Developing Online Laboratories in Engineering Education

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ABSTRACT

CONTEXT

In recent years, factors such as the global pandemic, technological advancement, and shift in learning preferences, have increased the demand and the importance of online education. As engineering courses significantly rely on practical experiments, it is vital to develop online laboratories for engineering courses. The online laboratory offers a time and place-independent environment that promotes self-regulated learning. Also, the Australian accreditation body (Engineers Australia) highlighted the necessity of providing online laboratories for remote learning environments.

PURPOSE OR GOAL

Many online engineering programs utilise simulators and virtual labs to teach experimental components of the courses. Although these tools are effective for education, they often do not provide students with the same learning experience as in-person experiments. The study aims to develop a remote environment that encompasses all elements of traditional laboratory settings. This setup is expected to provide an authentic experience for students similar to what they would encounter at in-person laboratories.

APPROACH OR METHODOLOGY/METHODS

To develop the test setup, units that are more adaptable to fully online transformation were selected, and their laboratory components were studied to capture the elements required to create an online model. As a result, an experimental model called Curtin Online Laboratory (COLab) was successfully designed, developed, implemented, and run over a few semesters. Students and instructors participated in this experiment from different locations and their feedback was collected. The data from system logs was also captured to gather information about the system usage.

ACTUAL OR ANTICIPATED OUTCOMES

The evidence shows that the online laboratory model provides a comparable experience to the physical environment as was anticipated during the design phase. This has been supported by collected data from users and system's logs. The remote laboratory proved to be a manageable and sustainable model, that effectively handled high traffic usage while satisfying user requirements.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

During this study, the key elements in designing an online laboratory were identified for best practice. Parameters such as authenticity, students' learning autonomy, manageability, security, ease of use, flexibility, reliability, and cost-effectiveness were identified as crucial requirements for designing an online laboratory environment.

KEYWORDS
Online laboratory, Remote, COLab

Introduction

Throughout history, education has evolved in response to societal needs, leading to the development of various learning theories and teaching methods. In recent years, one of the main factors driving the current educational environment is the demand for online availability of course materials. The use of the internet significantly altered the way we perform in our day-to-day life activities including our learning behaviour. The extensive use of smart devices caused a massive reduction in the attention span. According to studies within the first 15 years of the Internet growth from 2000 to 2015, human attention span decreased by 25%. The research confirmed that the average attention span is 8.25 seconds (Ting, 2015).

Students are experiencing a busier lifestyle compared to decades ago. Factors such as the current economic climate require them to balance work with their studies more than ever(Ting, 2015). While the availability of the vast amount of information and range of choices creates opportunities for learning what you like, it also poses challenges regarding how to start learning, which source is more accurate, and what is the most efficient way to learn. Additionally, employer expectations have changed, and employees are now expected to learn new skills independently. This increases competition to in the job market.

To address these challenges, educators are required to create a flexible study environment where learners have access to the course material ubiquitously, allowing them to study anytime, anywhere and on any devices. Additionally, they should be able to divide the material into more manageable parts, allowing them to focus on the smaller tasks rather than the entire content at once (Nafalski et al., 2009).

This approach fosters a flexible and self-regulated learning environment where students take more responsibility for their learning activities. The current learning theories such as constructivism and connectivism, support these types of learning environments (Conradie, 2014). As a result, the education methods are shifting from lecture-centred to student-centred.

Universities and educational institutions are rapidly adopting the online model to offer and deliver various courses. Certain requirements need to be met to transfer a course to the online format so that it closely resembles the in-person version without overlooking any essential aspects. One of the most challenging programs to convert to an online format is engineering courses, where practical components are an imperative part of education.

The responsibility of maintaining the quality of academic courses falls to professional bodies in each country, which evaluate whether the courses meet the required standards. "*In Australia, professional accreditation of entry to practice engineering programs is the responsibility of Engineers Australia and is normally carried out every five years*". The "*Engineering Australia Policy on Accreditation of Programs Offered in Distance Mode*", document states the necessity of including the laboratory environment in the remote or online version that is equivalent to the in-person version (*Program accreditation overview*).

There are many methods and technologies including multimedia tools and web applications, available to convert the theoretical part of the course to the online form. However, the main challenge resides in the conversion of in-person laboratory experiments to the online version.

In many cases, simulators are used to address this requirement. While there are many exceptional simulation programs available to be used for laboratory experiments, in general, they cannot replace real-environment laboratory experiments (Azad, 2011).

Another method to address the need for practical experiments in online engineering courses is the use of remote laboratories. These online laboratory setups must meet specific essential criteria to serve as an effective replacement for in-person laboratories.

