

**School of Electrical Engineering, Computing and Mathematical Science  
(EECMS)**

**Developing a Framework and Pedagogies for the Delivery of  
Remote Accessible Laboratory Systems in Science and  
Engineering**

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**This thesis is presented for the Degree of  
Doctor of Philosophy  
of  
Curtin University**

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**Declaration**

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

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

**Human Ethics** (For projects involving human participants/tissue, etc) The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number 11078.

**Signature:**

**Date:**

# Abstract

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Online laboratories provide opportunities to teach science and engineering courses in the form of remote and blended learning. They also create a time and place independent environment for all students to achieve a more efficient learning experience. However, the teaching and learning methods applied to the in-person classroom are not entirely capable of addressing the requirements for an online laboratory environment. Accordingly, there is a need to develop learning objectives, pedagogies, and educational frameworks for online laboratories based on learning theories and philosophies. These help with standardizing the educational aspect as well as the development of the online laboratory environment.

The primary aim of this study is to propose methods to design the online laboratories and develop an educational framework that increases the effectiveness, efficiency, and practicality of teaching science and engineering courses. To achieve this, a test environment was developed and user observations were captured over four years. The experimental laboratory environment was built based on the pedagogical study and engineering design process. For a comprehensive investigation, the test model included several laboratory setups equivalent to in-class experiments. User's feedback was collected via survey, comments, and system log files. The captured data were analyzed using inductive and deductive methods.

This research investigated the best practice model for developing the online science and engineering laboratory and summarizes the most significant aspects to be included in the design. This also includes the development of the educational framework. The key finding was that pedagogies for online laboratories must be built on a combination of learning theories and philosophies. The proposed framework was created using the three major learning theories, cognitivism, constructivism, and connectivism while highlighting the importance of self-regulated learning. In the future, the principles of this educational framework can be extended into other science and engineering disciplines.

# Dedication

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This thesis is dedicated to all the amazing teachers who guided me through my life especially my parents who first taught me the value of education. To my beautiful mother Mahnaz for her unconditional love and my late father Rozan who always believed in me and encouraged me to study.

# Acknowledgement

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*We acknowledge that Curtin University works across hundreds of traditional lands and custodial groups in Australia, and with First Nations people around the globe. We wish to pay our deepest respects to their ancestors and members of their communities, past, present, and to their emerging leaders. Our passion and commitment to work with all Australians and peoples from across the world, including our First Nations peoples are at the core of the work we do, reflective of our institutions' values and commitment to our role as leaders in the Reconciliation space in Australia*

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# Statement of Contribution by others

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**Chapter 4** of this thesis includes the research paper “N. Mohammadi and I. Murray, "Developing methodologies for the presentation of graphical educational material in a non-visual form for use by people with vision impairment," in Proceedings of 2013 IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE), 2013: IEEE, pp. 373-377.”. It is my work except for the contribution in interpretation and discussion that is provided by Iain Murray.

**Chapter 5** of this thesis includes the research paper “N. Mohammadi and I. Murray, "Developing methodologies for the presentation of graphical educational material in a non-visual form for use by people with vision impairment," in Proceedings of 2013 IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE), 2013: IEEE, pp. 373-377.” contribution details are as above. It also includes research paper “N. Mohammadi, I. Murray, and G. Hsiung, "Remote renewable energy laboratory: Green Electric Energy Park (GEEP)," in *Experiment@ International Conference (exp. at'17), 2017 4th*, 2017: IEEE, pp. 196-201.” That is my work but there are contributions from Geoffrey Hsiung in the configuration and implementation of the GEEP remote access experimental model, and Iain Murray in the interpretation and discussion section.

[Student]

[Supervisor]

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# List of Terms and Acronyms

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<b>Accessible</b>	Accessible to blind and vision impaired users
<b>ADC</b>	Analogue-to-Digital Conversion
<b>AP</b>	Access Point
<b>API</b>	Application Programming Interface
<b>ASA</b>	Adaptive Security Appliance
<b>Blended Learning</b>	Combination of online and in-person teaching approach
<b>CAVI</b>	Curtin Academy for Vision Impaired
<b>CCNA</b>	Cisco Certified Network Associate
<b>CCNP</b>	Cisco Certified Network Professional
<b>CLI</b>	Command Line Interface
<b>CNAP</b>	Cisco Networking Academy Program
<b>COLab</b>	Curtin Online Laboratory
<b>CS</b>	Control Switch
<b>DAC</b>	Digital-to-Analogue
<b>DDC</b>	Digital Down Conversion
<b>DUC</b>	Digital Up Conversion
<b>Epistemology</b>	The Theory of Knowledge
<b>GEEP</b>	Green Electric Energy Park
<b>GUI</b>	Graphic User Interface
<b>HCI</b>	Human Computer Interaction
<b>ICT</b>	Information and Communications Technology
<b>IPC</b>	Inter Process Communication
<b>I/Q</b>	In-phase/Quadrature
<b>LAN</b>	Local Area Network
<b>MIMO</b>	Multiple-Input Multiple-Output
<b>MOOC</b>	Massive Open Online Course
<b>NDG</b>	Network Development Group
<b>PCI</b>	Peripheral Component Interconnect
<b>PDU</b>	Power Distribution Unit

<b>PT</b>	Packet Tracer
<b>PTMP</b>	Packet Tracer Messaging Protocol
<b>SAN</b>	Storage Area Network
<b>Science and Engineering</b>	Engineering and Engineering Science
<b>SDR</b>	Software Defined Radio
<b>SLIIT</b>	Sri Lanka Institute of Information
<b>SOC</b>	Security Operations Center
<b>SSH</b>	Secure Shell
<b>SSL</b>	Secure Sockets Layer
<b>TCP</b>	Transmission Control Protocol
<b>TSL</b>	Transport Layer Security
<b>USRP</b>	Universal Software Radio Peripheral
<b>VI</b>	Virtual Instrument
<b>VLAN</b>	Virtual Local Area Network
<b>VPN</b>	Virtual Private Network
<b>WKS</b>	Workstation
<b>WLC</b>	Wireless LAN Controller



# Chapter1: Introduction

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## 1.1 Research motivation and significance

Throughout history, science and engineering education methods experienced many changes. It moved from pure practical teaching method to theoretical and currently it is considered by engineering accreditation bodies as a combination of the theoretical and practical method with laboratory experiments as the focal teaching component [1] [2].

Therefore, it is not possible to teach science and engineering courses without laboratory exercises.

With the ever-evolving opportunities in remote education and the requirement to teach courses in an online and blended environment, the importance of developing online laboratories for science and engineering courses is unavoidable [3].

There are significant changes in student's learning behaviour and lifestyle with the extensive usage of 24/7 Internet-connected smart devices. According to Microsoft Corporation recent study, the human attention span reduced to 8 seconds over the last decade [4]. The availability of Internet connection and the reduction of the human attention span created an environment in which users expect to access any resources anytime and anywhere [5].

Today, people work for longer hours and experience a busier lifestyle as the cost of living has soared and there is a greater feeling of job insecurity [6]. With this busy lifestyle, students have less time to attend the classroom and prefer to access the teaching and laboratory material based on their time availability.

To address these new lifestyle changes, universities and educational institutions are increasingly focusing on expanding their remote teaching programs [7]. The rapid development of Internet technology introduced a credible environment for this modern teaching approach including in science

and engineering [8]. The advancement of technology especially in computer networking and multimedia creates opportunities for developing interactive and effective online educational contents. The ability to remotely teach engineering material such as electrical and computer-based laboratory experiments have substantial benefits in online teaching [9]. Virtual environment, Simulators, and remote (online) laboratories are techniques used to resolve this issue.

Although the simulation environments are effective tools in remote teaching models, they are artificial and not able to fully replicate the traditional hands-on laboratories experiments [10]. Developing a simulation environment for all engineering experiments is an expensive, complicated, and time-consuming project. Designing and creating a simulator environment that is very close to reality requires an extremely complex data structure and software development [11]. According to the nature of the laboratories in science and engineering, especially in fields like computing, it is very likely that regular update, modification and even redesigning is required for the simulator program.

Initially, many argued that remote engineering laboratories are not able to give the same experience as hands-on experiments and they should be the second choice compared to the traditional laboratories [12]. However, with the use of the new technologies available in this field, remote laboratories are increasing in popularity and have substantial advantages compared to the hands-on traditional experiments [9].

In remote laboratories, software interacts with the laboratory equipment and provides an environment for users to communicate directly with real devices via web-based interfaces [11]. In the event of update and modification, replacing and upgrading laboratory devices is not as complex as with simulators. If remote laboratories are designed and implemented under appropriate condition, they have the ability to replace traditional laboratories providing better access to devices with reduced cost and institutions can share the expenses [13].

In designing and developing the online laboratory environment there are two separate aspects to be considered, the technical features of the infrastructure and the creation of the learning materials. While they are both important for

building a usable and effective system, there are more resources available on the technical aspect compared to the learning material framework.

Having pedagogies and framework in designing the learning materials for online laboratories helps educators to formally create, verify and set standards for their designed environment.

The quality and effectiveness of the online laboratories rely on both of these directly associated parameters. It is not possible to teach the comprehensive online learning contents on a laboratory system with a low-quality technical design. Also, if the learning materials are not developed based on the online educational standards, an advanced laboratory setup with cutting-edge devices could be considered as an unusable expensive system.

This research mainly concentrates on developing the pedagogies and frameworks required in the online laboratory environment by evaluating user experience in an online laboratory setup.

The Curtin Online Laboratory (COLab) was designed and developed as the test environment. While the main focus of this study is the development of pedagogies, some technical requirements in designing the COLab that are related to educational experience were discussed as well.

The study was developed over time starting with the master of philosophy degree that was converted to the doctor of philosophy due to the expansion of the study scope. The researcher performed this work as a part-time student from 2013 to 2020

## **1.2 Research objectives**

The purpose of the proposed research is to develop a framework and pedagogies to deliver engineering laboratories in a remote and accessible modality. The focus of the research is to design a dynamic accessible remote environment that incorporates all the requirements in science and engineering local in-person laboratories.

The main research objectives are as follows:

- Review the traditional science and engineering laboratory teaching methods to identify the required modifications for online educational

material development. This includes the study of fundamental learning theories and philosophies.

- Classify the desired technical configurations in creating an effective online laboratory environment by studying the different aspects of the existing remote experimental setups such as usability, authenticity, reliability, security of remote hands-on exam, and scalability.
- Identify technical and pedagogical requirements for accessibilities in the online laboratory environment.
- Selecting a pedagogical framework as the foundation model to build the new framework. This is done by evaluating several educational frameworks suitable for the science and engineering learning environment and validate them by experimenting in the classroom.
- Identify the learning philosophy/philosophies that best defines the process of knowledge acquiring in the science and engineering online laboratory education.
- Developing pedagogies and framework based on the identified learning philosophy/philosophies for science and engineering online education. This must be supported by the outcomes of the experimental online laboratory investigated in the classroom.

### 1.3 Thesis outline

This thesis is organized into seven chapters. A summary of each chapter is presented here:

**Chapter1:Introduction** is an overview of study motivation, objectives and contribution.

**Chapter2:Background Study and Literature Review** presents a background study on pedagogies and learning theories in general then it explains the elements in modern study. This chapter continues with the engineering education study highlighting the necessity of the laboratory

component. Then it describes the influence of the demand for online/blended educational environment on teaching engineering courses and the need for the online laboratory system.

**Chapter3:Research Methodologies** focusses on the research paradigm, approach, strategy, and design adopted in this study. It explains the methods of data collection and analysis suitable for this research. Ethical concerns are also discussed in this chapter.

**Chapter4:Experiment Design** proposes an experimental environment to deliver the engineering curriculum via online laboratory. It explains the rationales in selecting and developing different aspects of this environment. This chapter includes the design proposal of the Curtin Online Laboratory (COLab) to perform the pedagogy study on online/blended environment in teaching engineering programs.

**Chapter5: Curtin Online Laboratory (COLab) Implementation** presents the complete design and implementation of COLab. It covers the technical aspects of the design including the type of hardware, software, license management, storage allocation, and network configurations. This chapter also explains the various laboratory content incorporated in the COLab such as the Cisco Networking Academy Programs (CNAP), Wireless Network, Software Defined Network, Renewable Energy, and Embedded System.

**Chapter6: Analyzing the Results** represents the outcomes of the survey and collected feedbacks throughout the study period in the form of qualitative and quantitative data. It also includes the inductive and deductive data analysis performed on the accumulated statistics. A proposed pedagogy and teaching framework are presented based on the learning theory study on the collected data.

**Chapter7:Conclusions and Recommendations** summarizes the study outcomes, limitations, suggestion, and future development.

## **Chapter2: Background Study and Literature Review**

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### **2.1 Introduction**

This chapter presents a background study on the different aspects of the thesis subject. There are three main sections in studying the pedagogies for engineering online laboratories. The first section is the pedagogies and educational frameworks which require the study of the knowledge learning process. It is important to understand how knowledge is learnt by individuals and which theory, philosophy, or psychological position is the better match for engineering experiments in an online model.

The second is the educational environment. Why should a laboratory setup be accessible over the Internet and what are the characteristics of this environment?

The third section is presenting a review of engineering education and its characteristics. It explains the importance of laboratory experiments in engineering education and why they should be included in the online and blended learning environment.

### **2.2 Fundamentals of knowledge acquisition**

A thorough and cognizant understanding of learning theories is required to develop educational frameworks and pedagogies. This section provides background information on learning theories and explains the fundamental characteristics of each theory.

#### **2.2.1 Significance of Theories**

The importance of learning is apparent for all educators and learners, however, due to the existence of diverse opinions on various part of learning concept amongst the researchers and educators in this field; there is no common definition for learning. Schunk introduced one of the most general definitions of learning that states, "Learning is an enduring change in behaviour, or in the capacity to behave in a given fashion, which results from practice or other forms of experience" [14].

According to this definition, learning is a continuing process that happens over time and produces changes through experience. Observing and processing the knowledge and making a long-term change is not a simple procedure as there are many elements involved that influence the learning. Researchers and educators have been developing learning theories to analyze the knowledge acquiring process and describe how it happens. Learning theories scientifically explain the occurrence of the complex human learning process [14].

The learning theories are originated from epistemology the philosophical study on nature, source, limitation and justification of knowledge. What is the origin of knowledge? How do people learn? What are the limits? How much can a person learn? These are some of the questions that epistemology examines, and they were already known even before Plato's and Aristotle's time [15]. The two main opposing opinions in modern epistemology are Rationalism and Empiricism [16].

### **2.2.1.1 Rationalism**

Rationalism declares that all knowledge forms on reason and not sensual experience. Understanding concepts like mathematics, logic, human rights, justice, and morality is not possible through our five senses. All rationalist philosophers believe in innate knowledge - that means whatever we learn is already in our mind such as space and time however they have a different opinion on the various objects of innate knowledge.

Plato stated that humankind has an innate knowledge of forms and all information received from human senses is naturally processed, organized, analyzed and reasoned in the mind [14].

Descartes is famous for his dictum "I think, therefore I am" claiming that humans exist as a mind, not a body. Based on Descartes rational intuition, human knowledge on understanding the absolute ideas like perfection, God, eternity and existence are originated in the mind by nature [14].

Immanuel Kant claimed that innate knowledge is touched by empirical knowledge of the external world [14].

Noam Chomsky believes that the nature of language acquiring is based on innate knowledge [17]. For example, without teaching grammar to three-year-



old kids, they can put words they have not heard before in a correct manner to form a sentence [18].

The differences between rationalists' positions are on whether the knowledge is absolute or action toward the information from sensorial experience of the world however they all agree on the mind as the origin of knowledge [14].

### **2.2.1.2 Empiricism**

Empiricism emphasizes the significance of experience and sense as the primary source of knowledge. The empiricists do not believe in the existence of innate knowledge and argue that knowledge acquisition is gained by observation.

Aristotle considered the pioneer in Empiricism doctrine, claimed that the external world is the source of ideas and knowledge. He originated the law of the association of ideas stating that remembrance, recall and experience of objects evoke from three principles: similarity, contrast, contiguity [19].

**Similarity:** The human brain tends to associate similar objects together, the thought of one object can elicit an object similar to that.

**Contrast:** opposite objects are also grouped in mind and seeing an object can trigger the remembrance of the complete opposite object. For example, thinking of the day can recall the night.

**Contiguity:** elements or events that were experienced together are linked or associated in mind.

Aristotle also noticed that the frequency of experiencing things together will increase the probability of recalling one when experiencing the other. This is what later on developed into the law of frequency. The law of association and frequency together are the basis of modern psychology and learning theories [19].

John Locke is another empiricist who also rejected the ideas of innate knowledge in his work *an essay concerning human understanding* in 1690. He refers to the human brain at birth as a *tabula rasa* or blank tablet that the five senses, experience and personal awareness will write on as a person

grows up [14]. He denoted that sense experience creates simple ideas and the combination of simple ideas creates complex ideas and form the mind [19].

David Hume believed knowledge is acquired through the personal experience of each person therefore all conclusion and interpretations of experiences made by people are subjective. According to Hume we “*can be sure of nothing*” and concepts like laws of nature, morality, and causation, are all concluded based on the subjective associated ideas [19].

Rationalism and Empiricism as the two philosophical positions on learning are trying to explain the origin of knowledge and they are not precisely mapped to the learning theories, however, Empiricism relates more to conditioning theories such as behaviourism and Rationalism relates more to cognitive theories [14].

### **2.2.2 Learning and psychological study**

A systematic study on the psychology of learning commenced at the end of the 19<sup>th</sup> century. The two influential researchers in this area are Wilhelm Maximilian Wundt (1832-1920) and Hermann Ebbinghaus (1850-1909) [14].

Wundt founded the first psychological laboratory to study consciousness during the experience process and the outcomes and effects achieved from these perceptions [19]. According to Wundt the psychological matters should be investigated through the experimentation process, hence he created the laboratory environment to control the stimuli and measure the outcomes. By establishing the laboratory Wundt managed to classify psychology as a discipline and determine the experimentations as a learning method [14].

Hermann Ebbinghaus substantiated that psychology is independent of philosophy by conducting experiments and research on memory [14]. He studied the process of learning as it occurs in memory, based on the principle of association and law of frequency [19]. He intended to show that memory gets stronger as it gets exposed to the learning materials frequently. To assess and prove this hypothesis, he developed material that learners had no previous experience in. In this experimental environment, Ebbinghaus developed “nonsense material” in which three-letter meaningless words

(syllable) with two consonant and a vowel in the middle (e.g., TEW, TIG, or QAW) was used to study the memory [19].

Ebbinghaus made a list of twelve “nonsense material” and using himself as the subject investigated the learning process by looking at each syllable, pause for fifteen seconds and then looked at the next syllable, he recorded the number of times required for him to learn the whole list and the number of errors he made in this process.

Based on the outcomes Ebbinghaus demonstrated that the frequency of exposure to the material improves the learning and reduces the number of errors, which is known in psychology, as learning curves [19].

The other area of his research involved memorizing the meaningful passages as testing material and signified that, it is easier to learn them compared to “nonsense material” [14]. Although Ebbinghaus was the only subject in his research and was not representing the typical learner, his research outcomes are significant in the commencement of systematic psychology of learning study and investigating the “higher mental processes” concept in the laboratory experiment [14].

### 2.2.3 Psychological schools

The systematic psychological study introduced by Wundt and Ebbinghaus initiated structuralism and functionalism methodologies.

**Structuralism** is one of the first learning theories introduced by Edward Titchener (1867-1927) at Cornell University by modifying Wundt’s voluntarism experimental laboratory. Both structuralism and voluntarism used introspection as a tool to measure elements of thoughts in human consciousness with the aim of discovering how complex thoughts are shaped [19]. In introspection, study participants are required to examine the conscious process and not the stimulus, for example when shown a flower they are expected to report the shape, colour, size, and special characteristics rather than labelling “flower”.

The main difference between voluntarism and structuralism to explain the elements of thought as part of the complex thought was the fact that voluntarism was based on rationalism and structuralism was based on Empiricism and followed the law of association [19].

Introspection was not a reliable and suitable method to study a complex aspect of mental processes during learning [19]. Without training, the human brain does not operate in a way to precisely classify information so it can only observe the conscious process without interference from its interpretation of the phenomenon.

Structuralism failed to describe the process of acquiring knowledge and only analyzed the law of association of ideas [14]. Due to these shortcomings, the structuralism study ended after a short period.

**Functionalism**, initiated by William James (1842-1910) who believed that big ideas could not be divided into small ideas and people consciousness is a continuous process that involves the adoption of their environment, not the discrete elements [19]. James is a very influential researcher in psychology study and his book "The Principle of Psychology" published in 1890 is a significant work in this area [14].

John Dewey (1859-1952) who is known as an exceptional philosopher in the psychology of education argued that an isolated environment is not suitable for studying psychological stimulus and response relationships whilst the purpose of these studies are to investigate the importance of behaviour in environmental adoption [19]. Charles Darwin's theory of evolution also influenced functionalism and helped researchers to signify the mind process and organism adoption of the environment for survival.

Functionalists believed that studying a phenomenon in an isolated environment overlooks the contribution of this phenomenon in an organism's survival and therefore introspection is not a suitable method for studying psychological matters [14].

The significance of functionalism was its contribution to learning theories and applied psychologies [19].

### **2.3 Learning Theories**

The psychological paradigms and epistemology positions explained so far are the two bases of learning theories. While epistemology is describing the origin of knowledge, the psychology of learning explains how knowledge forms in the human brain. Subsequently, learning theories are developed to describe the process of learning, constructed on these philosophical and

psychological positions. The study of learning theories is an essential foundation for creating educational frameworks and pedagogies. In this section most common learning theories are explained including, behaviourism, cognitivism, constructivism, and connectivism.

### **2.3.1 Behaviourism**

Behaviourism, introduced by John B. Watson (1878-1958) as a conditioning theory, leading learning psychology at the beginning of the twentieth century [14]. Watson postulated that consciousness could not be measured or studied as the only research measuring tool in the unreliable process of introspection, therefore, it is not possible to consider consciousness as an object element in the scientific and psychological study of learning [19].

Behaviourists study the measurable properties of learners' behaviour and observe the behaviour changes produced by the learners' association process of stimulus and response. Learners choose a response to stimuli depending on the environment and prior psychological conditions.

Behaviorisms learning theory postulates that all behaviours are learned and it is possible to unlearn the learned behaviour and replace them with the desired ones and the key factor for this process is the reward-punishment associations such that behaviours increase if rewarded and decrease if punished [20].

Behaviourism theory was greatly adopted by educators in the first half of the twentieth century and behaviourist methods were applied to achieve the desired behaviour and discourage the unfavourable ones in the classrooms [20].

Although behaviourism's concept of stimuli and response could rationalize some of the learning processes, learners' mental processes such as thoughts, feeling and beliefs should be considered to explain complex learning [14].

### **2.3.2 Cognitivism**

Cognitivism theory was developed in 1952 following ineffective attempts of behaviourism to explain the mental processes and cognition during learning [21].

The cognitivism theory was founded based on Jean Piaget (1896 – 1980) development of human cognition theory. He introduced the four stages of human cognitive development including Sensorimotor, Preoperational, Concrete Operational, Formal Operational and stated that all children experience all these stages sequentially in their cognition development [20].

Piaget defined *equilibrium* and *adaptation* functions clarifying how children move between different stages. *Equilibrium* is the process of organizing an optimal balance between the cognitive structure and environment that results in *adaptation* [14]. Adaptation consists of two complementary processes, *Assimilation* and *Accommodation*. Assimilation is the process to understand new events based on the existing cognitive structure and Accommodation is the process of changing the cognitive structure to fit the new event [21].

The Piaget cognitive development stages are illustrated in Table 2.1.

Stage	Age Range	Description
Sensorimotor	0-2 years	Coordination of senses with motor response, sensory curiosity about the world. Language used for demands and cataloguing. Object permanence developed
Preoperational	2-7 years	Symbolic thinking, use of proper syntax and grammar to express full concepts. Imagination and intuition are strong, but complex abstract thought still difficult. Conservation developed.
Concrete Operational	7-11 years	Concepts attached to concrete situations. Time, space, and quantity are understood and can be applied, but not as independent concepts
Formal Operations	11+	Theoretical, hypothetical, and counterfactual thinking. Abstract logic and reasoning. Strategy and planning become possible. Concepts learned in one context can be applied to another.

Table 2.1-Piaget's stages of cognitive development [22]

Piaget emphasizes designing an active educational environment in a way that student with different characteristics can discover their creativity and educators can perform progressive teaching and discover how each student learns [21].

Following further studies and analysis by researchers in the field, some limitations were identified in the Piaget cognitive development stages:

- Usually, children develop thoughts and learn the knowledge earlier than defined stages by Piaget.
- Cognitive development across different subjects can vary and does not follow the stage order. Each person might acquire different knowledge of the same topic, and they might think of this same topic in a preoperational, concrete operational, or formal operational way [14].

Despite the problems mentioned above, cognitive development stages theory provides an appropriate general framework for educators.

### **2.3.3 Constructivism**

Constructivism is an epistemology theory that originated from Jean Piaget cognitive theory that explains learning as a process of constructing knowledge in the learner's mind [23]. Constructivists follow the Empiricism belief and postulate that new knowledge forms on the basis of the previous knowledge [24] considering objects and environment engagements as significant factors in learning development [23].

The other influential philosophy in constructivism is Vygotsky's sociocultural theory that highlights the significant effect of the social environment on learning development and constructing the meanings process [23].

Constructivism is considered an inconsistent contemporary theory that has many types and variations when it comes to the learning development process [24], however, all constructivist learning models share four main characteristics [25]. Figure 2-1 illustrates the Constructivism focal characteristics proposed by Brunning et al [25].

