab to be comparable (or better) than the hands-on labs. The e-Lab has effectively tested the student's 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 is parallel with (Corter, Nickerson et al. 2004) that e-Labs have provided increased access to equipment to students. No longer are students constrained to learn within a group like in traditional hands-on laboratories. With e-Labs students can perform and repeat any 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 in the limitations of it.

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

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