This research aims to develop an online laboratory environment and evaluate its performance across different user groups to determine how the experimental environment compares to the in-person laboratory and whether it can serve as a suitable replacement.

The test environment, named Curtin Online Laboratory (COLab), was developed using current technologies and was tested over four years. Feedback from user groups, including instructors and students from various geographical locations, was collected and evaluated.

Simulation Programs and Virtual Laboratories

These software programs are either installed on user machine or accessed via a web browser. Learners are expected to interact with the software by following a set of predefined instruction to perform an experiment (Balamuralithara & Woods, 2009).

Laboratory simulator programs are effective tools in the following situations:

- In the initial stage of interacting with experimental environment, to improve students confidence and skills without the pressure of possible causing damage to real laboratory equipment.
- Replacing expensive and hazardous equipment
- Testing a large scale and complex system
- Teaching a practical concept in the classroom during the lecture

While simulator programs are useful tools in some scenarios, relying solely on them as the exclusive source of a laboratory environment has its drawbacks. Some of these shortcoming are listed below:

- To present a real environment in simulation program, a formalized mathematical function is required. The complexity of each environment, reduces the practicality of designing simulation program for various teaching units (Tuttas & Wagner, 2001).
- Simulators produce artificial results and in most cases the accuracy of the results entirely depends on the user's software utilisation competency and not the actual skills required for experimental performance (Balamuralithara & Woods, 2009).
- Updating the simulator program is very expensive activity. In many engineering field specially in computer engineering updates are required frequently (Balamuralithara & Woods, 2009).
- Students are not gaining hands-on experience with laboratory safety skills through simulators (Balamuralithara & Woods, 2009).
- Students who receive their entire practical knowledge via simulator program may not have the competency of using the real equipment (Balamuralithara & Woods, 2009).
- There is a limitation on parameter and scenarios offered by simulators (Balamuralithara & Woods, 2009).

An alternative or additional technique is required to address the drawbacks existed in simulation program.

Online Remote Laboratory

In the online remote laboratory, learners access and interact with the real laboratory equipment via a web browser over the internet (Balamuralithara & Woods, 2009). It is a client-server model where the web browser acts as a communication channel between user (client) and laboratory setup (server). Figure 1 illustrates the basic design of a remote laboratory.

The web browser utilises network protocols such as Secure Shell (SSH) to connect to the laboratory server and security protocols such as Secure Socket Layer (SSL) and Transport Layer Security (TLS) for authentication. After connecting and authenticating, the web browser will accesses the user interface on the server, which is designed for interacting with laboratory equipment and possibly booking system.

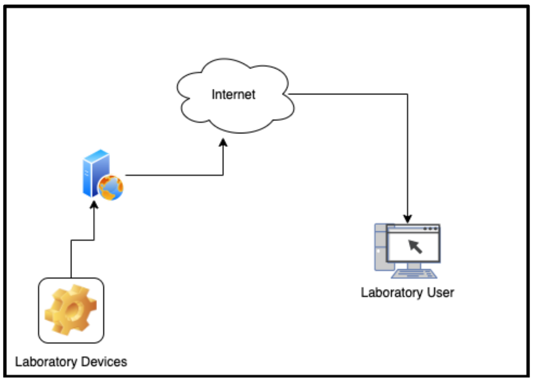

Figure 1: Captions for figures are displayed below the graphic

The online laboratory's key characteristics and design requirements are summarised below:

Availability and Scalability

The most unique and significant characteristic of the online laboratory is its availability feature. Users have 24/7 access to the laboratory setup, and unlike a simulator, it does not require software installation. This feature provides a ubiquitous learning environment where learners have the flexibility to interact with the system whether they are local or remote users (Ko et al., 2006).

In the case of laboratory expansion, all updating and scaling tasks are performed at the physical laboratory setup, similar to an in-person scenario. Users do not need to update any software or change any settings on their end. As a result, the remote laboratory system supports an economical and straightforward scalability procedure.

Real Equipment Experience

Since learners interact with the real devices in the online laboratory setup, the real-feel experience is accomplished and students are provided with the required and essential engineering practical skill training (Balamuralithara & Woods, 2009).

However, The authenticity of practical experiments in remote laboratories relies on both technical configuration and quality of the Human-Computer Interaction (HCI) design of the user interface.

Similar to other online educational settings, invigilation presents a challenge in COLab. However, the setup offers an environment where a variety of hands-on assessment scenarios can be created, and the use of cameras can help address this issue

Remote System Operation Skill

Another skill sets promoted by online laboratories is the ability to remotely examine engineering systems. This equips students with work-ready skills required to meet the current work environment demands. It also help students develop and enhance their self-study skills and promote the learners autonomy (Lynch & Dembo, 2004).