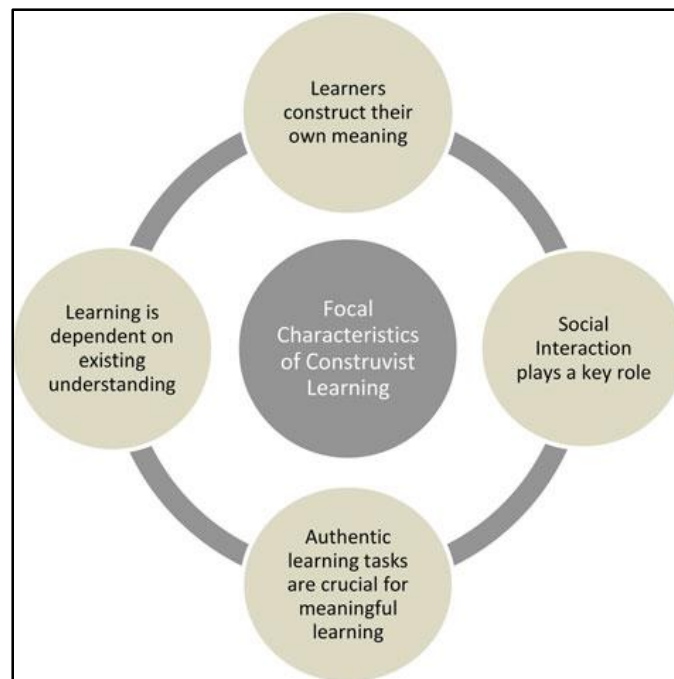


Figure 2-1-“Focal Characteristics of constructivism” [25]

In constructivism, pedagogical methodologies concentrate on providing the environment for student’s active learning so each learner can construct the knowledge individually. As a result, constructivists replace the traditional guided instructions with more self-regulated instructions that require learners to be actively involved with the learning environment and create ideas and construct thoughts [14]. Some examples of constructivist instructions are [14]:

**Discovery and inquiry learning:** a method minimizing the guidance from educators and let learners discover the facts and construct the knowledge on their prior experience by themselves. It is done through problem-solving and questioning activities created by teachers.

**Peer-assisted learning (PAL):** in this method peer (another learner usually with a higher level of knowledge) actively assist students in the learning acquisition process.

**Discussion and debates:** this method is used when there are opposing positions in the subject of study. During the debate and discussion, learners develop a better understanding of the opposition point of views and enhance skills such as communication and critical thinking [26].



To ensure the quality of education, it is essential to assess the discipline of study then create a constructivist learning environment and chose the pedagogy that most suits that area of study.

#### **2.3.4 Behaviourism, cognitivism, and constructivism constraints**

The learning theories described to this point are all developed before technology impacted education. Behaviourism, Cognitivism, and Constructivism all endeavour to explain the process of learning as it occurs in the learner's mind and often applied by developing an environment for some type of instructions. Although these theories have different positions in understanding the learning development procedure, they all describe knowledge as an object acquired inside the mind by either rationalization or experience [27].

In the past decade, technology had a significant impact on all aspects of our life including communications, employment, and education. The exponential production of information influenced by technology changed the lifetime of knowledge from a decade to a year and a month [27]. Just sixty years ago education in a related area would create an opportunity for a lifetime career with minimum re-training. However, today's career is continuously changing and it is not unlikely for people to change to an unrelated career field during their working lifetime [27]. With the rapid growth of information and shrinking lifespan of knowledge, it is vital to measure the worthiness of knowledge to be learnt. In today's networked environment learners are required to evaluate the value of knowledge before starting the learning process. Behaviourism, Cognitivism, and Constructivism are only capable of investigating the process of learning and not the knowledge value therefore there is a requirement for a digital age learning theory [27].

#### **2.3.5 Requirements for new learning theory**

In the current digital world with the rapid growth of knowledge, people are required to perform outside their personal knowledge under various circumstances and this is not possible without forming, organizing and utilizing the connections.

This connected knowledge is stored either in the machine (database) or in other people. Karen Stephenson states that it is not possible to gain essential

knowledge for today's life from personal experiences anymore, as people are not capable of experiencing everything. She declares the collection of knowledge through other people experiences is the solution for this matter and "I store my knowledge in my friend" is an axiom for this type of learning [28].

The relatively new science of Chaos and Network has a significant influence on the current learning process [29].

### 2.3.6 Connectivism

In 2005 Siemens introduced the connectivism theory in his article "Connectivism: A Learning Theory for the Digital Age". The principles in the four theories of Chaos, Complexity, Self-organizations, and Network are combined to form the connectivism [29].

Nigel Calder refers to **chaos** as "a cryptic form of order" [27]. Chaos theory states that there are order and pattern in a random **complex** system such as water flow [30].

**Self-organization** is defined as the "spontaneous formation of well-organized structures, patterns, or behaviours, from random initial conditions" by Luis Mateus Rocha [31].

**Network** as a learning science is the connections of nodes such as learning fields, ideas, or communities. More specialized nodes will receive more recognition from other nodes [27].

Unlike previous learning theories, connectivism postulates that knowledge can reside outside the person's mind (database or organizations) and the objective of this theory is to recognize the pattern and organization, form networks, and connect to specialized and recognized data in the network.

Decisions are made on the foundation of knowledge and as the knowledge is produced and learnt rapidly it is vital to recognize when the foundation is altered in a way that can affect the decisions made previously [29].

The principles of connectivism described by Siemens are:

- "Learning and knowledge rest in diversity of opinions.

- Learning is a process of connecting specialized nodes or information sources.
- Learning may reside in non-human appliances.
- The capacity to know more is more critical than what is currently known
- Nurturing and maintaining connections are needed to facilitate continual learning.
- Ability to see connections between fields, ideas, and concepts is a core skill.
- Currency (accurate, up-to-date knowledge) is the intent of all connectivist-connectivism is the learning activities.
- Decision-making is itself a learning process. Choosing what to learn and the meaning of incoming information is seen through the lens of a shifting reality. While there is a right answer now, it may be wrong tomorrow due to alterations in the information climate affecting the decision” [27].

The connectivism is the most current learning theory in which learners are required to utilize self-organization techniques to identify the pattern and order in chaos and complex system. In this process, the connection between the nodes of knowledge is clarified to form a network.

## **2.4 Modern teaching environment**

The growth of Internet technology initiated the foundation of the online education environment. This model of education received a great deal of attention from various parts of the teaching sector. The online education environment is a technology-enhanced learning approach that uses the Internet as a medium to connect learners, digital devices, and educators (nodes) forming a networked organization model and enhance the learning objectives.

The online learning environment evolution and rapid adoption by universities and educational institutions are under the influence of concepts created by the digital world. The following section describes some of these modern world aspects.

### 2.4.1 Digital age lifestyle

In the current digital world that social media dominated people lives promoting quick and short messages as a form of communications, the concentration level has deteriorated. Microsoft Corporation recent research on digital life indicates that currently, the human attention span is 8 seconds, which shows a reduction of 4 seconds in just more than a decade [4].

Additionally, the technology impact creates an extremely busy lifestyle in which people struggle to find time for various activities. According to Inga Ting, Australians aged 18 to 29 are predicated to do too much and two-third of them find themselves busy almost all the time (Figure 2-2) [32].

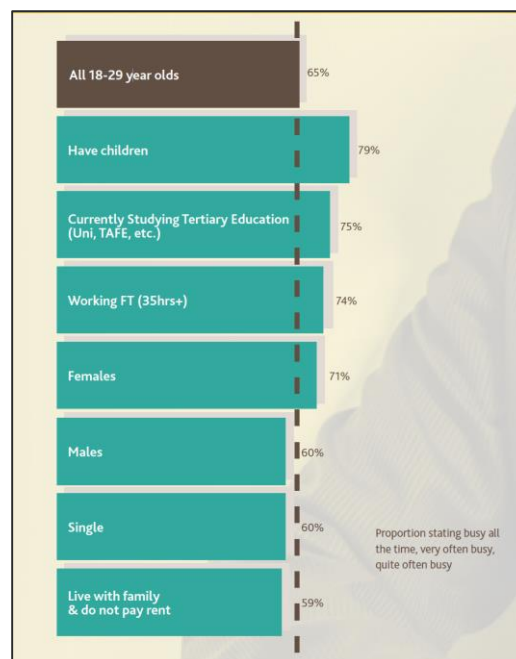


Figure 2-2- who is the busiest [33]

According to the research outcome conducted by The Insight Room in partnership with Co-Op and BDO Australia, tertiary students are the second busiest group among 18-29-year-old Australians.

### **2.4.2 Ubiquitous Computing**

Ubiquitous computing or pervasive computing refers to the 24/7 available network-connected smart devices. The ubiquitous computing system is a many-to-many model connection that consists of a heterogeneous set of smart devices such as laptop, smartphones, tablets, sensors, and wearable devices, which have different operating system, network connections, and input/output capabilities [34]. The objective is to provide a smart connected environment that occurs at anytime, anywhere, with any device, in any data format, and any type of network [35].

Ubiquitous computing environment applications are rapidly produced in a number of areas including education [32].

### **2.4.3 Self-regulated learning skill**

Self-regulated learning is a learning method in which students take control of their learning [36]. With the rapid production of information and the short lifespan of knowledge, people are expected to be retrained and learn on regular basis promoting self-regulated learning method as an essential skill.

Self-regulated learning is enhanced through online education methodologies.

All these technology-influenced changes emerged educational organization to further develop online teaching and learning in multi-disciplinary areas including science and engineering. It is essential to consider the quality of the educational materials and achievement of learning objectives when developing any new teaching environment and models. The use of any tools including technology must be meaningful and towards enhancement of the learning experience, therefore using “technology only for the sake of technology” must be avoided [37].

Before explaining the requirements for an engineering online learning environment, it is beneficial to have a good understanding of engineering knowledge and education.

The next section begins with explaining the development and evolution of engineering knowledge, then it focuses on engineering education and the significance of laboratory experiments in teaching the concepts.

## 2.5 Engineering evolution

The evolution of engineering knowledge occurred in four overlapping stages of history.

1. **Pre-scientific evolution:** engineering originated from art and artisans were the pioneer engineers who produced exceptional works by associating the knowledge with imagination through the trial and error process [38]. Founded on the Empiricism epistemology supported by geometry, mathematics, and some physical science [39], the initial concepts of civil engineering and architecture designs were developed in this period that resulted in the creation of remarkable works such as the Egyptian Pyramid, Roman and Persian road system, Great Wall of China, Mesopotamian Ziggurat, and many more. Based on this description, Imhotep (about 2550BC) the architect of Step Pyramid is the first known engineer [39].

In the 11th century, the term Engineer developed from a Latin word *ingeniator* that described a person who operates the engine, which at the time only referred to military engine [40].

2. **Scientific evolution:** between the 18th to early 19th century engineering practice principles changed from art to science through discoveries in biology, chemistry, physics, and mathematics divisions such as calculus [41]. Many engineering historians remarked Galileo's work as the foundation of "theoretical predictions in the design of artifacts [41]".

During this time the engineering learning transformed from technical training to formal education [41].

3. **Industrial evolution:** development of electricity and mass production had a substantial impact on engineering in this historical period and the salient invention of the steam engine replaced muscle power with machine power facilitating mechanization. The significant role of iron and coal in steam machinery enhanced the value of mining and

metallurgy [41]. Other engineering areas including chemical, mechanical, electrical, marine, aeronautic, and industrial engineering also experienced a rapid progression during this time changing the engineers' role from technicians and draftsmen to conceptual designers [41].

The engineering higher educational programs were prominently developed and college and schools of engineering were established deploying scientific laboratories instead of simple workshops.

4. **Information age:** engineering research thrived during this time under the influence of World War II and the Cold War resulting in the expansion of new technology development such as aerospace, turbojet, atomic and nuclear power, microelectronics, computer, telecommunication, etc. The computer associated engineering fields including; telecommunications, microelectronics, mechatronics, computer and software engineering were established during the period of the information age.

Figure 2-3 illustrates the evolution of engineering through history.

From the observation of the engineering evolution, it can be determined that the development of engineering science is driven by societal changes and engineers have a dynamic perception of society requirement [42]. While today's engineering is still influenced by physical science, the concepts like globalization and multidisciplinary fields such as the Internet of Things (IoT) and biotechnology require proficiency in other fields of science such as economics, business and biology therefore engineers are expected to have the competency of collaborating the conventional science in multiple fields [41].

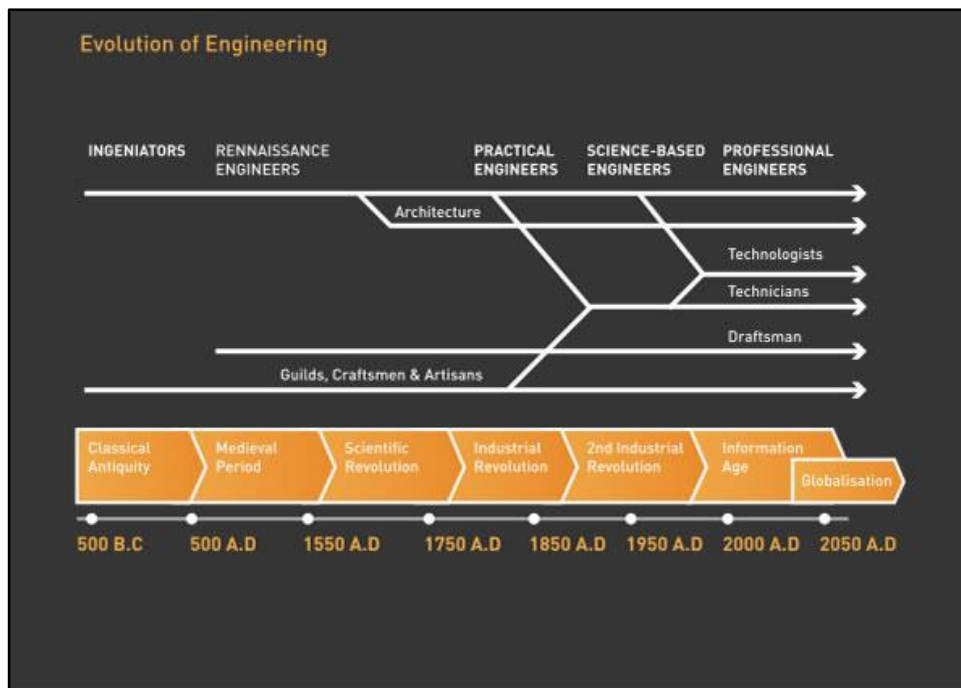


Figure 2-3- Evolution of Engineering [41]

Also, while re-training programs were always an inseparable part of the engineer's profession, with the rapid technology advancement they are more needed. These training programs are more formalized in recent decades and are represented as Continuing Professional Development (CPD) courses. The CPD courses are not only considered as a tool for individual development but strategies for employees to succeed in competition with other companies by increasing the client's confidence in their employer's professional level [43].

### 2.5.1 Engineering education

The word engineer is generally defined as a professional with well-developed problem-solving capabilities that serve society by creating products. The engineering design project aspects including products, processes, and systems are becoming more sustainable and technologically complex. As a result, industries are expecting engineers to have technical competence, social awareness, and creativity as the fundamental skills for modern engineering work environment [44].

For engineering education to successfully educate competent engineers prepared for modern society, it is imperative to consider synchronizing learning material to engineering community perception of required skill for a



job environment where engineers can fulfil the technology expertise among with entrepreneurship and productivity in a collaborative environment [44].

From the late 1970s to 1990s engineering communities criticized the science-based model taught as engineering higher education program and revealed that the graduates are not competent on professional and interpersonal skills required for the design system building creating a gap between theory and practice [44]. Bernard M. Gordon in his presentation “*what is an engineer?*” at the *European Society for Engineering Annual Conference*, in Nurnberg in 1984 stated that “Unfortunately, it is apparent that society around the world, particularly the western world, is not entirely pleased with the current state of general (engineering) education [42]”. He also documented the definition of engineer along with the industry expected engineering skills, knowledge, and attitudes [42]. The criticism of engineering education programs increased during the 1990s from engineering communities motivating individuals and organizations in educational sectors to perform research and develop a response. Conceive-Design-Implement-Operate (CDIO) approach is an example of one of the solutions initiated by four universities; Chalmers University of Technology (Chalmers) in Göteborg-Sweden, the Royal Institute of Technology (KTH) in Stockholm-Sweden, Linköping University (LiU) in Linköping- Sweden —and the Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts, USA [44].

CDIO is an educational framework with an open architecture model developed for educating the new generation of engineers that focuses on technical, personal, interpersonal skills as well as Conceive-Design-Implement-Operate abilities [1]. It defines the engineering skills, knowledge, and attitudes based on focused group research outcomes and outlines 12 standards for the design and development of educational programs.

Standard 6 of CDIO emphasizes the importance of laboratory activities promoting student direct engagement for self-development and social collaboration. The learning development stages introduced by Piaget in cognitivism theory (2.3.2 above), and the constructivism discovery and inquiry learning instruction (2.3.3 above) are reflected in the design of the CDIO framework [44].

### **2.5.2 The importance of the laboratory in engineering education**

Engineering was consistently considered as a profession established on practical knowledge principles and the necessity of experimental environment inclusion in educational programs was referred to as an irrefutable part of the process. Despite the imperative role of laboratories and practical experiments in engineering education, there was always an absence of consensus on defined laboratory objectives among engineering educators and researchers that resulted in the lack of united teaching frameworks for practical experiments in engineering education [1].

Engineering education was predominantly focused on practical experiments as the teaching framework in its early days and before the creation of a formal engineering institution [2]. This educational perception continued even after the engineering institution creation in the 19<sup>th</sup> century and until the end of the Second World War [1]. The accreditation professional bodies established in the 20<sup>th</sup> century are responsible for granting recognition of the engineering programs through a qualitative and quantitative evaluation process that indirectly supported the laboratory as a fundamental part of the engineering education [1]. However, after World War II the engineering education programs shifted toward the adoption of the more theoretical focused model, diminishing the laboratory significance. Accordingly, accreditation standards changed to accommodate this new model [1]. By the 1970s due to economic constraints resulted from Project Apolo and the Vietnam War, engineering education funding significantly dropped, forcing schools and institutions to reduce the cost of delivery. Since laboratories were generally the more expensive aspect of engineering education, some schools decided to decrease engineering laboratory components as a cost reduction strategy, resulting in educating engineering students with reduced practical competency and an emphasis on theoretical knowledge [1].

While the industry indicated that engineers who graduated from the theoretical based educational system did not possess the skills required for the work environment, institutions and schools addressed this issue by initiating the engineering technology courses. However, the similarities and overlap between engineering and engineering technology programs generated confusion among all engineering societies. Therefore,

accreditation bodies signified the requirement for major reform in engineering education that resulted in reorganizing and developing the educational engineering programs with laboratory experimental activities as the focal components of the course [1].

In recent years the technology evolution and development of ubiquitous computing assisted in reducing the cost of expensive laboratory installations and enhanced the experimental experience make it possible to enrich the laboratory environment and achieve better quality in engineering educational programs [1].

## 2.6 Online engineering education

As previously stated, the exponential evolution of technology and its influence on societies' lifestyle, creating opportunities to develop the modern online educational environment that may be rapidly deployed as part of teaching methods by various education sectors, including engineering.

Transference of any engineering educational courses to an online model requires the consideration of both distinct engineering-learning aspects comprising of theoretical and practical knowledge [3]. There are many web-based e-learning platforms available accommodating the conversion of engineering theoretical teaching material to online model using HTML, SMIL, XML, and many other multimedia tools and editors [3]. However, converting the engineering laboratories to the online accessible version that provides students with the real feel of in-person experiments is a complex challenge and requires the evaluation and utilization of the current technology in the design process to acquire the laboratory objectives [3].

The academic course quality assurance evaluation is the responsibility of a professional body in each country to ensure the courses are meeting 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" [45]. The "*Engineering Australia Policy on Accreditation of Programs Offered in Distance Mode*" document (Appendix A) highlights the requirements for providing a remote laboratory and experimental environment equivalent to the one delivered in person [46].

Thus, online laboratories are required as part of any online engineering courses to be accredited in Australia.

To address the requirements for online engineering laboratories, simulators and remote laboratories were created as experimental environment models.

### **2.6.1 Online simulation**

Engineering educational simulations are software programs either installed on a client PC or accessed through a web browser, that substitutes the physical laboratory for representing and training the engineering practical learning materials [3]. Some of the exceptional simulation programs that effectively replicated the real environment are MATLAB/SIMULINK, P-Spice [3], and Cisco Packet Tracer. Simulators are considered to be more effective by engineering educators in the following situations:

- During laboratory preparation exercises while students familiarize themselves with the experimental environment and improve the laboratory skill;
- To enhance the student experience with a practical performance before performing the same experimental task in the real laboratory;
- Replicating the large, complex, expensive, and dangerous systems.

Although simulators are considered to be an effective solution for some situations, they are not capable of completely replacing the physical laboratories due to the following limitations:

1. The real laboratory system must be formalized by mathematical function for the close to reality simulation model through a long, tedious and expensive procedure [47] makes it impractical to produce several simulators for various teaching units.
2. Simulation software is the mathematical representations of the real system and the results it produces are artificial and in most cases dependent on users' software competency level, so it cannot be considered as the exact replacement of real experiments [3].

3. To reflect any updates and expansion in the real system, the simulation package requires an expensive full revision process [3].
4. Simulation software does not provide an environment for learning safety and laboratory ethics [3].
5. Students trained using simulated environment lack competency in using the real equipment [3].
6. Simulation programs have limited parameters and scenarios, restricting students in a confined environment that reduces students learning interest and innovation [3].

These drawbacks emerged educators and researchers to create a more substantial laboratory environment for online engineering education.

### 2.6.2 Online Remote Laboratory

The online remote laboratory is a system providing remote access to real laboratory equipment giving students abilities to configure real devices and observe the results through a web browser [3]. In general, any online laboratory is a client-server system in which a web browser in the client machine interacts with laboratory equipment via server over the Internet. Figure 2-4 illustrates the basic design of a remote laboratory.

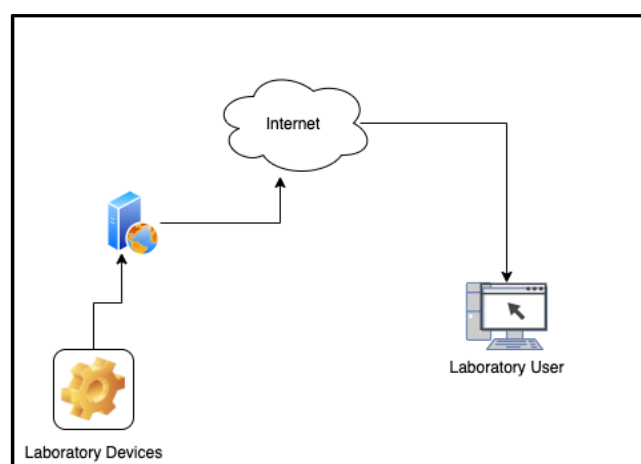


Figure 2-4 - Remote Laboratory Basic Design

The services and opportunities created by the online remote laboratory system accomplished and enhanced a various number of requirements for practical division of engineering education for both online/distance and in-person learning environment and research collaboration [48].

Following are the fundamental characteristics of online remote laboratories:

#### **2.6.2.1 Availability and scalability**

One significant beneficial characteristics of the online remote laboratory are the geographically and time independence availability that does not exist in conventional experimental laboratories and is a conditional ability in simulators. Utilization of web browser as an interface to interact with real devices provides the 24/7 availability for remote online laboratory while this ability in the simulation environment is subject to obtaining and installation of simulator software.

While the necessity and benefits of an online laboratory for distance learning are apparent, it can also be considered as a valuable environment for local students to enhance engineering practical knowledge by providing continuous availability. The teaching model in engineering education may require each student to perform certain laboratory activities in a defined limited period. However, with the confined laboratory operation time, this may result in either quality reduction or exclusion of some students. Whereas with online laboratory students have more flexibility with the time to perform the experiments and the ability to repeat them [48].

Expanding, upgrading and updating the remote laboratory is similar to a physical laboratory that requires obtaining new equipment. These tasks can be simpler and more economical in the simulation environment depending on the type of simulator software.

#### **2.6.2.2 Real Equipment Experience**

Simulator based laboratories are not successful in creating a realistic experience as a physical laboratory environment and rate poorly in delivering the knowledge required for students practical skills in engineering education [3]. However online laboratories potentially are capable of replicating the real experimental environment via the utilization of real devices accessed through the Internet that gives students the opportunities to configure and interact

with real equipment rather than predefined simulation scenarios for better achievement of relevant and appropriate engineering practical skills [3].

The authenticity of online laboratory experiments depends significantly on the quality and HCI design of the user interface.

### **2.6.2.3 Remote system operation skill**

While student performs experimental activities in an online laboratory environment, they develop competencies in controlling remote equipment and effective usage of technologies that are significant attributes in the contemporary self-regulated educational model and learner autonomy mentioned earlier [49].

Also, the exponential growth and adoption of ubiquitous computing environment modified the concepts of traditional workspace and occupation perceptions. In this current environment, employees are not restricted to office spaces and expected to operate anywhere and anytime using remote online access, therefore experience with online laboratories and the ability to control and manage devices remotely prepare students for their future career.

### **2.6.2.4 Cost reduction**

Several resources are required in the design and implementation of an engineering laboratory experimental environment including laboratory devices, physical spaces to run the experiments, technical and professional staff to teach and run the laboratory in a safe atmosphere.