Cost Reduction

In traditional laboratory setup budget must cover the resources including laboratory equipment, physical space, utility costs, and technical and professional staff to supervise the sessions.

However, an online laboratory environment significantly reduces these expenses. There is no need to have a classroom, and the only physical space required is the laboratory setup itself, which reduces the utility costs as well (Ko et al., 2006). Since students perform laboratory tasks remotely, no health and safety monitoring in the classroom is needed, which reduces the cost of staff.

Collaboration

A remote laboratory setting fosters effective collaboration by removing geographical restrictions. Students from different universities worldwide can work together on lab tasks or research projects. This environment allows for the distribution of lab resources, knowledge, and professional skills. Experienced instructors can demonstrate lab tasks to students from any location with internet access, making education accessible to those in rural areas where there are no training services (Lynch & Dembo, 2004).

Teaching Tools

Demonstrating related laboratory experiments while teaching engineering theory enhances student learning and understanding experience. Both simulation and online laboratory environments can be used to demonstrate practical concepts during lectures. However, the online laboratory uniquely provides students with a real-world experience.

Considering all the above factors, characteristics and requirements, an experimental model was developed to examine the remote laboratory design and its authenticity.

Experimental Environment

An operational online experimental model was needed to evaluate remote laboratory learning activities and identify effective design aspects. This remote environment had to replicate the in-class laboratory setup with access to real devices. Learners should easily access the system, ideally without client-side software installation, and it should be user-friendly with minimal learning requirements. User privilege levels must correspond to their roles, such as instructors having higher privileges to review student work during lab tasks. An engineering design process were adopted to create the online laboratory setup (Figure 2).

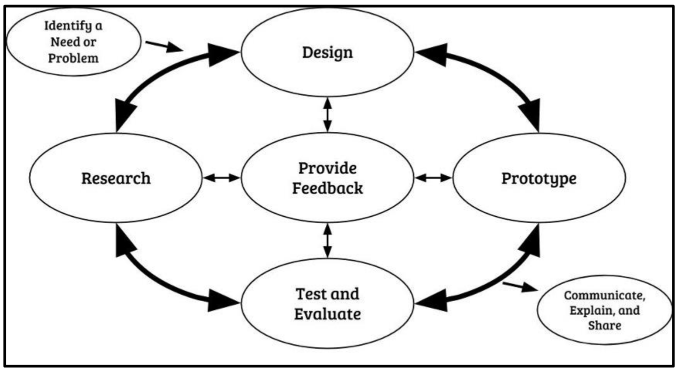

Figure 2: Engineering Design Process

Engineering design begins by identifying the problem or need, which in this research is an online laboratory system. Information is gathered to determine the best design model, which is then built as a prototype for testing. Evaluation methods are used to test the prototype, and the results are used to refine the design until the optimal model is achieved. Research occurs at the start to develop the initial design, continues through implementation to refine the design, and after collecting evaluation data for further improvement (Mohammadi, 2021).

Several courses were utilised to create a diverse environment for a comprehensive study of practical activities using online laboratories.

Curtin Online Laboratory (COLab)

The new online laboratory concept was inspired by the Cisco Academy for Vision Impaired (CAVI) program, which began in 2002 and expanded to online courses in 2004. The CAVI program's online laboratory enabled vision-impaired students to remotely perform advanced IT course lab experiments successfully. The new online laboratory aims to incorporate more labs from various engineering courses, while also enhancing the remote lab experience.

After evaluating various remote environments, NETLAB+ was chosen as the primary component of the current design to address the issues such as lack of booking system and scalability existed in the CAVI remote laboratory. The original setup has been replaced by the Curtin Online Laboratory (COLab), available at: https://colab.ece.curtin.edu.au/.

NETLAB+ is a remote laboratory environment developed by the Network Development Group (NDG), which partners with various academic institutions to create online courses, including Cisco Networking Academy and VMware IT Academy (Ndg). NETLAB+ functions as a server that provides online access to laboratory devices via HTTPS with SSL/TLS encryption. While NDG previously offered both hardware and virtual servers, only the virtual option is currently available.

The Pod Scheduler booking system allows students to reserve sessions for laboratory activities, locking the setup during their use. If teams are defined, collaboration among members is possible (*Administrator Guide*, 2014).