Although the same number of resources are required in setting up an online laboratory, there is potential to lower the expenses with the time and geographical independence availability of the system. Since the laboratory environment is accessible at any time and students are not restricted to perform the experimental tasks simultaneously, the quantity of laboratory equipment can be reduced for the same number of students compared to the physical laboratory. Also smaller spaces are required to store the experimental equipment as they are accessed remotely and it is unnecessary to design large laboratory rooms for students attendance [48].

Direct supervision and safety monitoring is not required during the experimental operation in the online laboratory as students are remotely

accessing the devices in a controlled environment reducing the number of technical staff for running the laboratory [48].

#### **2.6.2.5 Collaboration**

A remote laboratory setting can offer a more effective collaboration environment, as users are not geographically restricted. Students from different universities in different part of the world can collaborate in performing a laboratory task or research project. In this collaborative environment not only the lab resources are distributed, but the knowledge and the professional skills are efficiently shared as well. The experienced instructors in a different area of teaching are able to demonstrate the laboratory task for students from any Internet-connected location. In this collaborative zone, education can be offered to students leaving in rural areas where there is no training service [49].

#### **2.6.2.6 Teaching tools**

There is no doubt that the ability to demonstrate related laboratory experiments while teaching the engineering theoretical subject enhances students learning and helps them understand the topic more effectively. While both simulation and online laboratory environment can be used as teaching recourses to demonstrate practical concepts to support the theories during the lecture, the online laboratory is the one capable of giving the feel of the real environment to students.

### **2.6.3 Online remote laboratory pedagogies**

Earlier in this chapter, the four major learning theories were explained as the foundation of pedagogies development.

The learning theories are the foundation of pedagogies development therefore it is imperative to acquire theory/theories that best correspond to the educational environment for the adequate design of teaching approaches. While all learning theories produce the philosophical position to explain the nature of knowledge (except connectivism) and people learning process, to apply the theory in practice, educators are required to have a comprehensive perception of the educational environment and characteristics for developing the teaching strategies, approaches and methods based on the most corresponding learning theory/theories [50].



Behaviourism observes the measurable and predictable trait of human behaviour and describes the human learning behaviour as the process of producing a defined response to particular stimuli considering punishment and reward as the main driver of learning while declining the influence of immeasurable behavioural aspects such as consciousness and attitudes [50]. However, knowledge acquisition approaches in online laboratory educational environment such as self-regulated and collaborative learning considered complex procedure relying on individual capabilities that cannot be explained with the simple stimuli-response process defined in behaviourism.

Cognitivism theory emphasizes brain complexity and the influence of an individual's thoughts, experience and senses in the learning process while believes that knowledge acquisition is occurring in cognitive development stages [24] considering the brain processing function as a computer program [50]. Cognitivism promotes an active educational environment that corresponds to online laboratory teaching and learning system however the idea of restricting the learning process in predefined cognitive stages [24] and computational presentation of brain activity disregards the individualism and complexity of the human mind [50].

Individual abilities are extensively highlighted in constructivism and the importance of social environment, pre-existing experience, and consciousness in constructing knowledge in learners mind are emphasized [50]. Constructivist teaching methods concentrate on the active educational environment and self-regulated learning model that aligns with online laboratory teaching and learning objectives.

The new connectivism theory is less philosophical and more applicable compared to the preceding learning theories. In this theory, the main attention is on acquiring knowledge by individual contributors through the flow of information in the networked environment [50]. Teachers are responsible to create educational resources facilitating collaboration and autonomy in learning that provides students with the ability to build their learning environment and connect to network nodes for knowledge acquisition [50]. Evidently, the online laboratory environment is very similar to the educational environment proposed by connectivism theory.

The online engineering laboratory environment is considered as a complex system that promotes interactive liberal learning and its theoretical foundation can be explained under constructivism, connectivism and in some extends cognitivism learning theories hence pedagogies and frameworks ought to follow the principle of these theories.

## **2.7 Summary**

From the background study presented in this chapter, it can be concluded that the educational environment is moving toward blended and online learning to address modern society requirements. While laboratories are a significant part of the engineering educational materials, it is essential to create an online model for practical experiments.

However, the learning objectives, pedagogies, and educational frameworks that applied to in-person classrooms require variations to address the new environment. These variations and the development of new pedagogies must be supported by learning theory/theories and philosophy/philosophies.

Among all learning theories explained in this chapter, behaviourism has none or limited usage in modern education, while cognitivism and constructivism are receiving more attention from educators. However, there are still some shortcomings in these two theories for the digital age learning environment that researchers attempt to address by developing the new connectivism theory. The science and engineering online laboratories are the combinations of educational materials that can be developed using cognitivism and constructivism and the implementation of these materials in a digital environment that is more in line with connectivism.

## Chapter3: Research Methodologies

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### 3.1 Introduction

The chapter two literature review on the development of pedagogies for delivering science and engineering remote laboratory signified the importance of understanding the learning theories that best corresponds to educational material and the effective design of the laboratory environment providing real-world experience. The research methodology of this thesis is established on principles provided by these two fields giving profundity to this study.

This chapter explains the methodology and conceptual design deployed in response to the following research question based on the study topic.

***How an online remote accessible laboratory design can be effective, efficient, and practical in teaching science and engineering?***

The research is divided into two sections, first is an engineering design project, conducted by creating the “best practice” online remote laboratory experimental environment and the second part is the engineering education study that examined the effectiveness, efficiency, and practicality of applied pedagogies and frameworks based on learning theories by observing students’ satisfaction level and technical aspects of the design.

The research methodology is presented in 5 sections in this chapter starting with the research paradigm and approaches in the first two sections followed by strategy and research design in section three. Section four explains the methods used for data collection and analysis then the chapter ends with the research ethics, reliability, validity, generalizability and limitations.

### 3.2 Research paradigm

To structure a study based on the research question stated in section one, it is necessary to collect data using both qualitative and quantitative methods. The quantitative data collected from the online laboratory log reporting section and survey questions presenting the utilization percentage and significant changes in the usage pattern of the system [51] provide abstract and general information about the experimental environment [52]. However,

by relying on quantitative information as the single method the individual's behaviour and experiences are omitted and it is unlikely to study some part of research problems specifically aspects such as effectiveness and practicality of the system.

Accordingly, the survey was designed to collect qualitative data simultaneously to create contextual or "thick" description of effectiveness, efficiency and practicality of the online laboratory in engineering education [51]. Likewise using the qualitative method as the only source of data is not feasible due to its subjectivity, dependency on the study group's individuality, and influence from the researcher's bias.

Therefore, to obtain the optimal answer to the research question, add credibility to the study, and for a complete and comprehensive understanding of the research problem, a selection of approaches is required. Based on this condition the philosophy of the research is considered as pragmatism that encourages the mixed-method paradigm [52].

Creswell et al. define mixed-method research as: "A mixed methods study involves the collection or analysis of both quantitative and/or qualitative data in a single study in which the data are collected concurrently or sequentially, are given a priority and involve the integration of the data at one or more stages in the process of research" [53].

In this research, the qualitative and quantitative data were collected and analyzed concurrently while integrated frequently throughout the research process.

### **3.3 Approach**

Among many available research approaches, the most suitable one when multiple methods are employed to collect and analyze the data is *methodological triangulation* [54]. Originally the triangulation term is used when the position of the unknown point is calculated using two fixed points with the defined distance using trigonometry calculation [54].

The term triangulation for research design was first used and encouraged by Norman K. Denzin as an approach to combine complementary research methods [55] to increase the study accuracy and comprehensive understanding of a phenomenon [54].

The concurrent qualitative and quantitative data collected from online laboratory log reports and student observations from the survey are analyzed and interpreted to examine the effectiveness, efficiency and practicality of the experimental system and evaluate the designed curriculum to establish framework and pedagogies for delivering the remote laboratory as illustrated in Figure 3-1.

The methodological triangulation approach is categorized into within-method and between-method. In within-method, one type of data (either qualitative or quantitative) is collected from more than one source, and in between-method, both types of data (qualitative and quantitative) are used in the same study [54].

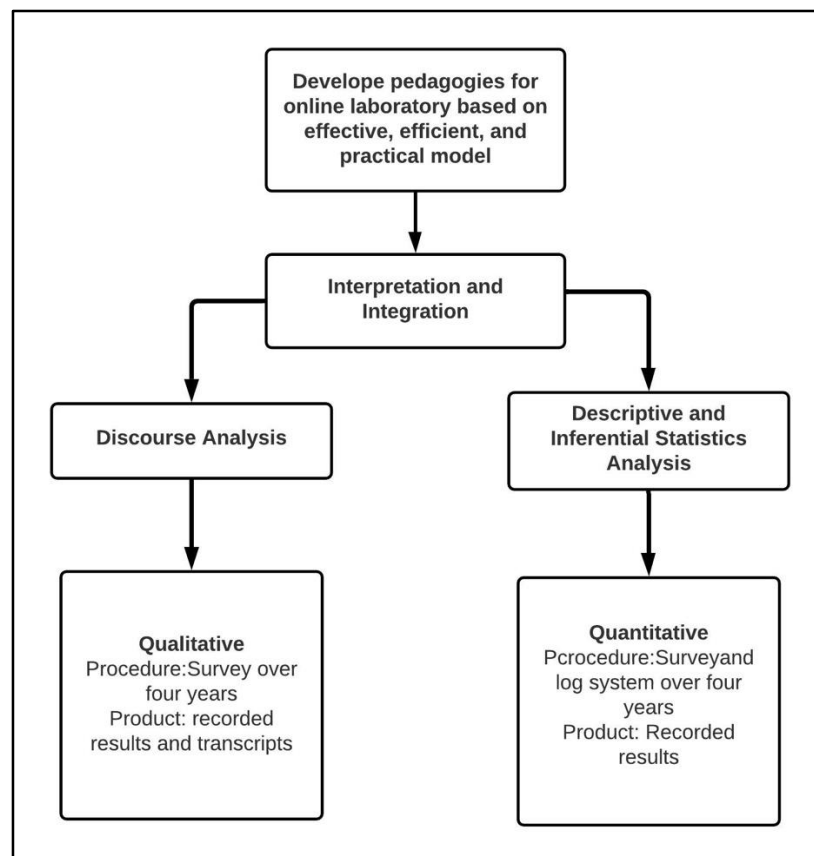


Figure 3-1-Between-Method Triangulation Approach

The fact that both qualitative and quantitative methods are applied in this study, the research approach is considered “between-method triangulation” [55].

### 3.4 Strategy and research design

Referring to the research question to evaluate the effectiveness, efficiency and practicality of the online laboratory for engineering education an experimental environment to conduct an empirical study for measurement of these factors and tactics to record and observe the users experience is essential.

To address these requirements a combination of *experiment* and *survey* research strategies was employed in this research [56].

#### 3.4.1 Experiment strategy

An online laboratory system was developed using the engineering design methodology to create an environment for the experimental study on the hypothesis stated that ***the availability of online laboratory has positive effects on engineering education.***

The investigation of cause and effect relationship between online laboratory utilization as an independent variable and positive effects on engineering education as a dependent variable was conducted by collecting qualitative and quantitative data using system usage report (Figure 3-2) and survey [56].

POD USAGE EARLIEST to NOW				
ID	NAME	TYPE	LABS	HOURS
1	Pod01-Multipurpose-ASA	AE Multi-purpose Academy Pod with ASA	1059.0	1930.4
2	Pod02-Multipurpose-ASA	AE Multi-purpose Academy Pod with ASA	502.0	856.9
3	Pod03-Multipurpose-noASA	AE Multi-purpose Academy Pod	486.0	440.9
1005	AdvCommEngPod03	NDG 1 Host Pod	209.0	316.1
1003	AdvCommEngPod01	NDG 1 Host Pod	273.0	259.4
5	Pod04-Multipurpose-noASA	AE Multi-purpose Academy Pod	194.0	228.9
1009	GEEP POD 01	NDG 1 Host Pod	58.0	134.3
1000	GEEP POD 02	NDG 1 Host Pod	56.0	118.5
1004	AdvCommEngPod02	NDG 1 Host Pod	135.0	110.1
1006	AdvCommEngPod04	NDG 1 Host Pod	67.0	55.2
1001	MCU01	NDG 1 Host Pod	28.0	53.0
1007	AdvCommEngPod05	NDG 1 Host Pod	56.0	43.3
1008	AdvCommEngPod06	NDG 1 Host Pod	48.0	39.5
1002	Embedded	NDG 1 Host Pod	18.0	18.6
4	Wireless	Wireless	6.0	15.8
1011	RedHat_Pod01	RHSA7	3.0	0.2
1010	RedHat_Master	RHSA7	1.0	0.0
TOTAL			3199.0	4621.1

Figure 3-2 - Remote Laboratory Usage Log System

For research accuracy and effective investigation of the hypothesis in the experiment strategy, the dependent variable was measured while

manipulating the independent variable [56]. Hence the effect of the experimental environment on engineering education was observed for several different laboratory setups implemented and tested on the online laboratory.

Also, the various factors influencing the experimental online laboratory were controlled by isolated design nature of this environment to ensure the accuracy of measured values [56].

### **3.4.2 Survey strategy**

A survey strategy is used to capture the user's observations and experiences on the experimental online laboratory in the form of qualitative and quantitative data for an analytical study on user's satisfaction without recording the identity of participants.

The survey was accessible via a student portal and participants were encouraged to fill in the survey throughout the course.

Since this survey is aimed at students as exploratory sample who experienced the online laboratory system, the sampling technique is considered purposive where participants are selected based on the specific knowledge they can provide to enhance the investigation results [56].

## **3.5 Data collection method**

Data collection is considered as the foundation of any research study that is performed using different methods based on the study purpose and condition [56].

The two methods selected for this study to collect both qualitative and quantitative information are *questionnaire* and *observation*.

### **3.5.1 Questionnaire**

A list of questions in the form of closed, open, and Likert-scale was produced and presented as an online survey available on the student portal.

The questions were brief, relevant to study purpose, easy to interpret and unambiguous, clear and specific, and objective [57]. Also to avoid overwhelming participants with a long questionnaire, a limited number of questions was included in the survey [56]. The pilot version of the

questionnaire was tested to determine questions clarity, comprehension and time efficiency [56].

### **3.5.2 Observation**

In “observation method” the usage of online laboratory and students task performance was directly observed using experimental environment log report system and student work monitoring. The participant observation provided the holistic and in-depth understanding of students’ experience of online laboratory and produced the context-sensitive results [56].

## **3.6 Data analysis method**

Data analysis is the process of interpretation of the raw data into meaningful information. Since this research follows the mixed-method paradigm and triangulation approach, both qualitative and quantitative methods are required to analyze the data.

### **3.6.1 Qualitative data analysis**

The qualitative data collected from the open question in the survey, observation, and students’ feedback were investigated and interpreted using discourse analysis. In this method, the aim is to extract the hidden meaning of the qualitative data such as text, highlighting the intentions of the participant as the significance point not the direct meaning of words [56].

The qualitative data analysis in this research is a form of inductive reasoning that observes students’ experience with the online laboratory to produce theories on creating the best practice educational model.

### **3.6.2 Quantitative data analysis**

The descriptive and inferential statistical analysis was performed on ordinal and ratio quantitative data collected in the research [56]. Ordinal data were collected from the Likert-scale questions that expected students to rate their experience with the online laboratory environment and the ratio data was gathered from closed questions, system usage log report, and student results.

The quantitative data analysis in this research follows the deductive reasoning that examines the hypothesis using statistical methods.



### **3.7 Ethical concerns**

This research like any other research was required to adhere to the ethical principles [58].

#### **3.7.1 The public interest**

The educational division including schools, institutions and universities will benefit from the online laboratory environment and pedagogical framework developed in this study for their remote and blended teaching and learning environment and there is no harm associated with the usage of the developed system.

#### **3.7.2 Informed consent**

The participants' details were not collected as they were anonymously and voluntarily contributing to the research data collection. However, according to Curtin University requirement based on National Statement on Ethical Conduct in Research (2007) (Updated May 2015), the Human Ethics document was submitted and approved by Curtin Human Research Ethics Committee (approval number: 11078).

#### **3.7.3 Privacy**

To protect the privacy of research survey' participants, personal details were not recorded and users' private information including name, student ID and email address is only accessible by course instructor/s for the duration of their enrollment.

### **3.8 Reliability, validity, and generalizability**

This research is an extension to the Cisco Academy for Vision Impaired (CAVI) program introduced by Curtin University in 2002 that primarily focused on remote teaching techniques including laboratory environment [59]. The researcher of this study was directly involved with the enhancement and expansion of CAVI program since 2007, extending the online environment to various courses, including mainstream students, and the development of the current online laboratory system. To ensure the quality, usability, and technical practicality of the new system, several evaluation processes were conducted before presenting the online laboratory as the integrated part of several teaching units. Next, the online laboratory was offered to students as

an addition to the laboratory component of six teaching units and number of educational experiments, while observed and investigated over six semesters.

Throughout the research, the effectiveness, efficiency and practicality of the online laboratory were investigated from different angles such as authenticity, environment usability, level of user interaction with the system, and the scalability and reliability of the setup for the enhancement of engineering education. The acquired framework and pedagogies for delivering the engineering educational material in online laboratories can be distributed among other science education disciplines in which the hardware can be accessed via the Internet directly or indirectly (through the virtual machine) as explained in Chapter4:Experiment Design.

### **3.9 Limitation**

The major limitation of this study was the low bandwidth problem in some international institutions and universities participating in the research that produced the non-optimal experience with the system. However, several improvements implemented throughout the research to minimize the effects of this constraint and recommendations are presented in Chapter7:Conclusion and Recommendations.

### **3.10 Summary**

This study is considered as a combination of engineering design and engineering education research that demands a flexible methodology with the freedom of selecting method/s based on the research requirement. Therefore, the pragmatism philosophy with the focus on mixed-method methodology paradigm was selected to combine qualitative and quantitative research methods and address the essential requirements of the study. The *between-method triangulation* approach was used to investigate the research problem by combining, interpreting, and integrating the observation results from qualitative and quantitative methods.

*Experiment* and *survey* were the two research strategies employed in the study design to collect and analyze the data concurrently.

For data collection *questionnaire* and *observation*, methods were used while *discourse* for qualitative data and *descriptive and inferential statistics* for quantitative data was used as analysis methods.

The ethics approval documents were submitted and approved by the Curtin Human Research Ethics Committee for conducting the survey and observing student experience in the experimental environment (approval number: 11078). The implementation of the online laboratory in various courses and data collection, observation, and analysis in an extended timeframe ensure the reliability and validity of the study and it has been indicated that based on the outcome of this research the design can be extended to the other area of science and engineering.

Philosophy	Paradigm	Approach	Strategies	Data Collection	Data Analysis
Pragmatic	Qualitative and Quantitative	Between-Method Triangulation	Experiment and Survey	Questionnaires And Observation	<i>Discourse analysis (Inductive)</i> <i>Descriptive and Inferential Statistics (deductive)</i>

Table 3.1 - Summary of Research Methodologies

In the end, the low bandwidth experienced by international research partners was denoted as a limitation in this study. A summary of the research methodology requirements is presented in Table 3.1.

The next chapter explains how the experimental model, laboratory setups, educational programs, and taxonomy were selected for this study.

## Chapter4: Experiment Design

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### 4.1 Introduction

This chapter is intended to explain the conceptual design and implementation of the remote laboratory based on the pedagogical study. The online laboratory was designed considering the importance of practical experiments in engineering courses for the blended, remote and in-person classrooms. In this chapter, the experiment design is explained based on the engineering design process model illustrated in Figure 4-1. This model contains four main stages including design, prototype, test and evaluate, and research. The feedback is provided in each stage for refining and improving reasons. These improvements are also relying on the feedback from previous and next stages. For example, based on the feedback from the prototype stage, changes may apply to the design. All engineering designs start with identifying the problem or need that is an online laboratory system in this research. The information is gathered to determine the best design model possible, then it is built as a prototype for testing. In the next stage evaluation methods are used to test the prototyped model and the results are used to refine the design and prototype until the optimal model is reached. The research stage is taking place at the beginning of developing the initial design, throughout the implementation to refine the design, and after collecting evaluation data for further improvement.

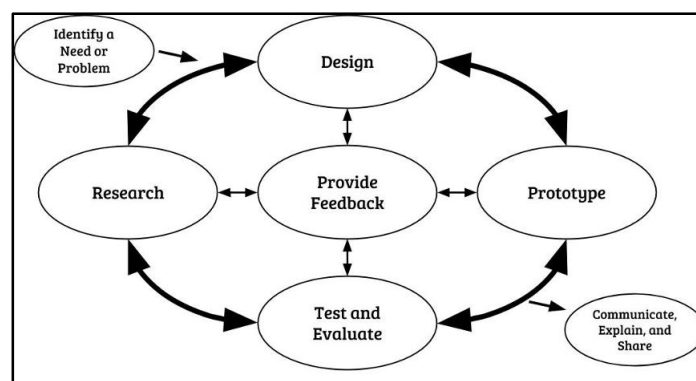


Figure 4-1- Engineering Design Process [60]

In this chapter, first, the motives in selecting the remote environment are explained following by a study on the educational framework, then the optimised online laboratory environment is presented as an experimental model.

## **4.2 Remote laboratory environment**

The concept of the new online laboratory was originated from the experience in the Cisco Academy for Vision Impaired (CAVI) program established in 2002 and expanded to an online course in 2004. The online laboratory implemented in the CAVI program has successfully created the opportunity for vision-impaired students to perform advanced IT courses' laboratory experiments remotely.

The new online laboratory is designed to extend the user audience from vision-impaired learners to mainstream students and incorporate more laboratories from a variety of engineering courses while studying the methods for enhancing the experience of laboratory experiment performance in a remote environment.

Also, the feasibility of using the remote laboratory was examined for engineering-based courses in the new growing open online environment model such as a MOOC (Massive Open Online Course). These open online courses are currently attracting a great number of students and for engineering content, they require a scalable laboratory set up with easy access over the Internet.

### **4.2.1 Base system**

The ability to study remotely is the key determination for students with disabilities to adopt e-learning and web-based educational applications. The existing potential in these types of educational applications provide various opportunities for educators to develop and teach courses in numerous educational fields including science and engineering. However, the e-learning and web-based applications are predominantly presenting educational materials in a graphical format that makes them inaccessible for blind and vision-impaired students [51, 61].

The existing inaccessibility problems in these types of environments creates a great obstacle for vision-impaired students training especially in the media-

rich educational field such as science and engineering. This is in contradiction of Article 26 of the United Nation universal declaration of human right that states “ higher education shall be equally accessible to all on the basis of merit” [62].

One of the main hurdles in designing the science and engineering e-learning environment is the development of accessible laboratory applications.

In 2004 Curtin University developed an accessible e-learning environment in an attempt to facilitate educational opportunities for vision-impaired students. This program was based on the Cisco Networking Academy Program (CNAP) offered to mainstream students as part of the bachelor degree in computer systems and networking course.

#### **4.2.2 Cisco Networking Academy Program (CNAP)**

The Cisco Networking Academy Program (CNAP) is a global blended learning environment developed by Cisco Systems as part of their economical and philanthropic strategies. CNAP offers competency-based training courses in Information and Communication Technology (ICT) with a focus on design, configuration, security, and troubleshooting communication networks [63]. Cisco Systems offers free academy partnership to schools, higher educational institutions, government and not-for-profit organizations globally. This includes the learning materials, online assessments, and educational tools along with training courses for educators. Where Cisco Networking Academies are responsible for providing qualified instructor and educational facilities required for teaching the CNAP courses [64].

Over 7 million students and 22000 educators in 180 countries joined CNAP over the past 20 years since its first official launch in 1997 [65]. The instructional model used in CNAP creates a comprehensive blended learning environment that is widely adopted by a wide range of users. This instructional model includes a robust learning management system presented as a portal (Figure 4-2) that facilitates instructors to access the learning material, manage enrolments, online assessment activation, and monitor student progress in provided grade-book [66].

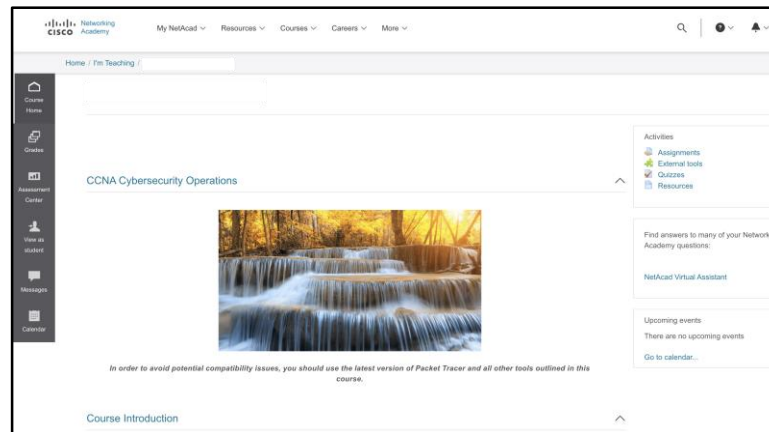


Figure 4-2 - Cisco Networking Academy Portal [65]

All programs offered in the Cisco Networking Academy can be delivered in a blended learning environment with the benefit of incorporating the following six components:

1. Instructor-led lessons: CNAP instructors are required to attend extensive hours of training programs to be qualified for teaching the course materials. Instructors present educational materials using traditional teaching methods such as lectures, workshop, and discussion [66].
2. Online learning curricula: the course materials are accessible through the Cisco Academy website for registered students and presented in the form of an e-book with the ability to navigate through the chapters and topics, search the chapters, receive feedback by completing the quizzes, and access extra information through various available links [66].
3. Self-paced lessons: the online availability and accessibility of the whole CNAP course material facilitate students' self-study [66].
4. Course index is an effective search tool to navigate through the CNAP curricula [66].
5. Laboratory work: to enhance students' learning experience, there are incorporated laboratory experiments within the chapters of CNAP courses. Students are expected to perform the laboratory tasks either

using a provided simulator (Packet Tracer) or hands-on in-class experiments [66].