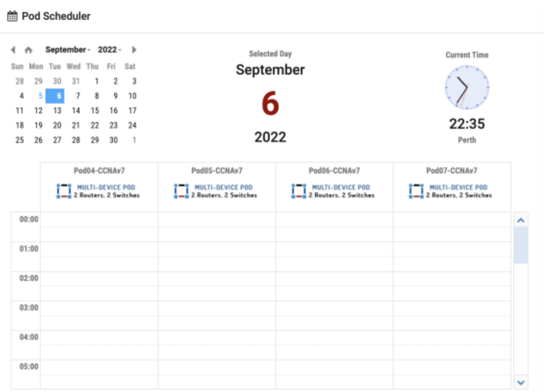

Figure 3: NETLAB booking system -Pod Scheduler (*Administrator Guide*, 2014)

Instructors have full access to monitor and manage sessions, including setting time limits and managing reservations. Users can save their configurations, and access is achieved through a web browser, eliminating the need for client-side software installation (*Administrator Guide*, 2014).

NETLAB+ ensures secure connections using SSL/TLS encryption and HTML5 WebSocket technology, which facilitates authentication and data integrity through a digital signature method (*Designated Operating Environment* 2019). Users can design laboratory setups by selecting from NDG partner templates or creating custom designs using the Pod Designer.

In the experimental model, learners connect to laboratory equipment remotely by accessing the NETLAB+ server interface through an Internet connection using any web browser (Figure 4). The laboratory devices are interconnected internally to create the desired experimental topology and can be configured remotely using an online console connection and power management features.

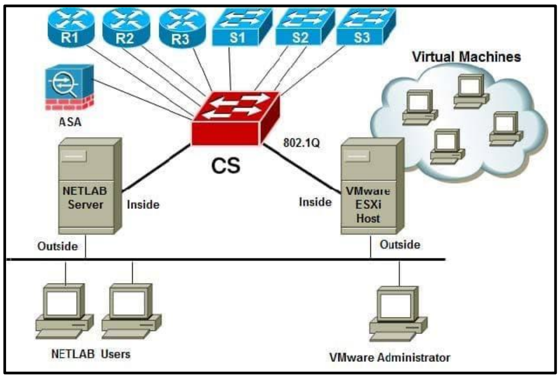

Figure 4: Control Switch in NETLAB+ Topology (*INSTALLATION AND CONFIGURATION GUIDE Multi-Purpose Academy Pod with ASA*, 2018)

Most of the laboratory content used in the experimental model (COLab) was adapted from Cisco Networking Academy Program (CNAP) courses. However, practical content from other courses was also configured and implemented in COLab, with some modifications made to the NETLAB+ setup. The implemented laboratory curriculums are:

- **Computer networking**: The CNAP courses has been incorporated to some of the Curtin University degrees as the laboratory component, providing an effective testing environment for online laboratory deployment using the COLab infrastructure. CNAP courses include an online theoretical section, a simulator program, and a laboratory component that is not available online. The CNAP laboratories implemented in COLab are CCNA Routing and Switching, CCNA Security, and CCNA Cybersecurity Operations.

- **Communication Engineering:** At Curtin University, Software Defined Radio (SDR) is utilised to develop laboratory experiments for communication engineering courses. SDR is a technology that allows the reconfiguration of Radio Frequency (RF) hardware through software implementation of communication algorithms, essentially providing a platform that simulates radio communication hardware. SDR devices create authentic testing environments for communication algorithms, attracting significant interest from researchers and educators for prototyping wireless environments and conducting laboratory experiments. The Universal Software Radio Peripheral (USRP), developed by Ettus Research and National Instruments (NI), serves as an SDR platform, with minor differences in hardware design and support between the two versions (Welch & Shearman, 2012). Curtin University employs the NI USRP 2920 for its communication laboratory experiments and topology is presented in Figure 5.

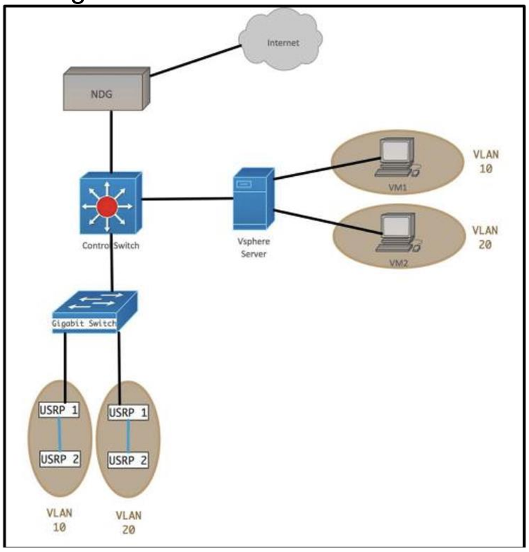

Figure 5: Communication engineering Laboratory Topology on COLab

  The integration of NI USRP with LabVIEW on the host machine creates a robust wireless prototyping system. The COLab version of the SDR laboratory enhances the use of USRP devices for both teaching and research purposes. Additionally, replacing PCs with virtual machines (VMs) lowers equipment costs and minimizes the number of required LabVIEW licenses, as VMs can be easily cloned (Rong et al., 2016a, 2016b).