6. Assessments: there are several assessments in the CNAP courses to help evaluate the learning outcomes. The Final Assessment testing the course theoretical knowledge and Practical Skill Assessment evaluating the hands-on ability are the compulsory exams. The Chapter assessments are recommended for Final and Skill assessment preparation. And quizzes are designed for student's self-knowledge evaluation practice [66].

Based on all the above information, it is concluded that CNAP is a good example of a comprehensive e-learning educational model. As has been mentioned in the earlier part of this chapter, the study subject of this thesis is based on the work done in the CAVI program. Both the CAVI program and this study are using CNAP as the test environment. CAVI uses the whole program to examine and study the feasibility of teaching ICT courses to vision impaired and blind students, however, the main focus of this study is on the design of a fully online and remote laboratory based on the CNAP. It also includes the development of a framework for delivering practical materials in the remote laboratory.

To study or create any educational models, pedagogies, and programs it is vital to clearly describe what is the expectation of the student's knowledge outcome and how they are going to attain this knowledge. Educational framework and taxonomies are the best methods to classify and develop these objectives.

J.F van Niekerk and K Thomson discuss that CNAP educational material objectives could be placed in the Bloom's Taxonomy table [66].

The next section of this chapter explains what is Bloom's Taxonomy and how it categorizes the educational objectives.

### **4.3 Taxonomy**

*What should students accomplish after completing the educational program?*

This is a fundamental question that needs to be addressed at the very first stage of developing any educational materials. Generally, the educational designers and developers present the answer to this question in the set of



objectives that covers the different aspects of the teaching subject. Even though objectives are created to assist with standardizing the educational content development, the lack of classification method results in a large number of unclear objectives. Therefore, the objective statements are required to be organized in a framework where they are precisely defined.

A framework breaks each phenomenon into several categories, each category includes objects, experience, and ideas that share the same characteristics. A set of organizing principles are used to classify the characteristics of each category. This classification assists educators with understanding and identifying each category content [67].

In science, a type of classification system or framework that places the categories along a continuum is called a taxonomy. The categories in taxonomy change gradually and are not noticeably different from the adjacent one therefore they are placed in a continuous system or continuum. An example of a continuum is the light spectrum that wave frequencies are used to organise the colour of the light. Taxonomy uses the continuum as an organizing principle to classify and distinguish between the categories. It means that categories are related but they have slightly different characteristics [67].

#### **4.3.1 Bloom's Taxonomy**

Bloom's Taxonomy is the most common taxonomy in education that takes objectives as categories and classifies them along a continuum. A group of cognitive psychologists led by Benjamin Bloom developed and published the original version of this taxonomy in a book named "*Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook 1: Cognitive Domain*" in 1956. In 2001 the revised version was published in another book under the title "A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives" [68].

Each objective statement describes the cognitive process that is required for students to acquire the intended knowledge. Commonly each objective statement comprises two main parts, a verb that explains the cognitive process and a noun that defines the intended knowledge. For example, in the objective statement: *calculate the area of geometric shapes*, the cognitive

process is described by the verb calculate and the area of geometric shapes is the knowledge that student needs to learn.

In the revised version of Bloom’s Taxonomy, the cognitive process and the knowledge form the two dimensions of the system and their interrelationships are presented as a taxonomy table (Table 4.1).

		Cognitive Process Dimension →					
		1. Remember:	2. Understand:	3. Apply:	4. Analyze:	5. Evaluate:	6. Create:
Knowledge Dimension ↓	<p><i>This revised Bloom’s Taxonomy will assist you as you work to improve instruction to ensure that</i></p> <ul style="list-style-type: none"> <li><i>standards, lessons, and assessments are aligned.</i></li> <li><i>lessons are cognitively rich.</i></li> <li><i>instructional opportunities are not missed.</i></li> </ul>	<p><b>1. Remember:</b> retrieving relevant knowledge from long term memory</p> <ol style="list-style-type: none"> <li>Recognizing</li> <li>Recalling</li> </ol>	<p><b>2. Understand:</b> determining the meaning of instructional messages</p> <ol style="list-style-type: none"> <li>Interpreting</li> <li>Exemplifying</li> <li>Classifying</li> <li>Summarizing</li> <li>Inferring</li> <li>Comparing</li> <li>Explaining</li> </ol>	<p><b>3. Apply:</b> carrying out or using a procedure in a given situation</p> <ol style="list-style-type: none"> <li>Executing</li> <li>Implementing</li> </ol>	<p><b>4. Analyze:</b> Breaking material into its constituent parts and detecting how the parts relate to one another and to an overall structure or purpose</p> <ol style="list-style-type: none"> <li>Differentiating</li> <li>Organizing,</li> <li>Attributing</li> </ol>	<p><b>5. Evaluate:</b> making judgments based on criteria and standards</p> <ol style="list-style-type: none"> <li>Checking</li> <li>Critiquing</li> </ol>	<p><b>6. Create:</b> putting elements together to form a novel, coherent whole or make an original product</p> <ol style="list-style-type: none"> <li>Generating</li> <li>Planning</li> <li>Producing</li> </ol>
	<p><b>A. Factual Knowledge:</b> basic elements that students must know to be acquainted with a discipline or solve a problem in it</p> <ol style="list-style-type: none"> <li>Knowledge of terminology</li> <li>Knowledge of specific details and elements</li> </ol>						
	<p><b>B. Conceptual knowledge:</b> the inter-relationships among the basic elements within a larger structure that enable them to function together</p> <ol style="list-style-type: none"> <li>Knowledge of classification</li> <li>Knowledge of principles and generalizations</li> <li>Knowledge of theories, models and structures</li> </ol>						
	<p><b>C. Procedural knowledge:</b> how to do something; methods of inquiry, and criteria for using skills, algorithms, techniques and methods</p> <ol style="list-style-type: none"> <li>Knowledge of subject specific skills and algorithms</li> <li>Knowledge of techniques and methods</li> <li>Knowledge of criteria for determining when to use appropriate procedures</li> </ol>						
	<p><b>D. Metacognitive knowledge:</b> knowledge of cognition in general as well as awareness of one’s own cognition</p> <ol style="list-style-type: none"> <li>Strategic knowledge</li> <li>Cognitive tasks, including appropriate contextual and conditional knowledge</li> <li>Self-knowledge</li> </ol>						

Table 4.1- Bloom Taxonomy Table (revised) [67]

As shown in Table 4.1, the cognitive process is defined in six categories: Remember, Understand, Apply, Analyze, Evaluate, and Create. Likewise, knowledge is categorized into four sections: Factual, Conceptual, Procedural, and Metacognitive.

In the cognitive process dimension, the cognitive complexity increases as we move from the first category or Remember to the sixth category or create. Therefore, cognitive complexity is the continuum of the cognitive process.

The continuum of knowledge dimension organizes the categories from concrete to abstract. Factual knowledge is known to be concrete where Metacognitive knowledge is abstract [67].

Each category in the two dimensions of the taxonomy is further explained in the next section.

### 4.3.1.1 Knowledge categories

**Factual knowledge** is the significant information associated with a subject matter. This information comprises basic elements or bits of information that are associated with some concrete referent presenting important data about the subject matter or discipline and are constant among different applications. This is essential knowledge for acquaintance with any academic discipline and solving problems within it. Factual knowledge is a base knowledge of the learning process; therefore, it can be described as more concrete and less abstract. Factual knowledge divides into two major types; “*Knowledge of terminology*” such as knowledge of scientific terms (e.g., electrons, voltage, waveform) and “*knowledge of specific details and elements*” such as knowledge of the main type of computer network protocols [67].

**Conceptual knowledge** is more complex than factual knowledge and is related to categorizing and classifying knowledge and explaining the association between them. This knowledge explains the individual thought process on how a subject matter is categorized into basic elements or bits of information, how these bits of information are associate with each other, and how they work together by using different cognitive psychological models.

Conceptual knowledge is presented in three subtypes: *knowledge of classifications and categories (Ba)* such as type of network topologies, *knowledge of principles and generalizations (Bb)* such as Metcalfe’s law in telecommunication, and *knowledge of theories, models, and structures (Bc)* such as connectivity testing strategy in a computer network [67].

**Procedural knowledge** is a knowledge of how to use methods, techniques, algorithm and skills to perform a task. These tasks can be as easy as following a set of instructions to perform an exercise to problem-solving activities. Procedural knowledge is knowledge an individual has on how to decide which steps and sequences to take and when to take them in each academic discipline or subject matter [67].

Procedural knowledge can be divided into three categories: Knowledge of subject-specific skills and algorithms (Ca) such as knowledge on how to use a simulator program, Knowledge of subject-specific techniques and methods (Cb) such as using troubleshooting techniques to identify a network

disconnection, and knowledge of criteria for determining when to use appropriate procedural (Cc) such as criteria for selecting a network protocol in power-constrained devices.

**Metacognitive knowledge** also referred to as metacognitive awareness, is the knowledge that individuals have about their thinking and cognition. The development of students' knowledge of their cognition will enhance their learning experience.

Lorin W. Anderson et al [67], in the revised version of Bloom's Taxonomy, divided the metacognitive knowledge into 3 different areas including:

Strategic knowledge (Da) such as knowledge of various problem-solving strategies, knowledge about cognitive tasks (Db) such as different skill demand in analysing quantitative and qualitative data, and Self-knowledge (Dc) such as awareness of own knowledge in solving a problem using Fourier transform.

#### 4.3.1.2 Cognitive process categories

There are six categories in the cognition process and their level of complexity increases from category 1 to six.

**Remembering** is retrieving the taught materials in the same form they were presented to students. Recognizing and identifying are the two cognitive processes related to remembering. For example, if students are asked to find the area of the circle in Figure 4-3, they need to recall the method or formula of calculating the circumference and recognize the radius in the picture.

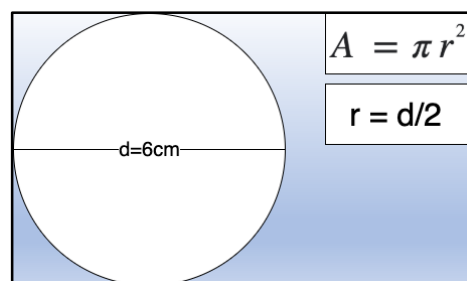


Figure 4-3 - Example- Area of a Circle

**Understand** is a cognitive process that aims to achieve transfer-based objectives using different forms of instructions. An example of these

instructions is a demonstration of a network device configuration using a simulation program during a lecture or laboratory session.

In Bloom's Taxonomy, understand is categorized into seven cognitive processes including interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining.

**Apply** is a cognitive process to use procedures to complete a task. This task can be performing a familiar exercise or solving a problem. Depending on the type of the task the cognitive process can be *executing* or *implementing*. To perform an exercise student is required to use a known procedure to achieve the goal which relates to *procedural knowledge* and categorized as the executing process. An example is area calculation of a basic geometric shape such triangle where the student already knows the formula and just need to substitute the numbers to the formula. However, in the problem-solving task, students do not know the exact procedure to perform the task. The first step to solve a problem is to understand it which requires the understanding of *conceptual knowledge*. Then in the second step students should be able to apply the *procedural knowledge* to create a specific solution for the problem. An example is a calculation of the area of a complex geometric shape where the known formula does not apply and student require to understand how to divide the shape into basic geometric shapes and apply the known procedure of calculating the area (Figure 4-4).

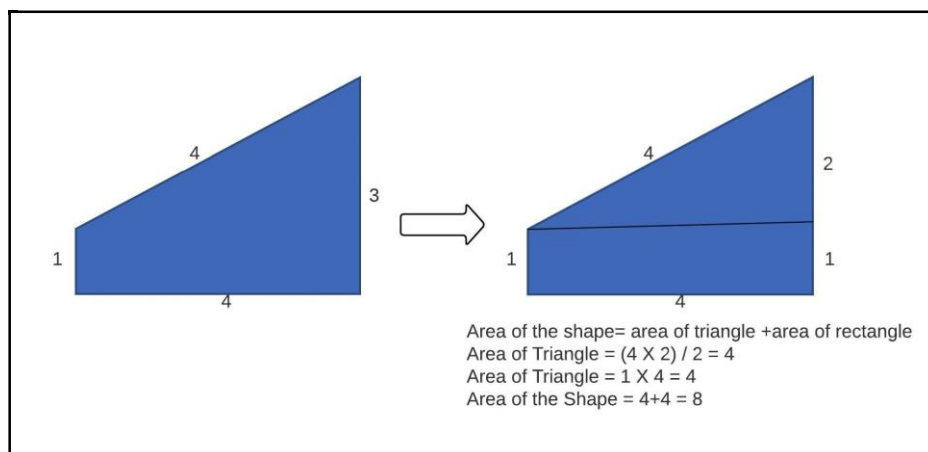


Figure 4-4 - Calculating the area of complex shape

**Analyse** is the fourth cognitive process in Bloom's Taxonomy which is a method of breaking the knowledge into its essential parts and defining the way these parts are associating with each other as well as their association

to the overall structure of the knowledge. Objectives that have to analyse as their cognitive process, are promoting three sections in the learning process.

1. Differentiating - identifying the constituent parts of the knowledge
2. Organizing - finding the organization methods of constituent parts of the knowledge
3. Attributing – recognizing the fundamental reasons for the knowledge.

**Evaluate** is a cognitive process of judgments according to criteria and qualitative/quantitative standards. Some of the most common criteria are quality, efficiency, consistency, and effectiveness. There are two categories in evaluating procedure. One is *checking* if there is any internal inconsistency such as testing any contradiction in a given material. The other category in evaluating process is critiquing in which a product or operation is judged based on criteria and standards imposed externally such as critiquing which low-power network protocol is more efficient or offers better quality in a specific design and environment. Since there is some form of judgment procedure in all six categories of cognitive processes, identifying the evaluate process might not be very clear. However, applying standards to defined criteria in evaluating judgment procedure is a unique characteristic that differentiates it from other cognitive processes.

**Create** is constructing a complete product by organizing knowledge elements and promotes deep understanding. The product is not presented to students before however, they create the structure based on their previously learnt experience. While in the other cognitive processes (understand, apply, and evaluate) students are identifying the relationship among given elements. To perform a task in an objective that is classified as creating, there is a high possibility to require sections of the other processes including understand, apply, and evaluate. however, it does not need to follow the taxonomy table order.

The create process can include structuring a unique and original product by students using their creative thinking skill. Although the main focus of objectives classified under create cognitive process are the products that all students are capable of creating them.

There are three stages in creating a procedure: in the first stage student understands the task and collects possible solutions (*generating*), the second stage student comes up with a solution and creates a plan of action (*Planning*), and the last stage is a plan execution (*Producing*).

### 4.3.2 CNAP and Bloom's Taxonomy

*J.F van Niekerk and K Thomson stated that the CNAP learning objectives can be categorized according to Bloom's Taxonomy based on the CNAP various content delivery mechanisms [66].*

Table 4.2 - shows some objectives from the course "CCNAv7. Introduction to Networks" in Cisco Networking Academy and demonstrates how they associate with the cognitive process and knowledge in Bloom's Taxonomy table.

The objective examples are:

*Objective 1- Explain how physical and data link layer protocols support the operation of Ethernet in a switched network. (2B)*

*Objective 2- Create IPv4 and IPv6 addressing schemes. (C6)*

*Objective 3 - Compare the characteristics of common types of networks. (4B)*

*Objective 4 - Verify network connectivity between devices. (5C)*

*Objective 5 - Use host and IOS commands to acquire information about the devices in a network. 3D*

*Objective 6 - Describe the four basic requirements of a reliable network. (2A)*

*Objective 7 - Identify the basic characteristics of copper cabling. (1 A)*

*Objective 8 - Calculate numbers between decimal and hexadecimal systems. (3C)*

Knowledge	Cognitive Process					
	1. Remember	2. Understand	3. Apply	4. Analyse	5. Evaluate	6. Create
A. Factual Knowledge	Objective 7	Objective 6				
B. Conceptual Knowledge		Objective 1		Objective 3		
C. Procedural Knowledge			Objective 8		Objective 4	Objective 2
D. Metacognitive Knowledge			Objective 5			

Table 4.2 - Example of Bloom's Taxonomy table for some of the objective in CCNAv7-Introduction to Networks course from CNAP

The process of identifying the corresponding cell for each objective starts with a verb and noun recognition in the statement then associating them with related knowledge and cognitive process. Considering that noun or noun phrases in the statement do not always include useful clues to identify the related knowledge. In these situations, further study and evaluation are required using multiple sources such as learning activities for accurate classification. For example, Objective 7 focuses on student learning skills in identifying a set of copper cable basic characteristics. The word *identify* is an alternative for *recognizing* which is a subtype of *Remember* cognitive process in Bloom's Taxonomy table. The noun that represents the knowledge is "basic characteristics of Copper cabling" which includes several facts about copper cables such as susceptibility to electronic noises, length limitation, and cost. Therefore, the knowledge can be classified as *factual* and this objective is placed in the lowest level of the cognitive process that is *Remember*. The learning process in objective 7 takes place by using practical activities to demonstrate the characteristics of copper cable such as interference and assessing student's knowledge through online quizzes or



assessments. These learning activities can also be classified according to Bloom's Taxonomy. With the same principles, other objectives are placed in the Bloom's Taxonomy Table 4.2. Objective 5 is another example that aims at a student's skill in using appropriate IOS commands to collect device information in a network. In this objective, students are going to *execute* some IOS commands based on the learnt material and their knowledge of strategies to discover specific data on network devices. The process involves metacognitive knowledge that identifies the strategies required to be used based on learnt materials and the cognitive process is *applying* the procedure to the known task (*Executing*). The student attains this skill by practical activities such as following a set of instruction for configuring network devices including routers and switches, testing network connectivity, and collecting network information. This can be performed as a blended learning program in a form of an instructor-led or self-study approach using either an in-class laboratory or network simulator. However currently, the only option for performing the practical learning activities for fully online study is the simulator program. The assessments for this objective also involved some sort of practical test or a type of questions that requires observation of the situation based on given information and extract the answer. An example is providing the output of a command that shows the routing table on Router-A (Figure 4-5) and ask the student to identify whether the host connected to this router can communicate to a host from another network giving that network addressing schema.

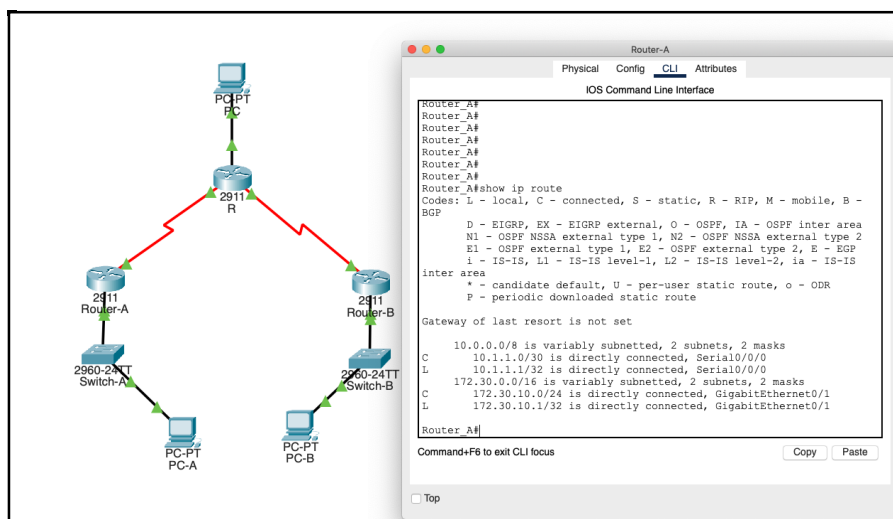


Figure 4-5 - Example of router's routing table

The CNAP courses are good examples of a blended learning environment where educators and students have the freedom of selecting the instructor-led or self-study method for educational material delivery. Moreover, the CNAP instructional model includes the learning objectives that can be organized according to Bloom's Taxonomy for further clarification on educational material arrangement.

These together make CNAP a good test environment to study framework and pedagogies for blended and online courses. However, both laboratories and some assessments for practical components of CNAP courses are missing the full online version. Although simulator programs are worthwhile educational tools to perform practical components of CNAP courses, they are not sufficient replacement for in-class laboratories. Several scenarios are not available on simulators due to complexity, and it does not present the real environment feel for students. Therefore, to provide a full online educational environment it is vital to create an online laboratory that includes the real equipment and provides easy access to students.

#### **4.4 Remote laboratory design**

As mentioned at the beginning of this chapter, the first experiment of an operational online laboratory for CNAP courses was developed in 2003 as a part of the Curtin for Vision Impaired (CAVI) program (Figure 4-6). The CAVI online laboratory was designed for a smaller audience and had some limitations, especially in the booking system. The current online laboratory is an expanded version of the CAVI experiment that is used to study the requirements for designing a framework for online engineering laboratory teaching materials.

##### **4.4.1 CAVI Laboratory Design**

Complete learning material for each CNAP course can be divided into three sections: curriculum content, laboratory experiments, and assessments. A variety range of assistive technologies was used to create an accessible environment for students with vision impairment [61].

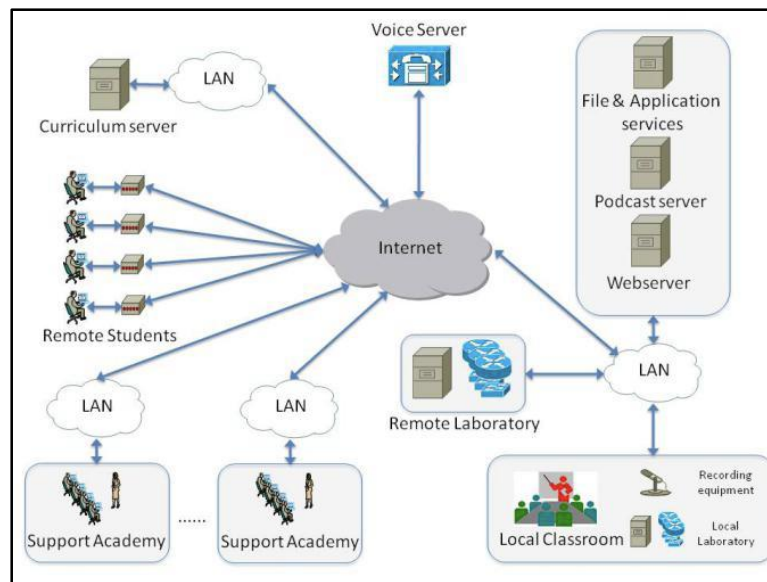


Figure 4-6 - the online environment designed for CAVI [69]

The curriculum content consists of text, activities and pictures that are not all accessible. Most text contents are accessible via Screen Reader software. However, the media-rich content such as pictures and interactive activities are created mainly using Adobe Flash. Adobe Flash is a software platform used to create multimedia contents that were inaccessible to Screen Reader programs (its End-Of-Life (EOL) was at the end of 2020). In the CAVI program this media-rich content was made available for vision-impaired students by methods such as creating accessible documents that explain the content of diagrams and pictures, text to voice converter applications, and virtual classrooms to teach the materials [61].

A similar approach was used for the online assessment questions except for the ones that required students to use the Packet Tracer simulator.

#### 4.4.1.1 Packet Tracer

Packet Tracer is a realistic simulator that helps instructors and students design and configure complex network scenarios and use them as lecture material, Labs, homework, or competitions [70]. This program supports the majority of protocols taught in Cisco Networking Academy Courses including CCNA, CCNA Security, CCNP, and IT-Essentials.

Packet Tracer includes logical and physical workspaces. Placing, connecting, and clustering the virtual network devices are done in the logical workspace,

while physical workspace demonstrates the graphical physical dimension of network devices such as router and switches. Figure 4-7 shows an example of a Packet Tracer interface.

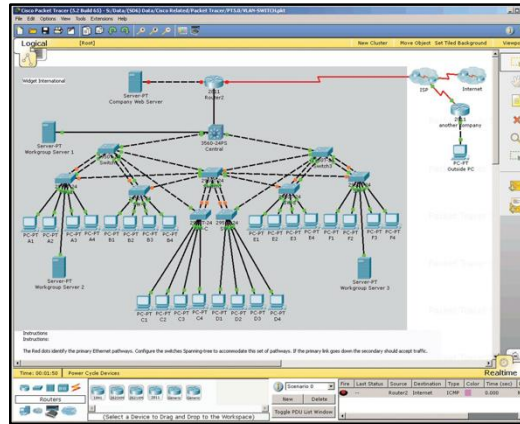


Figure 4-7 - Packet Tracer Interface [70]

Packet Tracer operates in two modes: real-time mode and simulation mode. In real-time mode students experience an immediate and real-time response similar to the response they receive from real equipment. However, in simulation mode users can see and control time intervals, the inner working of data transfer, and the propagation of data across a network [70].

#### 4.4.1.2 iNetsim

To overcome the accessibility problem in Packet Tracer, an experimental universal accessible network simulator called iNetsim for vision impaired, blind and sighted students, was developed to be used as part of the CAVI program. iNetsim was based on Mac OS X v10.4 (Tiger) which for the first time had the integrated screen reader called VoiceOver [61]. An example of the iNetsim interface is presented in Figure 4-8. iNetsim incorporated some features included in Packet Tracer such as network topology design and configuration of network devices [71].