- **Renewable Energy:** The Green Electric Energy Park (GEEP) is a facility at Curtin University that offers a cutting-edge laboratory environment for renewable energy power conversion systems. The units using this setup as the laboratory components are offered in multiple international campuses therefore there was a pre-existing remote access to utilise the system. To communicate with the GEEP facility, the remote access required to implement a VPN client (Cisco AnyConnect) to login to Curtin network, LabView client to interact with laboratory devices, IP Camera at the Geep facility to for monitoring purposes, two-way Audio system to communicate with on-site staff. The remote laboratory design faced challenges in meeting the needs of international campuses due to two key issues: bandwidth limitations and VPN account management. Students attempting to access GEEP facilities remotely encountered delays and disconnections due to exceeding available network bandwidth. This was caused by several factors, including high data streaming from LabVIEW client software, video streaming from IP cameras, and bandwidth consumption from two-way audio (Mohammadi et al., 2017).

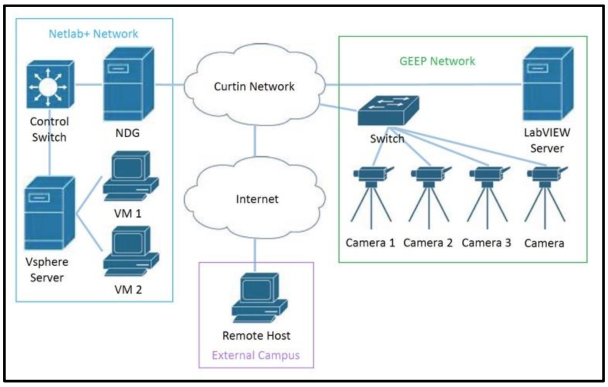

Figure 6: GEEP Remote laboratory design with NETLAB(Mohammadi et al., 2017)

The solution involved creating a VM pod on COLab and implementing a two-way audio system. This new design integrated the use of Virtual Machines (VMs) with the NETLAB+ scheduling system (Figure 6) to tackle the bandwidth and account management challenges present in the existing GEEP remote laboratory (Mohammadi et al., 2017).

- **Embedded Systems:** Another experimental laboratory setup involved remote access to program an MSP430 development board from a VM within the COLab environment. Students needed a visual view of the MSP430 during experiments to monitor feedback after loading their programs. An IP camera was positioned over the MSP430 board to provide a live video stream.
  Both the MSP430 board and the IP camera were connected to a USB over IP device (AnywhereUSB), allowing a connection from the pod VM to these devices. The Energia Prototyping Platform was installed on the VM to program the MSP430 board, and an HTTP connection facilitated access to the camera feed from the VM.

The laboratory setups originated from various subjects, allow us to evaluate and examine different aspects of COLab design.

User Audience

Diverse groups of users with varying levels of competency and background knowledge participated in the COLab courses. The main groups include:

- Curtin Local Students
- Instructor Trainees
- Remote Students

The users feedback was collected over four years.

Results and Discussion

COLab has undergone the iterative process of empirical research method involving design, testing, refinement, and implementation multiple times to achieve its optimal design. Additionally, a HCI study was conducted to determine the most effective ways for users to interact with the online laboratory environment. Analysing user feedback, questionnaire responses, and observations of COLab usage revealed several HCI-related issues in the initial design versions.

Based on the experiences gained from implementing and studying the COLab setup, along with user's feedback, the design of the online laboratory system must take into account factors such as authenticity, autonomy, manageability, scalability, availability, security, flexibility, ease of use, reliability, and cost-effectiveness to establish a best practice model.

Respondents primarily highlighted the availability and flexibility of the remote laboratory as the system's most important features. They expressed high satisfaction with the ubiquity, ease of use, and realistic experience provided by COLab. The effectiveness of the online laboratory was evident in the feedback, with over 80% of respondents recognizing the 24/7 availability and convenience of COLab as the most satisfying elements.

For future study It is recommended to expand and include more diverse laboratory setup from various engineering disciplines. Also examine the possibilities of using open-source recourses to replicate the NETLAB+ server functionalities for cost reductions.

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