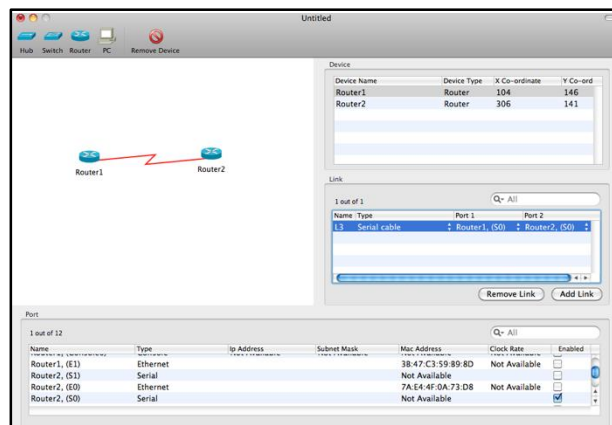


Figure 4-8 - iNetsim Interface [72]

The drag and drop, dialogue boxes, and pop-up windows in Packet Tracer introduced difficulties for screen reader navigation. To resolve this problem iNetsim stores information in tables, which enables rapid navigation of connections, devices and status for a screen reader application. By presenting data in a table format, all information is available in the main canvas, which makes it easier even for the sighted students to search and find equipment and check the connection status [72]. The usage of the mouse is replaced by a keyboard, helping vision impaired student to use the simulator.

Although iNetsim was an adequate solution for the Packet Tracer inaccessibility issue, as a separate environment, it required to be updated every time there is an update in Cisco courses curriculums. Due to the lower number of users (vision impaired and low vision students) compared to Packet Tracer, it gradually became outdated. Commercial network simulators such as Packet Tracer are rapidly changing to meet the requirements in teaching new technologies introduced to the market. However, iNetsim as an environment developed by researchers would not be able to keep up the currency with a commercial product. The only way to overcome this problem is by developing a method to synchronize the accessible program with the main program.

#### 4.4.1.3 In-class laboratory

The laboratory experiments are performed using either as an in-class form of activities using real devices or the Packet Tracer simulator. In most cases network devices and PCs configuration terminal applications are accessible

and students with vision impairments can perform CNAP laboratory tasks. However, to present the course in a full online mode and accommodate remote vision-impaired students, a functional online laboratory was designed and developed.

The remote laboratory design was based on the Cisco Networking Academy CCNA version 3.1. As illustrated in Figure 4-9 all laboratory setups and scenarios within the CCNA v3 course is performed via two main topologies, a router bundle and a switch bundle. The laboratory setup must allow students to configure network devices, perform connectivity tests, and power cycle equipment for experiments such as password recovery.

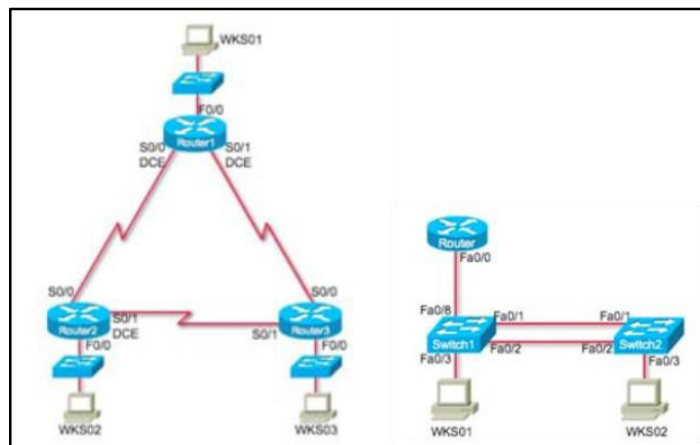


Figure 4-9 - CCNA v3.1 laboratory topology [73]

A console server (switch) was implemented to provide online access to the laboratory network device's terminal for configuration and testing. Console servers connect to the serial port of each laboratory network equipment. They also connect to the Internet via Ethernet link and allow users to access several consoles through this connection using programs such as Telnet. After authenticating to the console server students accessed a list of equipment in the laboratory bundle as is shown in Figure 4-10 [73]. Then by selecting a port number associated with each device connection was established to the console port of that specific equipment and students were able to perform the configuration tasks based on the laboratory manual.

```
[Murray-2:~] iainmurray% telnet 134.7.43.171
Trying 134.7.43.171...
Connected to 134.7.43.171.
Escape character is '^]'.

Enter Password: *****

PORT STATUS: Version 3.0, Site ID: Curtin -o o- --oo o- -o oo -
o

PORT | NAME | PASSWORD | STATUS | MODE |
BUFFER COUNT
-----+-----+-----+-----+-----
09 | Router1 | (defined) | Free | Any | 0
10 | Router2 | (defined) | Free | Any | 0
11 | Router3 | (defined) | Free | Any | 0
12 | WKS1 | (defined) | Free | Any | 0
13 | WKS2 | (defined) | Free | Any | 0
14 | WKS3 | (defined) | Free | Any | 0
```

Figure 4-10 - CAVI remote laboratory-router bundle [73]

A Linux server hosted Linux virtual machines (VMs) as workstations (WKS) in the laboratory topology. The Linux server and VMs are all installed in command-line interface (CLI) mode as graphical user interface (GUI) mode is not fully accessible through a console connection. With the ability to access the console of equipment in the laboratory setup, students were able to perform configuration and connectivity testing remotely.

The next required task as part of CCNA v3 laboratory experiments is power cycling the devices. In this remote laboratory setup, the ability to perform this task was provided by implementing a power server (switch). The power server was accessed through a console server, then by using the options available on the power server console each device could be powered on/off or rebooted. In Figure 4-11 user performed a remote rebooting of a router.

```

Terminal -- telnet -- 80x38
13 | --- | --- | --- | --- | --- |
14 | --- | --- | --- | --- | --- |
15 | --- | --- | --- | --- | --- |
16 | --- | --- | --- | --- | --- |
-----
"/H" for help.
RPMs: /boot ↓
Plugs to be booted:
Plug 1: Router1
Sure? (Y/N): y
Processing - please wait ...
Remote Power Manager 16 v1.42n Site ID: Curtin University
Plug | Name | Password | Status | Boot/Seq. Delay | Default |
-----|-----|-----|-----|-----|-----|
1 | Router1 | (defined) | ON | 0.5 Secs | ON |
2 | Router2 | (defined) | OFF | 0.5 Secs | ON |
3 | Router3 | (defined) | ON | 0.5 Secs | ON |
4 | --- | --- | --- | --- | --- |
5 | --- | --- | --- | --- | --- |
6 | --- | --- | --- | --- | --- |
7 | --- | --- | --- | --- | --- |
8 | --- | --- | --- | --- | --- |
9 | --- | --- | --- | --- | --- |
10 | --- | --- | --- | --- | --- |
11 | --- | --- | --- | --- | --- |
12 | --- | --- | --- | --- | --- |
13 | --- | --- | --- | --- | --- |
14 | --- | --- | --- | --- | --- |
15 | --- | --- | --- | --- | --- |
16 | --- | --- | --- | --- | --- |
-----
"/H" for help.
RPMs: █

Terminal -- telnet -- 85x38
ip subnet-zero
!
!
!
!
!
!
interface FastEthernet0/0
no ip address
shutdown
duplex auto
speed auto
!
interface Serial0/0
no ip address
shutdown
!
interface Serial0/1
no ip address
shutdown
!
ip classless
ip http server
!
!
line con 0
line aux 0
line vty 0 4
!
end
Router#
System Bootstrap, Version 12.2(8r) [among 8r], RELEASE SOFTWARE (fc1)
Copyright (c) 2003 by Cisco Systems, Inc.
C2600 platform with 131072 Kbytes of main memory
program load complete, entry point: 0x00000000, size: 0x5f2fa0
Self decompressing the image : ###

```

Figure 4-11 - Rebooting a Router Using a Power Server [73]

The CAVI remote laboratory didn't have an online booking system and students used the virtual classroom to allocate the time slot for laboratory usage. In the virtual classroom, students could verify if the remote system is available or is in use by another student. They also had an option to work together and communicate through the virtual classroom [73].

CAVI remote laboratory was a functional and cost-effective model, however, some significant shortcomings influenced the sustainability and expansion of this design including:

- Lack of booking system which is a major problem by increasing the number of students. Also, students had to have a virtual classroom application open during the laboratory experiment to notify others that the laboratory setup is occupied.
- The design could accommodate limited devices and it was too difficult to expand it for other engineering courses
- There are security concerns in the connection method. It used Telnet that is an insecure protocol for connectivity. Almost all organizations block the telnet port due to security risks it can impose on the network.



Despite the shortcomings in the CAVI remote laboratory and Packet Tracer replacement program iNetsim, they indicated notable benefits to students and inspired the researcher to enhance and expand the system.

#### **4.4.2 Current system**

The principle aims of designing a functional remote laboratory in the engineering sector are to study the educational requirement and develop pedagogies for the online practical learning experience. Consequently, the test model was developed to assess and analyze a variety of laboratory experiments used by a wide range of audience including sighted and vision-impaired students. As mainstream students are also required to have the facilities to help them access online laboratories for a more effective and efficient educational experience.

##### ***4.4.2.1 CAVI remote laboratory improvement***

As has been mentioned in the previous section, CAVI remote laboratory was designed to teach ITC practical activities to vision-impaired students. This setup had shortcomings that made it inflexible and difficult to scale. One problem was the lack of an effective booking system. The CAVI booking method is not scalable with a large number of students. Therefore, there was a requirement for an effective booking system that allocates time for each experiment performance and locks the laboratory bundle during this reserved session. By logging into the system students must be able to see the reserved and free laboratory bundles and the time durations for the reserved ones.

The other shortcoming of CAVI design was the security risk imposed by using a Telnet connection. This communication protocol must be replaced by more secure ones such as SSH, or HTTPS using TSL/SSL. One option is to replace the existing Telnet console switch with the SSH version. However, the SSH communication protocol requires some level of network administration skills and is not as easy to use as SSL/TSL.

To study the different aspects of pedagogies in remote laboratory experiments, a variety of laboratory setup must be implemented. The CAVI experimental environment was designed to cover the laboratory setup for CCNAv2. While there was some scalability option available in CAVI remote

laboratory, there were many limitations to include other topologies due to technical specifications.

After studying different available remote environment, NETLAB+ was selected as a main part of the current design implementation to overcome issues that existed in the CAVI remote laboratory. The Curtin Online Laboratory (COLab) replaced the original setup and is accessible via <https://colab.ece.curtin.edu.au>.

#### 4.4.2.2 NETLAB+

NETLAB+ is a remote laboratory environment designed by NDG (Network Development Group). NDG collaborates with most academy institutions developing online courses such as Cisco Networking Academy, RED HAT Academy, VMware IT Academy Program, and many more [74]. NETLAB+ is a server with the capability to provide online access to connected laboratory devices through HTTPS with SSL/TSL connection. NDG offered the NETLAB+ as a hardware server and virtual server for some time but currently, only the virtual one is available.

The booking system called Pod Scheduler on NETLAB+ allows students to select and reserve a session for intended laboratory activity [75]. Figure 4-12 shows the Pod Scheduler for CCNA/ CCNA security course on COLab. During this session, the laboratory setup is locked and other students are not able to access it.

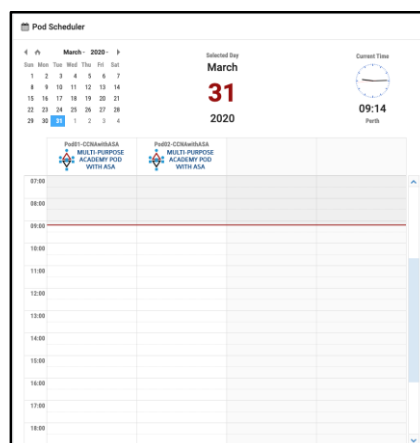
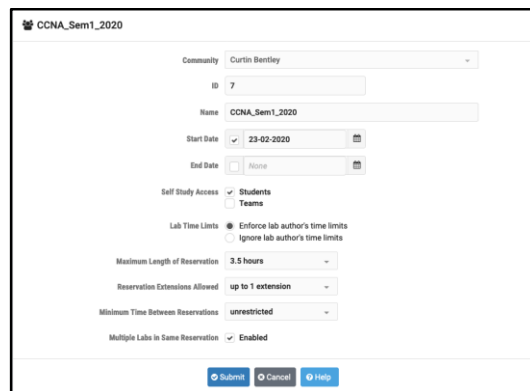


Figure 4-12 - NETLAB booking system -Pod Scheduler

However, if teams are defined in a class setup, collaboration option is available for team members to join the session Figure 4-13. While instructor

accounts have the privilege to access all running sessions, they can monitor and configure devices and even terminate the sessions. The other options that the instructor or administrator can define in each class setup are booking time limitations for each session, the number of times students are allowed to extend the reservation duration, times between the reservation, and the ability to switch between laboratory activities. Users also can save their laboratory activity configuration in their folder provided by NETLAB+ [75].



The screenshot shows the configuration page for a class named 'CCNA\_Sem1\_2020'. The interface includes the following fields and options:

- Community: Curtin Bentley (dropdown)
- ID: 7 (text input)
- Name: CCNA\_Sem1\_2020 (text input)
- Start Date: 23-02-2020 (calendar icon)
- End Date: None (calendar icon)
- Self Study Access:  Students,  Teams
- Lab Time Limits:  Enforce lab author's time limits,  Ignore lab author's time limits
- Maximum Length of Reservation: 3.5 hours (dropdown)
- Reservation Extensions Allowed: up to 1 extension (dropdown)
- Minimum Time Between Reservations: unrestricted (dropdown)
- Multiple Labs in Same Reservation:  Enabled

At the bottom, there are three buttons: Submit, Cancel, and Help.

Figure 4-13 - NETLAB+ class setup

The HTTPS protocol with SSL/TLS encryption is used for connecting the users to the NETLAB+ server [76]. As it is illustrated in Figure 4-14 users connect to the laboratory set up by authenticating through a web browser and perform all practical tasks within the webpage, therefore, there is no requirement for any software installation at the client side.

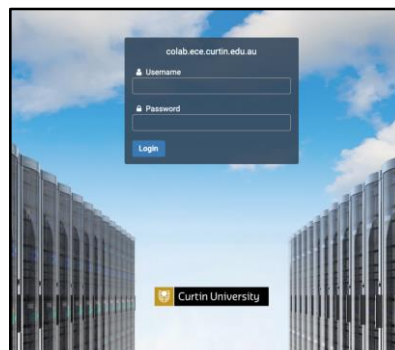


Figure 4-14 - COLab login page provided by NETLAB+ server

Using the provided interface to interact with the remote laboratory is very easy and does not require a high level of network administrative skill.

The SSL/TSL encryption and HTML5 WebSocket technology used in NETLAB+ form a secure connection between user and laboratory setup [76]. They initiate the authentication session, form a two-way TCP handshake, encrypt data sent across the web, and protect the data integrity by a digital signature method.

There are two options for designing a laboratory setup in NETLAB+. The first option is to select a pod from a list of templates that belongs to NDG educational academy partners such as Cisco Networking Academy and the second option is to create a costume-build laboratory design. Using the Pod Designer option in NETLAB+ laboratory design can be tailored to match the intended practical activity sets.

The disadvantage of the NETLAB+ remote laboratory setup was its inaccessibility for blind and vision-impaired students. Two solutions were proposed to overcome this limitation, adding the accessibility to the NETLAB+ interface or run the accessible CAVI set up in parallel for vision-impaired students.

All these abilities included in NETLAB+ made it a suitable environment for the remote laboratory test model.

#### **4.4.2.3 New design COLab**

In the current remote laboratory design called COLab (Curtin Online laboratory), NETLAB+ server setup is used to create several online practical systems.

The COLab setup was tested over 4 years and during this time it was refined multiple times to address technical issues such as the JAVA problem in loading some pages. During 4 years, several laboratory setups were added to COLab and virtual-server or NETLAB+ VE replaced the physical server or NETLAB+ PE.

The next chapter will include a more detailed explanation of each laboratory.

#### 4.4.2.4 Pedagogy study

To create a test environment that incorporates all required aspects of a remote laboratory for conducting a comprehensive study, various concepts were considered:

- **Type of environment:** while the focus of the study is on remote laboratory setup, both fully online and blended environments were included in the design for more inclusive research activities.
- **Method of program delivery:** a range of laboratory activity curriculums were selected to incorporate different types of course delivery styles. This includes self-study and instructor-led delivery methods.
- **Course diversity:** although the majority of examined laboratory content was adopted from CNAP courses, some other engineering practical activities were also included to increase the research subject diversity.
- **Audience diversity:** All COLab users were taken as research audience, that includes users with varying level of:
  - **Competency** – instructors and students were both included in the COLab user groups
  - **Study requirements** – sighted and vision-impaired users were included with different needs to use the laboratory setup
  - **Population per class** – research was conducted on different group sizes ranging from 3 to over 200 users per class
- **Monitoring methods:** NETLAB+ embedded log system, questionnaire, user feedback, and observing the users work on the remote laboratory were all methods used to monitor COLab.

The research was conducted on different aspects of learning activities performed on COLab as an experimental remote environment, so the

observation can be used to identify and organize the teaching methods appropriate for the online laboratory educational model.

#### 4.4.2.5 PT accessible design

The material in this section was published in IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE), 2013.

In the early stages of this study, a solution was proposed and implemented to overcome the inaccessibility of the Packet Tracer and iNetsim update problem.

External application development was introduced in Packet Tracer version 5.0 through the Inter Process Communication (IPC) feature and Packet Tracer Messaging Protocol (PTMP) [70]. The external API supports multi-user connections, which makes it possible for two instances of Packet Tracer to communicate with each other on different machines. Since the API is using authentication and channel encryption, the security of communication is also guaranteed [77].

By using the external API, an instance of Packet Tracer on a Windows machine (*PT Daemon*) was placed as an intermediate program between the main Packet Tracer program and the accessible interface (iNetsim) running on a Mac OS X machine (Figure 4-15).

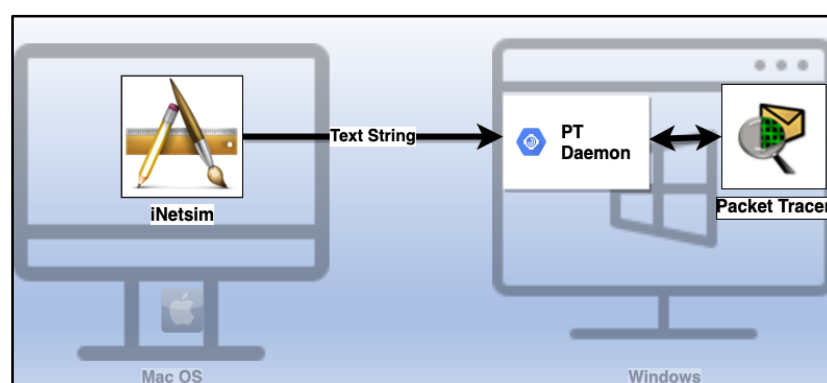


Figure 4-15 - Accessible Packet Tracer Basic Design

iNetsim was querying the PT Daemon using a text string and the communication between PT Daemon and iNetsim is done using IPC and PTMP. Figure 4-15 illustrates an example of communication between iNetsim

running on mac OS and Packet Tracer on Windows. Figure 4-16 shows the iNetsim interface running on mac OS. By selecting any network device on the top menu, iNetsim communicates to Packet Tracer running on a Windows machine for the type and model.

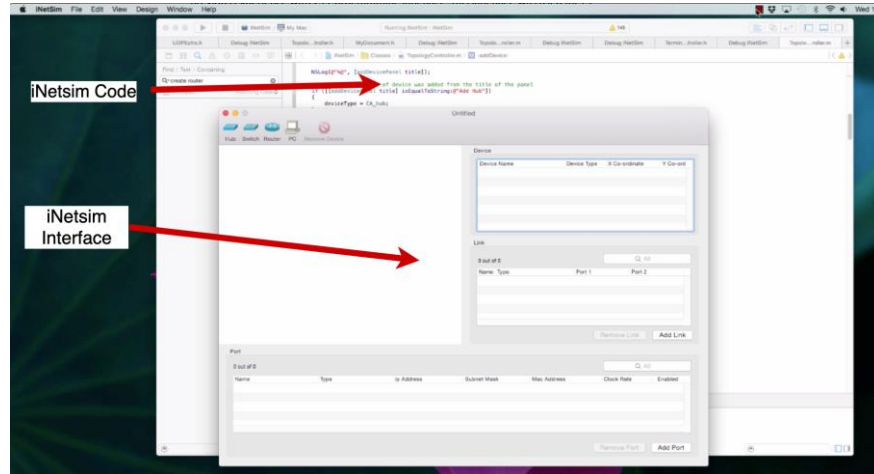


Figure 4-16 - iNetsim on Mac OS side

In this example, a router is selected and placed in the iNetsim workspace (Figure 4-17).

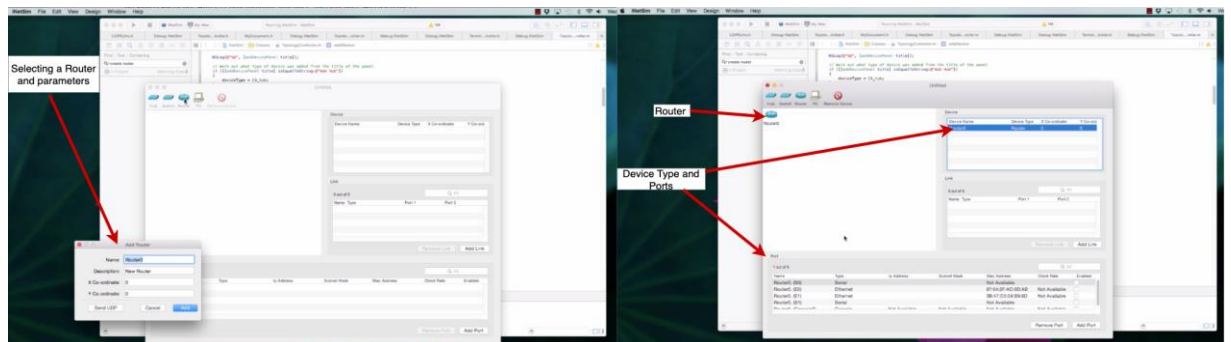


Figure 4-17 - Adding Router to iNetsim Workspace

Figure 4-18 shows the Windows side, illustrating the PT program, PT daemon and communication messages between iNetsim and PT/PT daemon.

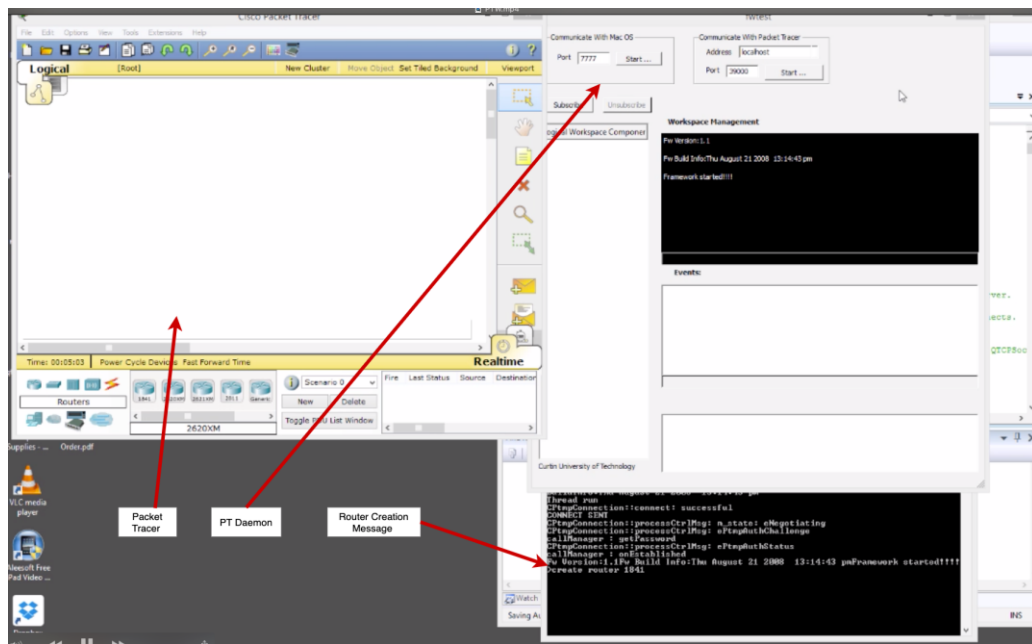


Figure 4-18 - PT communication from Windows to iNetsim

In this method, the new iNetsim includes all the features that exist in Packet Tracer and benefits from the VoiceOver program included in Mac OS X.

The implementation of this research is divided into two parts; PT Daemon development as an intermediate program and interface design in iNetsim to meet the requirements for the current version of Packet Tracer. Due to the researcher's previous experience with C++ programming language, this language was used for PT Daemon development although any object-oriented programming language can be used for this part. iNetsim is a program run in mac OS X environment, to design the interface for this program Objective C programming language was utilized and the old iNetsim was used as a template.

Although this was considered a successful solution for the Packet Tracer accessibility feature, the project did not progress any further due to the introduction of the Cisco mac OS Packet Tracer.

## 4.5 Summary

This chapter explained the criteria and motives to select the conceptual design for an online laboratory to study the pedagogies and educational framework. First, the previous experience in creating an accessible environment to perform laboratory tasks remotely was evaluated to identify



the feasibility of adopting the model for this research. This included the CAVI remote laboratory, and iNetsim and accessible PT as laboratory simulators. Based on the findings CAVI was considered a successful educational program and its remote laboratory model had the potential to adapt and expand for creating an effective online laboratory environment.

Second, Bloom's Taxonomy as the most used educational framework was selected to evaluate the teaching and learning aspects of the online laboratory environment. the details of Bloom's Taxonomy were explained in this chapter. Accordingly, the educational programs chose for this study were compliant with the criteria in Bloom's Taxonomy.

Lastly, NETLAB+ remote laboratory environment explained in this chapter were selected to implement the experimental design. This environment is using a model similar to CAVI remote laboratory with the ability for additional laboratory setups. NETLAB+ online laboratory was adjusted to create an optimal experimental model presented as COLab. The details on the design and implementation of COLab are explained in the next chapter.

## **Chapter5: Curtin Online Laboratory (COLab) Implementation**

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### **5.1 Introduction**

The study of user's learning experience in science and engineering courses with remote laboratory environment helps to evaluate the effectiveness and functionality of teaching strategies presented as practical activities in this type of setting.

An operative online experimental model was required to examine the remote laboratory learning activities and classify the pedagogies.

The remote environment is required to represent the in-class laboratory setup situation with access to real devices. Also, users should have easy access to the remote system preferably without any software installation required on the client-side. The system should be easy to use with minimum learning requirement for operating the remote setup. Additionally, user privilege level must be related to their roles in the system for example instructors must have a higher privilege level to have the right for checking student work while they are performing the laboratory tasks.

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

According to the aforementioned findings presented in Chapter4:Experiment Design, a combination of NETLAB+ remote laboratory server and CNAP courses can be considered as a suitable model for this study. However, some modification and adjustment were applied to form the experimental model developed as Curtin Online Laboratory (COLab).

### **5.2 The experimental remote laboratory design**

In the experimental model, users remotely connect to laboratory equipment via accessing the NETLAB+ server interface over the Internet connection (Figure 5-1) laboratory devices are connected internally to form the intended experimental topology, they are also remotely configurable via an online console connection and power management.

The NETLAB+ setup consists of a NETLAB+ server for external connection, control devices to interact with laboratory devices, and a VMware server for hosting the virtual machines (Figure 5-1).

The majority of laboratory content implemented on the experimental model (COLab) was adopted from CNAP courses. However, other course's practical contents were configured and applied on COLab with some modifications to the NETLAB+ setup.

### 5.2.1 Control devices

There are three types of control devices in the NETLAB+ structure, the Control Switch to provide internal connectivity between laboratory equipment, the Access Server for online console connectivity, and a power distribution unit for managing the laboratory devices' power. These devices are only controlled and configured by the NETLAB+ server and not accessible to users [78].

#### 5.2.1.1 Control Switch

The Control Switch (CS) manages the Ethernet network between the NETLAB+ server's internal interface, other control devices, and laboratory equipment as shown in Figure 5-1.

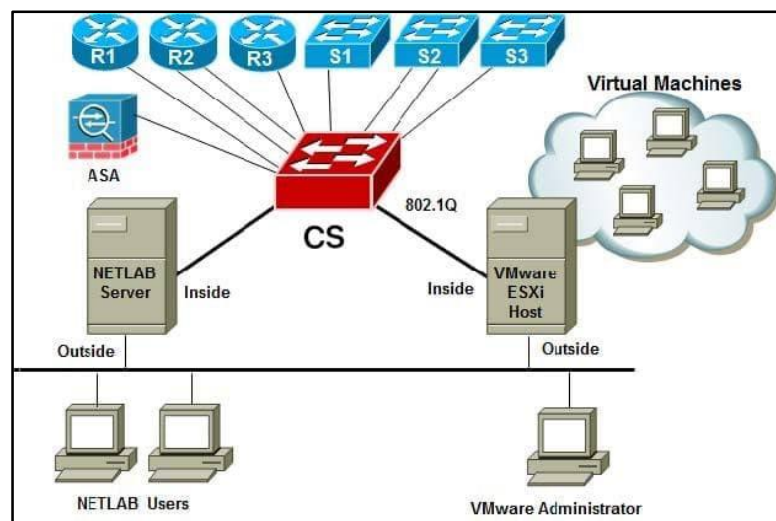


Figure 5-1 - Control Switch in NETLAB+ Topology [79]

The device that performs the Control Switch functionality must be selected from the NETLAB+ CS compatible list provided by NDG (<https://www.netdevgroup.com/>).

The number of Control Switches depends on the quantity of the laboratory equipment. NETLAB+ server is responsible for configuring and managing the Control Switch/s with minimum manual setup requirement for existing laboratory setup templates such as Cisco. However, Control Switch ports connected to the equipment for customized laboratories must be configured manually (see Appendix C).

#### **5.2.1.2 Access Server**

The Access Server is a router that provides console connections to laboratory devices via the asynchronous serial interface. This device acts as a terminal server that provides the ability to configure laboratory equipment via remote connection.

#### **5.2.1.3 Power Distribution Unit (PDU)**

The next essential feature that must be included in the online laboratory setup is the ability to remotely manage power on laboratory devices for the following reasons:

1. NETLAB+ server should reboot devices for automatic operations such as initial/final configurations.
2. users require to power on/off devices for operations such as password recover
3. Devices must be powered off when they are not part of a session or not in use, for power saving and cooling purposes [80].

A switched outlet or PDU with a remote management feature is used for online device power controlling requirement.

More detailed information on the control devices' specifications and configurations are provided in Appendix C.

## 5.2.2 VM server

Most of the laboratory setup in science and engineering consists of laboratory devices and PCs. In the NETLAB infrastructure, all the lab equipment is connected directly through control devices, however, to replace the PCs, Virtual Machines are implemented. In the previous version of the remote laboratory used for CAVI, Virtual Machines were used on a Linux server. In the current design and according to NETLAB specification requirement VMware ESXi servers must be implemented to host the virtual machines as remote PCs.

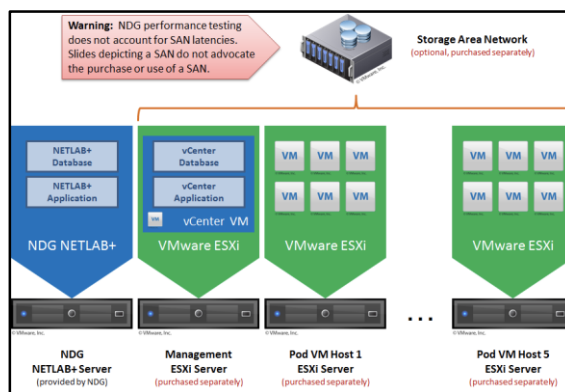


Figure 5-2 - NETLAB+ infrastructure [81]

As illustrated in Figure 5-2 the NETLAB+ server provided by NDG as physical (PE) or virtual (VE) machine hosts NETLAB+ database and applications only [81].

### 5.2.2.1 Hardware specifications

There is a requirement for three separate hardware to support the NETLAB+ server, management VMs, and pod VMs and a list of recommended server machines are presented by NDG. As the COLab setup expected to expand, four server hardware were allocated for pod VMs and a Storage Area Network (SAN) server was added to increase the space for hosting more VMs.

The other addition in the COLab server setup was the PCI expansion slots on the hardware hosting the pod VMs. These PCIs are utilized during the development of customized laboratory pods which did not fit with any templates from the NDG.

More information is given in Appendix C.

### 5.2.2.2 *Virtualization environment*

As has been mentioned, virtual machines are used in the remote laboratory infrastructure to replace the physical PCs and servers. Accordingly, a virtual environment is required to host and manage virtual machines.

NETLAB+ setup supports a virtual environment created by VMware vSphere to deploy, communicate and manage virtual machines.

VMware vSphere is a software package that includes three main components, ESXi, vCenter, and vSphere client.

- **ESXi-** is a hypervisor that runs on the host machine and performs the core virtualization operation that is sharing the hardware with guest virtual machines [82].
- **vCenter-** while ESXi is a server hosting the VMs in the vSphere environment, vCenter is a server management software responsible for centrally controlling the ESXi servers and VMs. All the management features offered by vCenter are intended to provide the three primary tasks including process automation, virtual infrastructure visibility, and scalability [83].
- **vSphere Client-** is an application that provides a graphical user interface (GUI) for monitoring and managing the inventory objects in a vCenter server including ESXi servers [84].

**Virtual Machines-** Virtual Machines are the PCs and servers in the laboratory topologies that should be remotely accessible. There are several VMs available as OVA or OVF files on the CSSIA website recommended by NETLAB+ for the courses offered by industry educational organizations such as Cisco Networking, Red Hat, CSSIA, VMware, Palo alto, and VMware. These VMs are available as a template and can be easily deployed on pod ESXi host server/s. VMs can be also created and deployed for the laboratory topologies that are not part of the course content list offered by industry academies and supported on NETLAB+.

### 5.2.3 Networking and laboratory devices

**Server network** - Depending on the type of laboratory pods intended to be installed in the NETLAB+ setup, there are two network models suggested by NDG to connect vCenter, NETLAB+, and ESXi host servers. If virtual machines are the only components of the laboratory pod and there is no real laboratory equipment in the topology, then the single-homed network should be implemented. In this network model, servers are connected to the campus LAN and evidently, there is no requirement for a control switch as no laboratory devices exist Figure 5-3 [85].

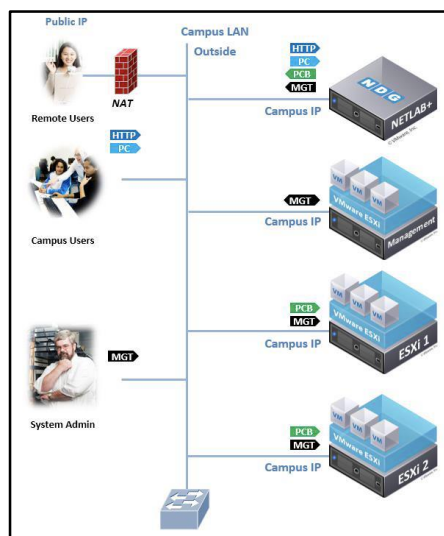


Figure 5-3 -NDG single-homed network model [85]

The dual-homed network model is used when there is a combination of VMs and laboratory devices in the NETLAB+ pods. Servers in this network model have two interfaces for inside and outside connections. As illustrated in Figure 5-4 a control switch is required to connect laboratory devices to the servers. The COLab setup includes laboratory topologies with real equipment and VMs, VMs only, and real equipment only.

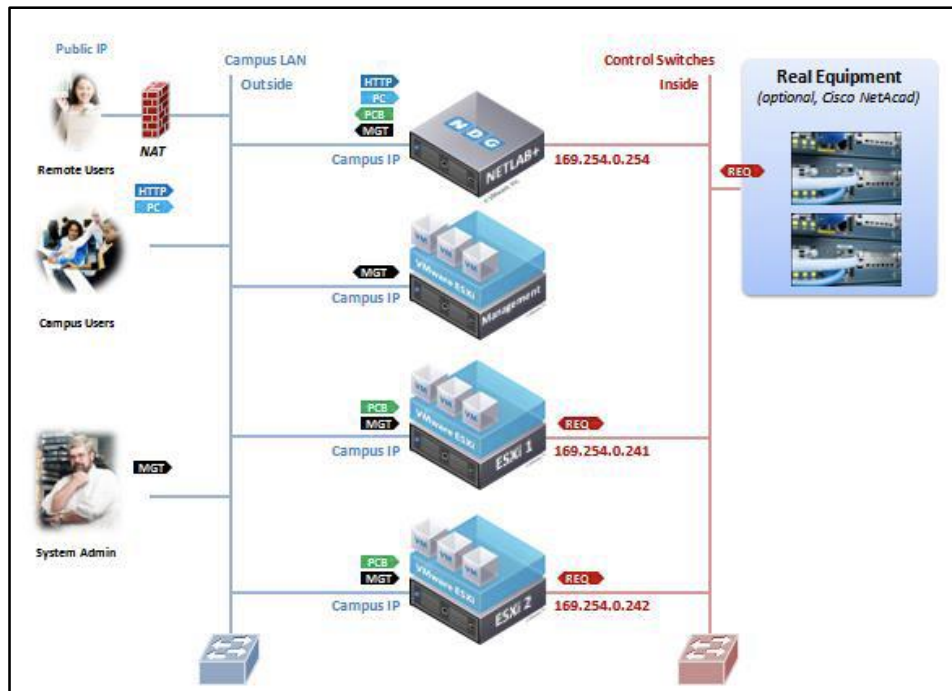


Figure 5-4 - NDG Dual-Homed Network Model [85]

Therefore, a dual-homed network is used and that requires two sets of IP address range for both inside and outside connections.

### Additional network configuration for COLab

The network configurations above are the requirement for the NETLAB+ infrastructure. This arrangement is sufficient for most of the laboratory pods offered by NDG. However, in the COLab design with additional customized laboratory setup, further network configurations were required. Some of these are the virtual router, PCIe switch, and SAN network configurations.

In the NETLAB+ infrastructure, there is no Internet connectivity for virtual machines and they are only communicating with laboratory equipment through the inside network. However, for some of the customized laboratory pods in COLab setup, each VMs needs to have an Internet connection. To accomplish this objective there are two options available. The first solution is to assign a unique public address to each VM, that depending on the number of VMs it can exhaust the system rapidly and creates security vulnerabilities [86].

The second solution is deploying a virtual router on the ESXi server to share the Internet connection with VMs. A virtual router is a virtual machine running software-based router applications that perform all the functionality of a



physical router [86]. Its main functionality is to route the traffic between LANs and the WAN connection using routing protocols so there is only one public address required. The communications' security measures are controlled by the firewall application inside the virtual router. Therefore, the implementation of a virtual router on the ESXi server to provide an Internet connection for Pod VMs is an appropriate solution.

After reviewing several open-source virtual router solutions, DD-WRT was selected for deployment on all ESXi servers for COLab setup. A free version of the DD-WRT image was downloaded and deployed on ESXi servers as a 64-bit Linux VM.

The virtual router VM has two network interfaces first one connects to the ESXi outside interface, and the second interface connects to the VM LAN. The virtual router also provides IP addresses for VMs through the DHCP configurations. All VMs should be configured with two network interfaces as well, one connects to NETLAB+ infrastructure inside the network, and the next connects to the DD-WRT inside LAN.

The virtual router deployment steps are [87]:

- Create a port group on the external interfaced to connect the virtual router outside the interface. Figure 5-5 shows the external network port group set up on one of the COLab ESXi servers.

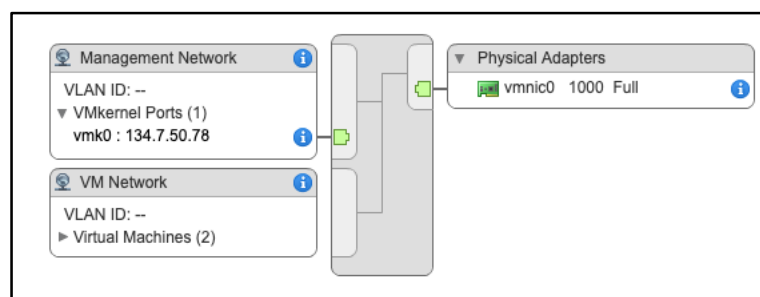


Figure 5-5 - DD-WRT external network connection

- Create a vSwitch with no physical interface connection and a port group as an internal LAN (Inside Network WRT). Connect DD-WRT inside network interface to this port group (Figure 5-6).

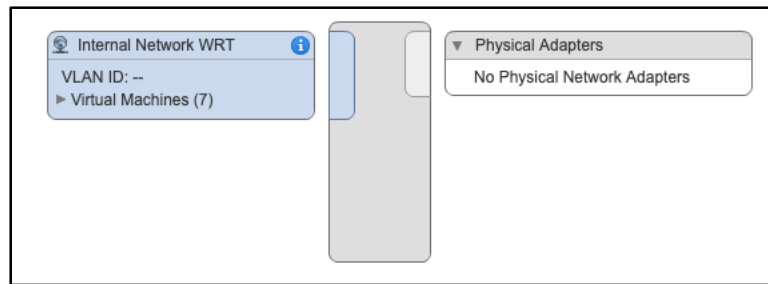


Figure 5-6 - WRT inside Network Connection

- Add an extra network interface to VMs if they only have one. Connect the new interface to inside LAN port group created in the previous step.
- The VMs connected to internal LAN receive an IP address automatically from virtual router DHCP configuration. By default, the IP subnet is 192.168.1.0/24.

Now the virtual router (DD-WRT) can be accessed from one of the VMs connected to the inside LAN from the web browser for router configuration (Figure 5-7). WAN IP address configuration is the most important part of the virtual router configuration as it connects the VMs to the external network and the Internet.

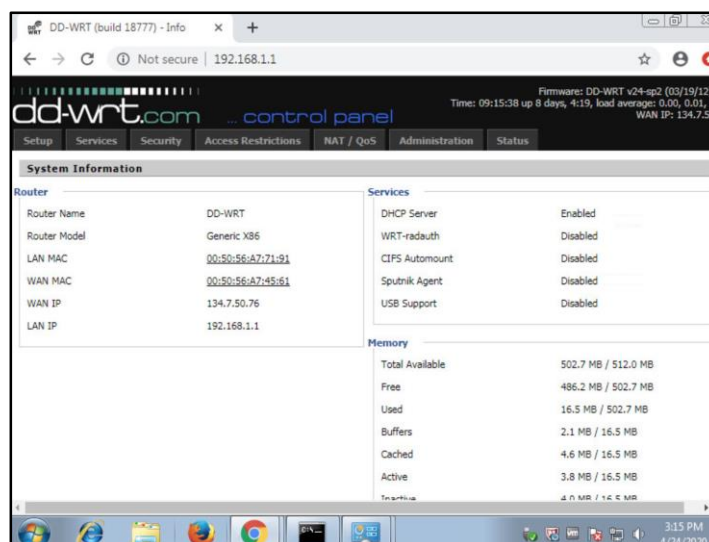


Figure 5-7 - DD-WRT management interface from VM web browser

The additional configurations such as security and services can also be performed. From the DD-WRT management interface.

The automatic startup was configured for the DD-WRT router was on the ESXi server

Now that the virtual router is configured, any VM deployed on the ESXi server and connected to the DD-WRT inside LAN will securely connect to the Internet.

### **Control devices and laboratory equipment**

There is no Internet connection required for control devices and laboratory equipment as they are accessed through the NETLAB+ server. Control Switch is the point of communications between all the other control devices, ESXi servers, and laboratory equipment with NETLAB+ server (Figure 5-4).

Although NETLAB+ VE is installed as a VM on a management server, it has its public address for connecting to the external network (Internet). The remote access to the control devices and laboratory equipment is provided through this public address on the NETLAB+ server either VE or PE version.

## **5.3 Laboratories**

All the devices and configurations presented in section 5.2 and the Appendix C are the general requirements for the laboratory setup on COLab. However, for each laboratory setup, there are additional configuration requirements and specific devices.

NETLAB+ incorporates many supported laboratory topologies from training programs such as Cisco Networking Academy, VMware IT Academy Program, Linux Professional Institute, Palo Alto Networks Academy, Red Hat® Academy, and other similar programs.

The laboratory topology templates and course contents of these supported programs are packaged by NDG and can be installed on the NETLAB+ server (VE/PE) by the administrator user. The NETLAB+ administrator must have a valid license agreement with training academies to access and install these course packages on the NETLAB+ server (VE/PE) [88].

NETLAB+ server also has the facility to allow for the custom laboratory topology and content. Some custom-designed laboratory pods were included in the COLab infrastructure for specialized courses that are not offered by

any supported training academies. In this section, the COLab laboratory implementations, contents, and delivery methods are explained.

The COLab instruction manual was presented to students for all of the laboratory programs.

### **5.3.1 CNAP laboratories**

The major part of computer systems and networking courses at Curtin University, utilize CNAP as their laboratory components. This creates a good test environment for online laboratory deployment using COLab infrastructure. As it has been explained in Chapter4: Experiment Design the two major parts of CNAP teaching materials are online learning curricula and laboratory experiments. The laboratory experiment section of CNAP courses was used in this study to evaluate the pedagogies deployment for the online environment. The CNAP laboratory implemented in the COLab is CCNA Routing and Switching, CCNA Security, and CCNA cybersecurity operations.

#### ***5.3.1.1 The CCNA routing and switching***

Cisco Certified Network Associate (CCNA) Routing and Switching program is a networking course associated with an industry certification. This course incorporates learning materials to acquire the fundamental knowledge and skill for configuring, managing, and troubleshooting network devices at the intermediate level. Initially, in 2015, version 6 of CCNA routing and switching laboratory experiments were implemented on COLab. This version of the CCNA R&S course consists of four sub-courses:

1. Introduction to Networks
2. Routing and Switching Essentials
3. Scaling Networks
4. Connecting Networks

From semester one of 2020, the COLab CCNA R&S laboratories were upgraded to version 7. However, as version 6 was still in use for some of the Curtin courses, CCNA R&S version 7 laboratories were implemented on four pods in conjunction with 3 pods delivering version 6 materials. CCNA R&S version 7 consists of three sub-courses:

1. Introduction to Networks
2. Switching, Routing, and Wireless Essentials
3. Enterprise Networking, Security, and automation

The CCNA R&S courses are deployed in 4 teaching units at Curtin University including two associate-level courses and two advanced-level courses. Table 5.1 - shows the CCNA R&S course associated with the laboratory components of these units.

Units	Unit Level	CCNA R&S Version 6	CCNA R&S Version 6	Study Period
Data Communications and networking	Associate	1-Introduction to Networks 2-Routing and Switching Essentials	1-Introduction to Networks	Semester 1 and 2
Computer Communications	Associate	1-Introduction to Networks 2-Routing and Switching Essentials	1-Introduction to Networks	Semester 1 and 2
Distributed Networks	Advanced	3-Scaling Networks 4-Connecting Networks	2-Switching, Routing, and Wireless Essentials (from 2021)	Semester 1
Network Design	Advanced	1-Introduction to Networks 2-Routing and Switching Essentials 3-Scaling Networks	1-Introduction to Networks 2-Switching, Routing, and Wireless Essentials (From 2021)	Semester 1

*Table 5.1 - Laboratory components for Curtin University units*

As it can be noted from the Table 5.1 - content, at the time of writing this thesis sub-courses 2 and 3 from version 7 were not examined and sub-course 1 was under examination. Some or all of these units are offered

across three campuses and all enrolled students have access to COLab as an option to perform the laboratory experiments.

Over the five years of study from 2015 to the end of semester one of 2020, the number of students who attended the CCNA R&S courses across all three campuses reached 1645 with 1272 students from Curtin Bentley.

Additionally, since 2016 close to 60 students enrolled in CCNA instructor training courses and have been granted access to COLab.

### Device topology and setup

According to the Cisco Networking Academy, to create a laboratory bundle for CCNA R&S version 6, three routers, three switches, and three PCs are required. And for version 7, two routers, two switches, and two PCs form the laboratory bundle.

Although each of the sub-courses in version 6 and 7 contain several laboratory experiments with different setup requirements, NDG recommends one topology that incorporates all those together. Thus, all the laboratory experiments in the CCNA R&S course can be performed using this topology that is referred to by NDG as Multi-Purpose academy pod for version 6 and Multi-Devices pod (MDP) for version 7. Figure 5-8 and Figure 5-9 present the topology for Multi-Purpose academy pod and Multi-Devices pod (MDP) respectively.

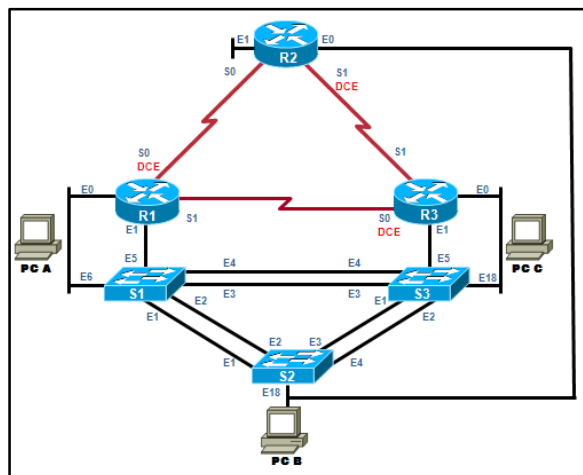


Figure 5-8 - Multi-Purpose Academy Pod (CCNAv6) [89]

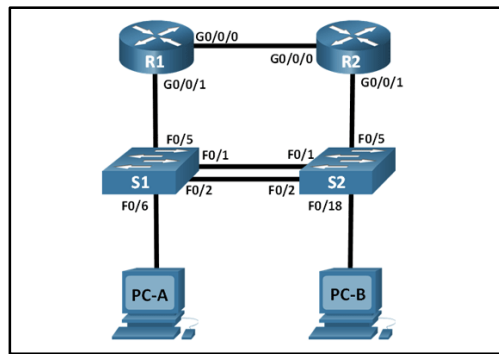


Figure 5-9 - Multi-Devices pod (MDP)-CCNAv7 [90]

These topologies are also covering the laboratory experiments device bundle requirements for some other CNAP courses including CCNA security.

Therefore, by implementing Multi-Purpose and Multi-Device pods, the same devices and setup can be efficiently utilized for the number of courses.

Cisco Networking Academy provides the supported laboratory device list and software requirements for each CNAP courses. There are seven CCNA R&S laboratory bundles in the COLab setup, including 4 Multi-Device and 3 Multi-Purpose pods. More detailed information is presented in Appendix C.

The first step in creating the Multi-Purpose pod or Multi-Device pod is to cable the laboratory devices based on the topology in Figure 5-8 or Figure 5-9. In each laboratory session, an interactive interface presents devices based on the experiment equipment requirement. However, users can still access other devices if they wish to.

To create a Multi-Purpose pod or Multi-Device pod, laboratory devices must be connected according to the topology shown in Figure 5-8 and Figure 5-9. A combination of straight-through cable and Cisco serial cable is used for Multi-Purpose pod but Multi-Device pod only straight-through cable is required to connect the devices.

### Laboratory delivery

The CCNA R&S laboratories have the highest number of users on COLab and were available for the full period of study (5 years).

Diverse groups of students attend this course with different levels of competency and background knowledge. Curtin University offers the CCNA

R&S course as an external and internal study program in both student and instructor level mode.

Curtin University CCNA R&S students can be divided into two major groups as local and remote students.

**Local students:** these students are attending the in-person courses offered by Curtin University. The group can be further divided into Curtin students and local Cisco instructor trainees:

- **Curtin students** are taking in-person units as part of their enrolled course offered by the University. As mentioned before, the CCNA R&S course is incorporated in some of the units as laboratory components. Students enrolled in computer networking related courses are expected to have a higher level of competency compared to other science and engineering students taking CCNA R&S course. Also, students from computer networking related courses are studying at both master and bachelor level.
- **Instructor trainees** are individuals who attend the Cisco Academy instructor training programs offered as an external course by Curtin University. These students are often IT trainers from the educational institutions who want to obtain CCNA academy instructor certification for eligibility to teach the course in their organizations. The learners have the option of performing laboratory experiments and skill assessments using either Curtin equipment or COLab. Their knowledge and competency level are higher than other student groups. However, not many instructors are willing to attend the in-person classes and their first preference is online courses due to their busy schedules and work duties.

**Remote students:** these are students enrolled in blended or online courses.

- Student's level-
  - **Remote campuses** – three remote Curtin University campuses are offering the same CCNA R&S related courses as Curtin Bentley. They all have some level of resource constraint on



laboratory equipment. That being the case, students are given the option to use COLab for performing the laboratory experiments. Also, there is a demand from students to use COLab as it removes the time constraint and gives them the freedom for performing laboratory tasks 24/7. The competency level of this group is the same as the Curtin students mentioned above.

- **External students-** Curtin University also offers CCNA R&S course as an external program for individuals who wants to upskill their knowledge in computer networking. Almost all of the external students are taking the online version of the course due to the geographical situation or work/study commitment. They are either employed in the computer networking field or students interested in this area of study. They generally have an intermediate to a high level of competency but the number of enrollments is low in this group.
- **Instructor trainees-** this is the same group of learners mentioned under the local students' section who are only taking the online version of the course. All laboratory experiments and skill assessments must be performed in an online fashion using COLab.

Based on the student's competency level and their geographical location, various laboratory delivery approaches were taken with utilizing COLab as a core or optional tool.

Curtin units either offered locally or internationally are considered as an in-person study program. However, COLab was an option along with a physical laboratory and Packet Tracer simulator for students to perform the experimental tasks. Students from this group receive laboratory instructions for each session but they have the option of using the COLab as a full online laboratory for practice. The computer networking students must perform a skill exam on the laboratory devices to include cable connecting assessment as well as other aspects of the learning material. Therefore, they utilize COLab as a laboratory practice environment.

Other students taking the Curtin units have all three options of in-class equipment, Packet Tracer simulator, and COLab environment to perform the skill assessment

The external learners including instructor trainees and students have the options of taking online, blended, or in-person (minimum five of students) classes. The full online version is the first preference for external students following by a blended and in-person version as the last option. All laboratory experiments are performed on either COLab or Packet Tracer simulator for the online version and students are required to take skill assessment on COLab only. The blended model is similar to online except students have the option to use the in-class laboratory equipment for experiments and skill assessments. There is an option for in-person teaching mode for external courses with more than five students which runs as an intensive four weeks program. The in-person classes are performed in the same manner as Curtin computer networking units with Packet Tracer, in-class and COLab laboratory availability for experiments and in-class equipment for skill test.

Since external students have work/study commitments and the majority of them are in a separate geographical place to Curtin Bentley, the online version of the CCNA R&S course is the most popular version for this group of learners.

The COLab configuration for CCNA laboratories offers an active and self-regulated learning system where students have a level of freedom to interact with the educational environment based on their learning ability. The resources are easy to access and laboratory experiments can be performed several times at the student's convenience. These characteristics are in accordance with the elements included in cognitivism and constructivism theories for the educational environment. While students experience autonomy in learning, they are responsible to identify and use the connections between the knowledge nodes such as lab manual, course content, online laboratory environment, and other learners (in case of collaboration learning) and instructor. Therefore, it can be stated that cognitivism, constructivism, and connectivism theories are used in the CCNA online laboratory educational environment.

### **5.3.1.2 CCNA security**

This course emphasizes the possible security threats and vulnerabilities on the network level, methods of recognizing the security issues, and techniques to develop mitigation plan and security infrastructure [91].

The CCNA R&S is the pre-requisite for Cisco Certified Network Associate (CCNA) security and both follow the same curriculum structure.

Curtin University delivers CCNA security and CCNA Cyber Security Operation (section 5.3.1.3) courses as a laboratory component of two units. One of these is an undergraduate unit offered on three campuses, and the other one is a postgraduate unit delivered on one campus.

From semester two 2015 to semester two of 2019, almost 320 students attended the CCNA Security course from three Curtin campuses. During this time the number of local students from Curtin University, Bentley campus was 212, with 117 from the undergraduate course and 95 postgraduate students. The rest of the students were from remote campuses enrolled in the undergraduate unit.

#### **Device topology and setup**

The NDG recommended topology for CCNA security is almost the same as CCNA R&S with the addition of a security firewall device or ASA (Multi-Purpose Academy Pod with ASA). Cisco Adaptive Security Appliance (ASA) is a firewall device that provides secure data transmission and incorporates technologies such as intrusion prevention, site-to-site VPN, high availability, etc.

Figure 5-10 illustrates the Multi-Purpose Academy Pod with ASA topology. As it is displayed in this figure ASA has four interfaces, three of them connected to switches and one to the ESXi server via a Control switch.

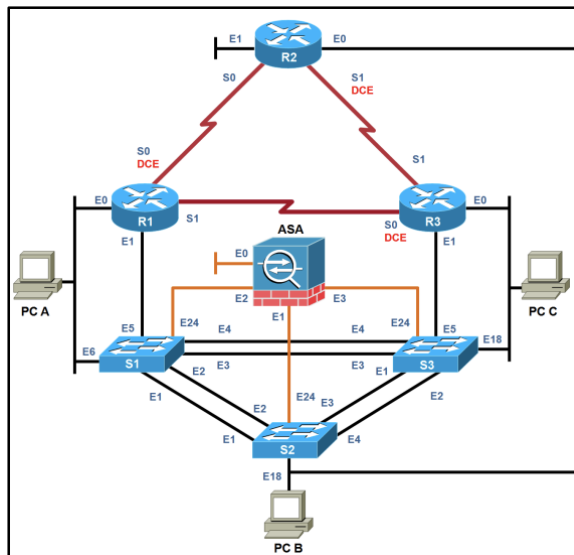


Figure 5-10 - Multi-Purpose Academy Pod with ASA topology [79].

The equipment connections to control devices are the same as the Multi-Purpose Academy Pod with the addition of ASA links. Figure 5-11 demonstrates the whole pod connection to the Control Switch.

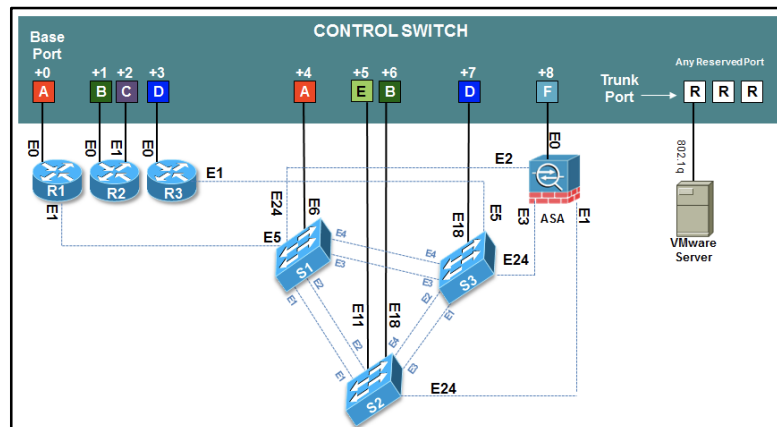


Figure 5-11 - Multi-Purpose Academy Pod with ASA on Control Switch [79]

All the devices including ASA are connected to Access Server and PDU in the same manner as Multi-Purpose Academy Pod explained in section 5.3.1.1 above.

There are two Multi-Purpose Academy pods with ASA in COLab that are used for both CCNA R&S and CCNA security. During the second semester of each year, CCNA Security students utilize the two Multi-Purpose Academy Pods with ASA in conjunction with CCNA R&S users. However, according to Curtin University enrollment statistics based on the course plans the number

of CCNA R&S students enrolled in the second semester is significantly lower than semester one. Therefore, it is possible to share the laboratory infrastructure between the two groups of students.

### **Laboratory delivery**

The laboratory delivery method and groups of students are the same as the CCNA R&S course with a lower number of enrollments. Therefore, students are categorized as local students (Curtin students and instructor trainees) and remote students (offshore students and instructor trainees). Also, course delivery methods are based on the student's competency similar to CCNA R&S.

#### **5.3.1.3 CCNA Cybersecurity Operation**

Cisco Certified Network Associate Cybersecurity Operations (CCNA CyberOps) is a CNAP course focusing on skills required to be a part of Security Operations Centers (SOCs). This course includes the fundamental knowledge and skills necessary for detecting, analyzing, responding, and preventing cybersecurity threats and attacks. CCNA CyberOps with CCNA security helps student develop the essential knowledge for protecting end-user devices, servers, operations, and network from cyber threats [92].

CCNA CyberOps is a more recent course compare to CCNA security that was adopted by Curtin University in 2018. Before CCNA CyberOps, a series of custom-made ethical hacking laboratory experiments were used to teach a similar concept along with CCNA security.

However, with the introduction of CCNA CyberOps by Cisco, and the substantial material included in this course, it has been decided to replace the aging hacking laboratories with this new course.

### **Device topology and setup**

CCNA CyberOps laboratory topology consists of five virtual machines connected through ESXi virtual network. There is not any network equipment in this laboratory setup [92].

As shown in Figure 5-12, CCNA CyberOps laboratory topology consists of three networks: outside network or Internet, Inside or secure network, and DMZ network that is used for sharing internal services with Internet users.

This topology is a replica of an organization network with each VM representing components of the real environment. The Kali is a VM with the most current penetration testing tool that initiates the security attacks from the Internet, security onion is a VM functioning as a firewall examining the data transmitted between the networks and enforces the configured security measures, Metasploitable is designed as a vulnerable machine in DMZ network, CyberOps Workstation is monitoring and analyzing the security, WinClient represents the inside machines.

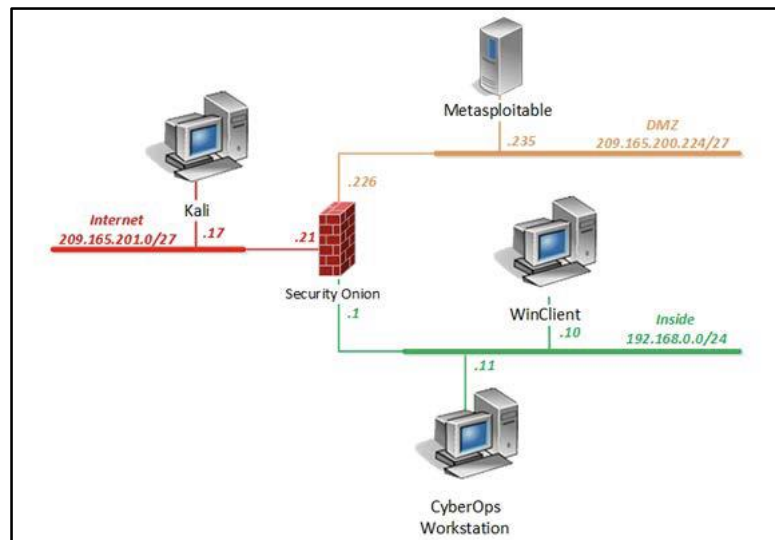


Figure 5-12 - CCNA Cybersecurity Operations topology [92]

The CCNA CyberOps laboratory topology can only be implemented on NETLAB+ VE and for each master pod, 37.1 GB of storage is required.

More details on CCNA CyberOps VMs and configurations is available in Appendix C.

### Laboratory delivery

The CCNA CyberOps and CCNA Security form the laboratory component for two units. As a result, the group of students and delivery methods are the same as CCNA security.

### 5.3.2 Communication engineering laboratory

At Curtin University Software Defined Radio (SDR) is used to develop laboratory experiments for communication engineering units. SDR is a

technology that creates a communication platform for reconfiguring the Radio Frequency (RF) hardware through software implementation of communication algorithms [93]. Fundamentally, SDR is a platform that includes the software presentations of radio communication hardware.

SDR devices' wireless channels create an authentic testing opportunity for communication algorithms. Therefore, it has received great attention from researchers and educators for prototyping the wireless environment and performing laboratory experiments [94].

The Universal Software Radio Peripheral (USRP) is an SDR platform developed and sold by Ettus Research and National Instrument (NI). The Ettus USRP and NI USRP have minor differences in hardware design, software driver support, and technical support [95].

Curtin University utilizes NI USRP 2920 for laboratory experiment in communications units (Figure 5-13).



Figure 5-13 - NI USRP 2920 [96]

NI USRP 2920 is an RF transceiver device that executes the following procedures (Figure 5-14):

1. Signals are received through a highly sensitive receiver
2. Performs DSP operations to digitize the signal and produce an I/Q baseband signal. These DSP operations are, Digital Down Conversion (DDC) and high-speed analogue-to-digital conversion (ADC)
3. Transmits the signal via Gigabit Ethernet to host computer running LabVIEW application for more DSP operations, processes and analyses,
4. Host computer transfers the generated I/Q signal to USRP

5. USRP performs DSP operations to generate RF frequency signal, amplify it and transmit it. These DSP operations include Digital Up Conversion (DUC), digital-to-analogue (DAC), and signal amplifying [96].

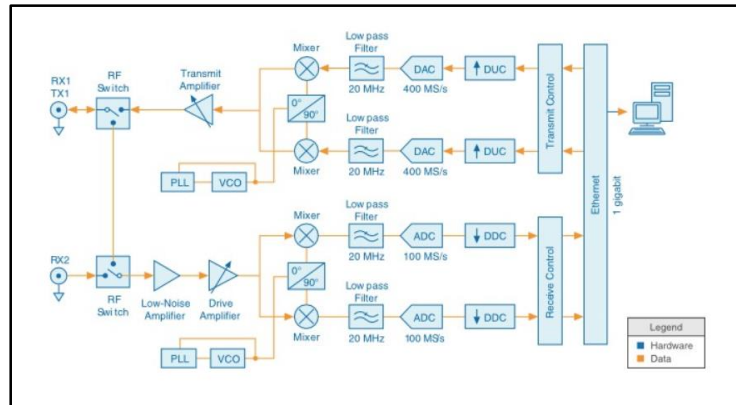


Figure 5-14 - The USRP-2920 operation diagram [96]

The use of NI USRP in conjunction with LabVIEW running on the host machine produces a powerful wireless prototyping system.

Curtin University offers communication units in three campuses including Bentley, Miri, and Sri Lanka Institute of Information (SLIIT). The SDR laboratory setup was created and tested at Curtin Bentley. However, due to resource limitations, other campuses couldn't replicate the same SDR laboratory system.

Although USRP is an affordable SDR platform compare to other product with the same functionality, it is still relatively costly for many educational institutions. Each laboratory setup requires two USRPs and a PC running LabVIEW. Therefore, the cost of the LabVIEW licensing and PC will be added to the laboratory bundle expenses.

Telecommunication is a highly technical study field that requires staff with the expertise to set up and configures the laboratory environment. The overseas campuses have a limited number of expert staff to set up the SDR laboratories [93].



Therefore, with the high cost of the SDR laboratory setup and demand for highly skilled staff, it is beneficial to share the existing setup among all campuses.

To achieve this objective, remote access to the SDR laboratory pods was created via a COLab environment with 24/7 accessibility. The COLab version of the SDR laboratory increases the utilization of USRP devices for both teaching units and research students [93]. Also replacing PCs with VMs reduces the cost of devices and a lesser number of LabVIEW licenses were required as VMs are cloned.

### **Device topology and setup**

The original communication engineering laboratory setup is shown in Figure 5-15. It consists of two USRPs connected using a multiple-input multiple-output (MIMO) extension cable, and a PC running LabVIEW with an ethernet connection to one USRP. At the basic level, the synchronization configuration between receiver and transmitter on two URSP is eliminated by using MIMO connection to help students focus on other communication aspects such as modulation and demodulation. However, at an advanced level, the MIMO cable should be removed for synchronization configuration and frequency offset estimation [93].

Laboratory Virtual Instrument Engineering Workbench or LabVIEW is a graphical programming environment released by National Instrument (NI) for the development of any testing, measurement, and control applications in the engineering field [97]. LabVIEW creates Virtual Instruments (VIs) that are LabVIEW programs developed using G programming language representing the physical instrument such as multi-meters [98]. The hardware integration functionality in LabVIEW allows engineers to connect devices such as USRP for configuration and control purposes [93]. The VI for USRP is used in a communication engineering laboratory to interact with USRPs.

In the COLab version of communication engineering laboratory topology, the PC is replaced with VM on the ESXi server. The USRPs were connected to control the switch via a gigabit switch to communicate with VM (Figure 5-15).

Twelve USRP devices create 6 laboratory bundles separated by VLAN configurations on a gigabit switch. A VM running licensed LabVIEW was created and cloned to accommodate all six pods. These VMs reside on the ESXi server were placed in the same VLAN as their corresponding pod USRPs. The Control Switch is responsible to provide communications with VM, USRPs, and NETLAB+ server.

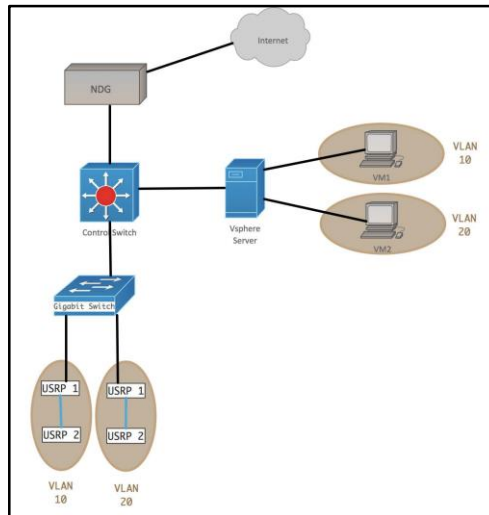


Figure 5-15 - Communication Engineering Laboratory Topology

The design was tested in the laboratory sessions and a clock synchronization problem was identified during the first week of operation. Users experienced a constant connection drop to the second USRP in each laboratory pod causing an unstable result from LabVIEW. The USRP devices require a gigabit ethernet network connection to operate accurately. However, in Figure 5-15 topology the gigabit ethernet communication stops at the gigabit switch and does not include the full path to VMs.

To address this problem, it has been decided to connect the USRP's network link directly to the PCIe module on Dell PowerEdge FX2/FX2s server and map the connected ports via the vSwitch network configuration on the ESXi server.

The new topology was implemented and the evaluation confirmed that the solution was successful in resolving the network connection loss problem. The six laboratory pods were used for two study periods by local and remote students.

## Laboratory delivery

The COLab version of the communication engineering laboratory was delivered to remote and local students in two study periods. This SDR based laboratory was used for the experimental component of two units: Advance Communication Engineering and Communications Engineering Fundamentals.

During the first study period, local students at Curtin Bentley and remote students at Miri Malaysia attended the COLab SDR laboratory. In the second study period, SLIIT students joined the remote user groups.

Seven laboratory activity manuals were designed for this laboratory setup comprising of three for Advance Communication Engineering and the rest for Communications Engineering Fundamentals. The lab instructions were manually added to the NETLAB+ server as customized course content. Access to laboratory experiment manuals was available to students after authenticating to the NETLAB+ server. The USRP devices are configured via LabVIEW installed on VM, therefore, students only require access to virtual machines with no installation and license issues on the client-side.

The laboratory contents were delivered in a blended environment with in-person teaching sessions and online self-study. The laboratory supervisor presented the introductory lesson at the beginning of the first session to prepare students for using the COLab system, LabVIEW programming platform, and USRP devices. Also, a short lesson was presented during each in-person session to explain the concept of the intended experiment.

Laboratory supervisors were available throughout the in-person sessions for assisting students.

While educators are more involved in delivering this laboratory compared to CCNA R&S, Security, and CyberOps, students are still experiencing a great level of active and self-regulated learning. They can perform the experiments as many times as required after each instructor-led session. Therefore, in term of teaching philosophies, cognitivism, constructivism, and connectivism theories still apply in communications engineering laboratory setup.

Due to resource limitations, students were divided into groups of two for laboratory performance during the in-person sessions. However, 24/7 access

was available for students to practice and self-study using the COLab SDR laboratory.

With the major changes in the delivery of communication engineering related units, the USRP SDR laboratory pods only used during the two study periods.

### **5.3.3 Remote renewable energy laboratory**

The material in this section was published in 4th Experiment@ International Conference (exp. at'17), 2017.

Green Electric Energy Park (GEEP) is a Curtin University facility that provides a state-of-the-art laboratory environment for renewable energy power conversion systems (Figure 5-16). The Institute of Electrical and Electronics Engineering (IEEE) recognized GEEP as one of the “new initiatives in power engineering education” in the 2011 annual general meeting [99]. There are various types of renewable energy sources available for student experiments in seven teachings and four research stations. The GEEP equipment includes:

- Three different types of solar PV arrays on trackers, which follow the sun from east to west
- A horizontal axis and a vertical axis wind turbine on 11-metre towers
- A micro-hydro turbine, generator, pump and tank
- Fuel cell, electrolyser and hydrogen storage
- A large, central battery bank and three small battery banks
- A large programmable three-phase resistive load bank and four small, single-phase load banks
- A weather monitoring station and anemometer on an 11-metre tower
- Micro-grid forming inverters and the central switching station for main grid versus micro-grid selection

- Various types of power converters for grid connection, battery charging and water pumping
- A custom-designed software platform for data acquisition, system integration, display, analysis and storage
- Foundations and cabling for the expansion of renewable energy sources [99].



*Figure 5-16 - GEEP facility- Curtin University Bentley Campus [99]*

Without a remote connection, this cutting edge high-cost laboratory environment is accessible only to local students during the facility opening hours while the international campuses in Malaysia and Sri Lanka are offering the same units, as a local campus in Australia. Remote students ought to receive the same standard as local students for the quality of teaching across campuses.

Therefore, a reliable remote access system is required to accommodate students independent of their geographical location and time zone. Within the configured consistent remote laboratory, the resources are shared among more users and collaboration across campuses is achievable whilst students benefit from 24/7 access.

There was a pre-existing online access system for the GEEP facility that provides users with remote access through the use of Cisco AnyConnect VPN client, LabVIEW client, IP cameras located in GEEP facilities for monitoring, and a two-way Audio system to communicate with on-site staff.

VPN (Virtual Private Network) client is a software application that provides a secure connection to the remote network [100] and in this scenario, Cisco AnyConnect VPN client is used to securely connect the remote user to GEEP Local Area Network (LAN).

LabVIEW is a software development environment that uses a graphical programming language called G to create Virtual Instruments (VIs) [10]. The LabVIEW client used in this environment is a custom-designed software platform for data acquisition, system integration, display, analysis and storage [99]. Figure 5-17 shows the home screen of the GEEP LabVIEW client.

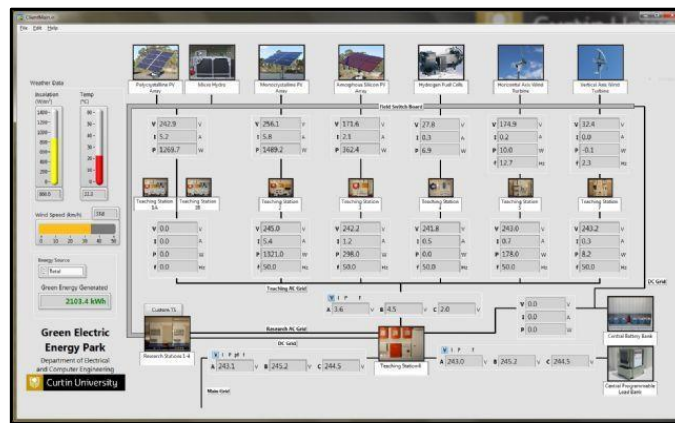


Figure 5-17 - The home screen of GEEP custom-designed LabVIEW client [99]

The remote access procedure starts with the installation of a LabVIEW client on a remote machine, next a connection to the GEEP LAN establishes via Cisco AnyConnect VPN for the LabVIEW client to communicate with the facility and collect data while two-way audio is accessible through this connection.

However, this remote laboratory design did not efficiently correspond to international campuses requirements as two main problems occurred during the remote access: bandwidth restrictions and VPN account management. While students established remote access to GEEP facilities, they experienced delays and even disconnection due to exceeding the remote user's network bandwidth. This issue resulted from several reasons including a high volume of data streaming from LabVIEW client software, IP cameras video streaming, and bandwidth usage from two-way audio.

Also, an account for each user is required to permit full access to GEEP LAN via Cisco AnyConnect VPN that in turns reduces the security of the GEEP facilities and adds vulnerability along with the additional task of account management. Therefore, to address these problems and improve students experience the new system was designed and implemented to remotely access the GEEP laboratory with lower bandwidth requirements and elimination of VPN usage.

The solution was a VM pod on COLab along with a technique to implement a two-way audio system. The new design consolidated the usage of Virtual Machines (VMs) and NETLAB+ scheduling system (Figure 5-18), to address the bandwidth and account management issues in the existing GEEP remote laboratory.



Figure 5-18 - NETLAB+ Scheduler accessed through a web browser

Although, the new challenge was adding the two-way audio to this design while NETLAB+ has no support for it.

### Device topology and setup

The new remote laboratory design is using virtual machines that reside on an ESXi server (Figure 5-19), therefore the LabVIEW client streaming data is occurring in the local network and not over the Internet, which in theory it should significantly reduce the usage of bandwidth for remote users. After research on the system, it has been found that the LabVIEW client pulls a constant data stream of upwards of 550 Kbytes/s while video feed from IP

cameras is adjustable to support lower bandwidth, and audio bandwidth usage is negligible.

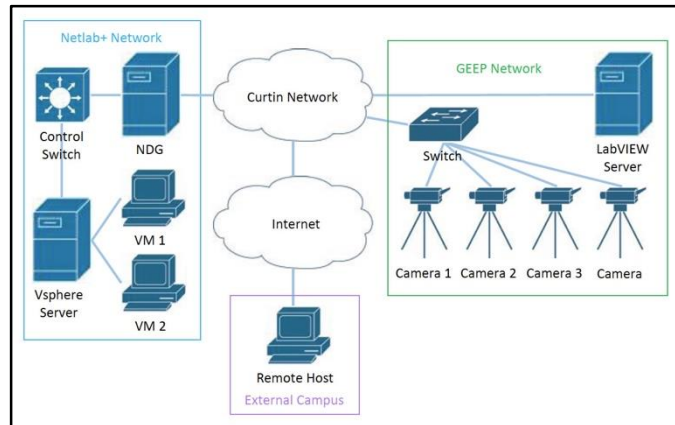


Figure 5-19 - GEEP Remote laboratory design with NETLAB+

Although the LabVIEW client is the main source of bandwidth issues, it is beneficial to move video and audio feeds to the VMs for ease of use and simplicity, as well as avoiding the concerns related to VPN accounts while still slightly reducing bandwidth demands.

Figure 5-19 shows the GEEP remote laboratory design. The operation of the system involves:

1. Remote host logging into one of the VMs through NETLAB+ server
2. Access the LabVIEW client installed on each VM to Monitor data from the server on the GEEP site
3. Use the relevant software for the NETLAB+ audio bypass (addressed further in this paper)
4. Access any of the four GEEP IP cameras via a web browser

The two-way audio communication with on-site technical operators would be handled on the same web page used to access any of the four cameras located in GEEP facilities. Staff and students from the Sri Lanka Institute of Information Technology (SLIIT) collaborated with Curtin University Bentley to test this new design.



## LabView client

The LabView client was installed on two Windows 7 VMs created on the ESXi server (Fig. 3) and has been successfully tested from both local (Curtin University Bentley) and remote location (SLIT). Remote users were able to effectively use the LabVIEW client through NETLAB+, without experiencing any significant issues concerning bandwidth constraints. Additionally, a dedicated VPN no longer needed for the LabVIEW client, as the remote access was handled by the NETLAB+ server.

## IP Camera

There are four AXIS P5534 Dome IP cameras (Figure 5-20) implemented in the GEEP facility that can be accessed through a compatible browser with the relevant plugins.



Figure 5-20 - AXIS P5534 PTZ Dome Network Camera



Figure 5-21 - Foscam FI9821P V2 IP camera

However, an experimental IP camera (Foscam FI9821P V2) was used during the testing phase for the proof-of-concept and to avoid the interruption on the GEEP laboratory while sending and receiving the audio feed through the IP camera (Figure 5-21).

## Two-way audio

As NETLAB+ infrastructure had no native support for audio and no API would enable audio integration into NETLAB+, extensive research had to be conducted to find a possible solution.

The solution that was eventually implemented on COLab was to use virtual audio cables to allow the VMs to relay two-way audio between the IP Camera and the remote host.

This would require the use of both VoIP (Voice Over IP) software that supports custom setting input/output audio devices and virtual audio cable software. Following investigating various software solutions with this specific requirement, it was ultimately decided to use Ventrilo for the VoIP software and VB-Audio Virtual Cable for the virtual audio cable software (Figure 5-22 and Figure 5-23). Ventrilo is available as freeware for a maximum of 8 clients on one server however for the larger number of users rented server is obtainable that supports up to 400 clients.



Figure 5-22 - Ventrilo Client

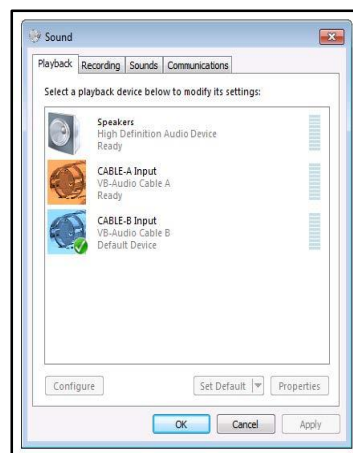


Figure 5-23 - VB-Audio Virtual Cable playback devices

First, the two-way audio was tested using the external Ventrilo server and experimental IP camera (Foscam) that resides on the same network as VMs. A chat room was created for each VM on the external Ventrilo server, each with two accounts one for the VM and one guest account for the remote user.

Then the same concept was tested using the IP camera located on GEEP facilities and Ventrilo servers located on VMs.

For audio Communication between VM and remote user, the Ventrilo client (Figure 5-22) is required to be installed on both sides (Figure 5-24).

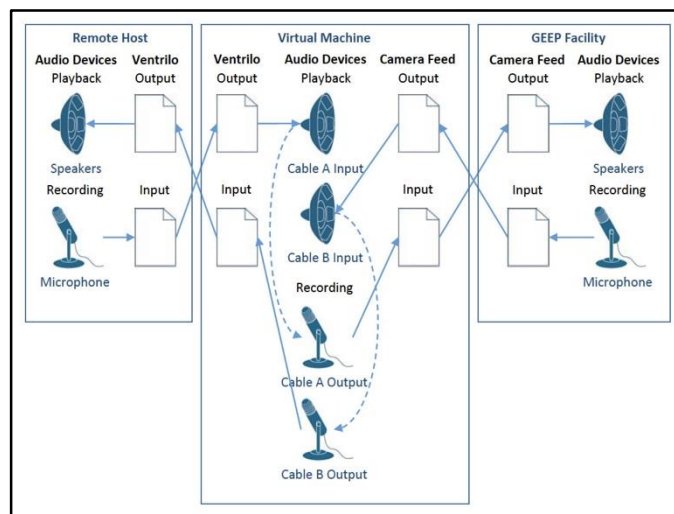


Figure 5-24 - Audio relay design for direct host-to GEEP communication

The client is configured to correctly relay the various audio I/O devices to each other and automatically activate the outgoing audio transition as soon as a sound was detected on the system.

### Laboratory delivery

Curtin University Bentley and SLIIT collaborated to evaluate the COLab access to GEEP over one semester.

The target group was students taking renewable energy units as part of the electrical engineering course on two campuses. Local students at Curtin University Bentley had online access or in-person option to join the laboratory sessions and remote students in SLIIT only had online access.

During the evaluation period, instructor-led laboratory sessions were conducted on the allocated time. COLab provides 24/7 access to the GEEP facility for the data collection on the preconfigured equipment. However,

instructor involvement and guidance are required to perform some of the laboratory tasks due to equipment operating conditions. Therefore, the nature of the laboratory device setup does not allow for fully online delivery of all the experiments.

The COLab remote access to the GEEP facility was a bandwidth-efficient solution that provides stable connection, eliminates the requirement for software installation on client machines, and operates without the use of VPN.

Despite these accomplishments, GEEP laboratory over COLab remained at the evaluation phase and did not proceed to the full operation phase due to changes in course delivery and experiment components of the teaching units.

### 5.3.4 Experimental laboratory setup (USB hub)

The two laboratory setups explained in this section were designed for proof of concept in computer networking and embedded system field of study.

Both of these laboratory systems encompassed peripheral equipment; therefore, a USB over IP device was implemented in the COLab system. A direct connection between a USB device and USB port on the PC in the local environment is replaced by mapping the USB over IP connectors to VM's virtual USB port.

A DIGI AnywhereUSB device with two Ethernet connection and 14 USB ports was selected as shown in Figure 5-25.

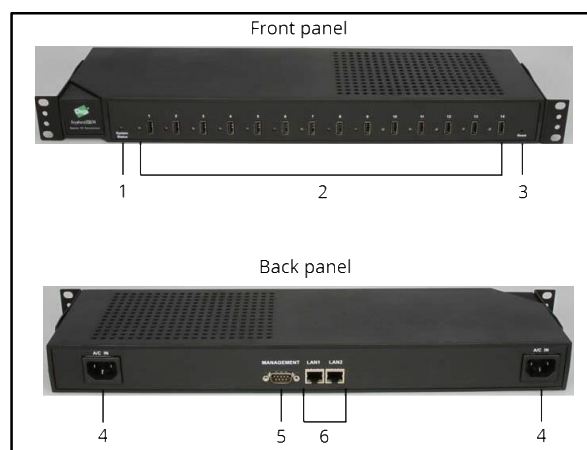


Figure 5-25 - DIGI Anywhere USB device

For VMs to access the peripheral devices, the DIGI Anywhere USB network interface (LAN1 or primary interface) connected to the same LAN as the

ESXi server and configured with a static IP address. A redundancy network connection can be configured on this device using the LAN2 interface as a secondary network.

Any computer/VM in the same LAN can access the DIGI Anywhere USB configuration interface via a web browser. The DIGI AnywhereUSB drivers must be installed on VMs for accessing the peripheral devices.

The required drivers were downloaded using the internet connection provided by the VMs extra network interface via a virtual switch (section 5.2.2.2) in the COLab system.

After Configuring and the AnywhereUSB device and installing drivers, VMs can utilize the connected peripheral devices using the DIGI AnywhereUSB configuration utility (Figure 5-26).

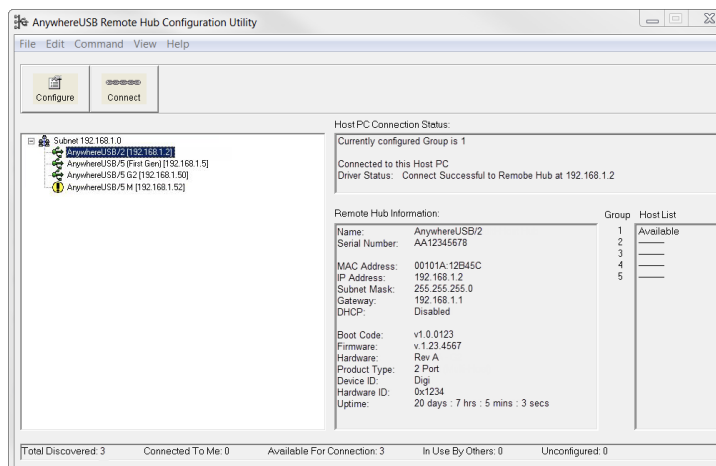


Figure 5-26 - AnywhereUSB Configuration Utility Interface

A list of USB devices connected to AnywhereUSB will appear on the left side of the configuration utility window. To connect the USB device first select it then click connect button on the top.

### Wireless laboratory – WDN

The Wireless Data Network is an ITC unit offered to bachelor and master students in Curtin University that covers the teaching objectives in wireless communication.

A customized wireless network setup was designed as a laboratory environment associated with this unit to assist student's understanding of wireless communications and network management. Figure 5-27 shows the wireless laboratory topology including an access point, a wireless LAN controller, a wireless PC, a wired PC, and a switch.

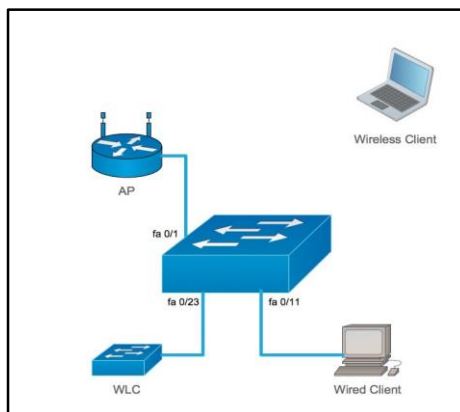


Figure 5-27 - Wireless Laboratory Topology

This laboratory setup intends to create a wireless network and centrally manage the access point from WLC. A switch is in the centre of the topology connecting AP, wired PC, and WLC via ethernet connection. It also works as a DHCP server releasing IP address to connected devices and represents a border device before entering the outside world (ISP connection). In the real-world environment access points in the wireless network is managed centrally similar to this laboratory setup. However, in the laboratory setup only one AP is used for proof of concept and extra Apps can be added following the same procedure as the one connected in the experiment.

This wireless network laboratory is in line with CCNA wireless certification content from Cisco.

There were two main challenges in implementing this laboratory setup on the COLab system.

1. A wireless antenna and network interface configuration are required for VM to work as a wireless PC in laboratory topology (Figure 5-27).
2. There was no WLC device in NETLAB+ server topology templates for managing power and console connection. One option was to use the Pod Designer utility on the NETLAB+ server. However, at the time of

implementing the laboratory, there was a limitation on the number of Pod Designer setups.

To address the first problem a D-Link USB Wi-Fi antenna was connected to the DIGI AnywhereUSB device. The required drivers were installed on VM planned to be the wireless PC. These included DIGI AnywhereUSB and wireless USB antenna drivers. After connecting and configuring the wireless USB antenna and mapping it to the VM network interface, the VM satisfied the conditions to act as a wireless client (Figure 5-28).

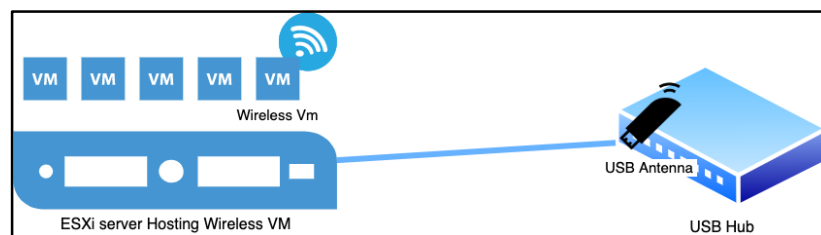


Figure 5-28 - Wireless VM

All these wireless network laboratory experiments start with WLC configuration through a console connection from a PC (mostly wired client). It has been decided to create a console connection from WLC to VM representing the wired client. A Keyspan USB-to-serial adaptor connected the WLC console cable to a port on DIGI AnywhereUSB (Figure 5-29).



Figure 5-29 - Keyspan USB to Serial Adaptor (Left)- Keyspan USB connection to AnyConnectUSB Hub (Middle)- Console connection to WLC (Right)

With Keyspan driver installed on VM (wired client), an emulator terminal can access the WLC for configuration purposes (Figure 5-30).

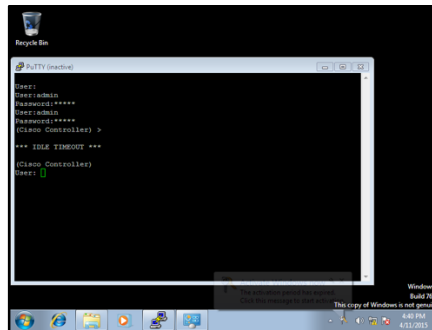


Figure 5-30 - Terminal interface to WLC

In COLab wireless pod, users had access to switch and two client's consoles. As has been mentioned, the WLC console connection was accessible through the wired VM and AP was configured via WLC. Once the initial configuration was performed on WLC, the rest of the configurations for each experiment could be performed using the WLC web interface. Figure 5-31 shows an example of a WLC web configuration interface.

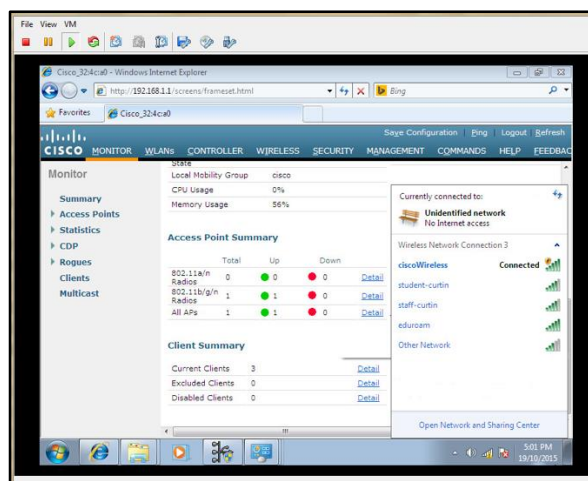


Figure 5-31 - WLC Web Interface on Wireless VM

This laboratory setup was designed to test the feasibility of remote implementation and the possibility of future expansion. However, due to resource constraints, interference problems between APs, and the probability of unit content changes, the COLab wireless laboratory pod did not go to the operational step.



The outcome of this design will be utilized to design the future updated version of the laboratory component in the wireless network unit.

### **Embedded systems laboratory setup**

Another experimental laboratory setup was the remote access to program an MSP430 development board from a VM on a COLab environment. Students must have a visual view of the MSP430 during the laboratory experiments for monitoring the feedbacks after loading the program. An IP camera was implemented over the MSP430 board to capture the live video stream.

The MSP430 board and IP camera were attached to USB over IP device (AnywhereUSB) and a connection was established from pod VM to these devices.

The Energia Prototyping Platform is installed on VM and used to program the MSP430 board. An HTTP connection was used to access the camera view from VM.



*Figure 5-32 - MSP430 remote connection*

Figure 5-32 shows the VM with IP camera view and Energia platform uploading the Blink example codes to MSP430.

Due to a very low number of students using the embedded systems laboratory pod, it was not possible to evaluate this experimental setup in the operational phase.

## 5.4 Summary

This chapter explained the detailed design and implementation of the online laboratory experimental model. The engineering design process was followed to implement COLab as a study environment.

- In the first step, the problem was identified that was the need for an experimental model in studying the online laboratory pedagogies.
- Then a prototype model for each laboratory was designed and implemented.
- Each laboratory implementation went through testing and evaluation to provide feedback.
- The adjustments were applied based on the research and provided feedback in each step.

Several laboratory setups were designed and implemented to form a comprehensive study model. This included the different types of course contents and the educational delivery models ranging from fully online to blended environment.

The COLab was used to study the online laboratory environment for almost 4 years. According to the findings it has been proven that COLab is flexible and transferable to a range of subdivision areas.

In the next chapter, the outcome of the COLab usage parameters and participant's feedback are analyzed to study pedagogy for the remote laboratory.

## Chapter6: Analyzing the Results

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### 6.1 Introduction

COLab was designed and implemented as an experimental engineering remote laboratory model to study the effectiveness of the online environment in teaching courses and developing pedagogies. The nature of the engineering education and the online environment are the two factors influencing study of pedagogies and teaching frameworks for remote engineering laboratories.

Therefore, this research included the evaluation of both engineering and remote education environment characteristics using learning theories as tools to describe the process of acquiring knowledge.

The research and survey were adopted as strategies to collect data and the outcome is presented in a framework according to the corresponding learning theories.

### 6.2 Study structure and Learning theories

The epistemological theories are the foundation of pedagogies and educational frameworks development. They explain how students learn what they are intended to learn. Educators use these theories to create teaching materials and a learning environment.

The major learning theories were evaluated in Chapter2:Background study and Literature Review- to determine the one that best describes the educational requirement for science and engineering remote laboratory environment. A summary of each learning theories position in major epistemological questions is presented in Table 6.1.

Property	Behaviourism	Cognitivism	Constructivism	Connectivism
How does learning occur?	Black box—observable behaviour main focus	Structured, computational	Social, meaning created by each learner (personal)	Distributed within a network, social, technologically enhanced, recognizing and interpreting patterns
Influencing factors	Nature of reward, punishment, stimuli	Existing schema, previous experiences	Engagement, participation, social, cultural	Diversity of network
What is the role of memory?	Memory is the hardwiring of repeated experiences—where reward and punishment are most influential	Encoding, storage, retrieval	Prior knowledge remixed to current context	Adaptive patterns, representative of current state, existing in networks
How does transfer occur?	Stimulus, response	Duplicating knowledge constructs of “knower”	Socialization	Connecting to (adding) nodes
Types of learning best explained	Task-based learning	Reasoning, clear objectives, problem solving	Social, vague (“ill defined”)	Complex learning, rapid changing core, diverse knowledge sources

Table 6.1 - Summary of Learning Theories [101]

The **cognitivism theory** states that learning knowledge occurs in the brain through cognitive stages and encourages the active learning environment.

The cognitive development stages are not always followed by science and engineering educational methods and it is not possible to fully apply these stages in the online learning environment. However, active learning is an effective method of teaching science and engineering courses in which students taking a role in teaching operations by attending activities such as laboratories. Online laboratories are also an example of an active learning environment.

**Constructivism theory** principles are built on the idea that the new knowledge forms in the brain on the basis of previously learnt knowledge. It supports the active learning environment as well as self-regulated educational methods. Although the knowledge construction on previously learnt material is an effective teaching approach, this learning pattern might not apply in many modern learning environments [50]. However, elements of this theory are adopted for developing the online laboratory education framework (explained in section 6.4.2.3).

The Bloom's Taxonomy explained in Chapter4:-Experiment Design as a most adopted educational framework is based on cognitivism and constructivism theories.

The most recent learning theory is **Connectivism** that claims knowledge exists in a network where people, technology, database, and resources are the nodes of this network. Educators are facilitating students by providing the resources for the autonomous learning environment [29]. The online educational system best fits within this theory, however, the science and engineering education methods do not fully support this idea.

Based on the study outcomes in Chapter2:- Background Study and Literature Review, and the fact that online educational laboratories are a complex system, a comprehensive study on the three recent learning theories: cognitivism, constructivism, and connectivism was conducted to design a framework and pedagogies for this environment.

Section 6.4 explains how these theories are combined to develop pedagogies and framework for online laboratories. The recommended framework is based on Bloom's Taxonomy (explained in Chapter4:Experiment Design) as the most adopted educational framework. Bloom's Taxonomy is established on cognitivism and constructivism theories while the new model adds aspects of connectivism theory to incorporate requirements for teaching laboratory experiments in the remote environment.

COLab is an experimental model designed to test the research hypothesis **"the use of online laboratory has a positive effect on engineering education"**. It is also used to investigate the engineering learning methods in an online environment. The engineering design approach was used in the development, implementation, and evaluation of COLab (Chapter5:Curtin Online Laboratory (COLab) Implementation). To observe and study an online laboratory learning environment, COLab was examined based on engineering education principles. The study investigation method was driven from the cause-and-effect relationship between the independent variable (COLab environment) and the dependent variable (COLab positive effect on engineering education).

The COLab system as the independent variable was altered and modified to capture its effect on the dependent variable (learning experience) . That included the implementation of different laboratory setups aimed at various study groups.

In the process of investigating the preeminent pedagogies for science and engineering online laboratories, two significant areas to study are the characteristics of science and engineering education and the characteristics of the online nature of the laboratories.

The other major aspect of this study is the accessibility for vision-impaired users. COLab environment was developed using NETLAB+ as a powerful remote laboratory system. However, the NETLAB+ server interface is not accessible therefore, the CAVI remote laboratory with some upgrade was running in parallel with the COLab to investigate the pedagogies for an accessible environment.

### **6.3 Data collection and analysis**

This study considers the following question as to the main determinant of the research

***“How an online remote accessible laboratory design can be effective, efficient, and practical in teaching science and engineering?”***

As defined in Chapter3:Research Methodologies on research methodology, for a comprehensive response to this research question, the collection and analysis of both qualitative and quantitative information were required. A selection of approaches was adopted to investigate these qualitative and quantitative data; therefore, pragmatism was the selected research philosophy in this study with the focus on the mixed-method research paradigm [52].

The research approach was the between-method triangulation that allows for collection and analysis of the combination of qualitative and quantitative data [54]. The research design was based on the experiment and survey strategies [56]. Qualitative and quantitative information was gathered from COLab usage observation (as the experimental model), student feedback, and student response to the questionnaire. Then inductive and deductive analysis was applied to qualitative and quantitative data respectively.

### **6.3.1 Data Collections**

Data were collected from three different sources including the responses to the online questionnaire (Appendix B), COLab usage observation and feedback/comments from users. As the information was gathered from the exploratory sample groups who are the user of the remote laboratory environment, the sampling technique is purposive [56].

#### **6.3.1.1 Questionnaire and feedback**

Several parameters should be considered in creating an effective questionnaire to collect effective data for the study subject and encourage participants to provide a truthful response.

All the questions were brief and relevant to the usage of the experimental model (COLab), unambiguous and easy to understand, and precisely directed to the objectives of the study.

A combination of Linkert-scale, open and closed questions were included in this questionnaire (Appendix B). As the first version of the remote laboratory was called NETLAB, the questions are using this name instead of COLab.

Students were from Curtin University Bentley and some of its international campuses accessed this survey via the educational portal (Blackboard) and a link to the questionnaire was shared with non-university students. The demographic information of the participants is presented in Chapter5: Curtin Online Laboratory (COLab) Implementation under the laboratory delivery title in sections 5.3.1, 5.3.2, 5.3.3.

The survey was conducted over four years (2016-2020) and presented to students from different courses. Summarization of all the results is displayed in this section.

The main part of the questionnaire aimed at three major concepts: the importance of each laboratory aspects, satisfaction level of COLab experience, Effectiveness of remote labs in comparison to in-class laboratories.

Figure 6-1 shows how students rated the importance of each laboratory aspect to perform successful experiments.

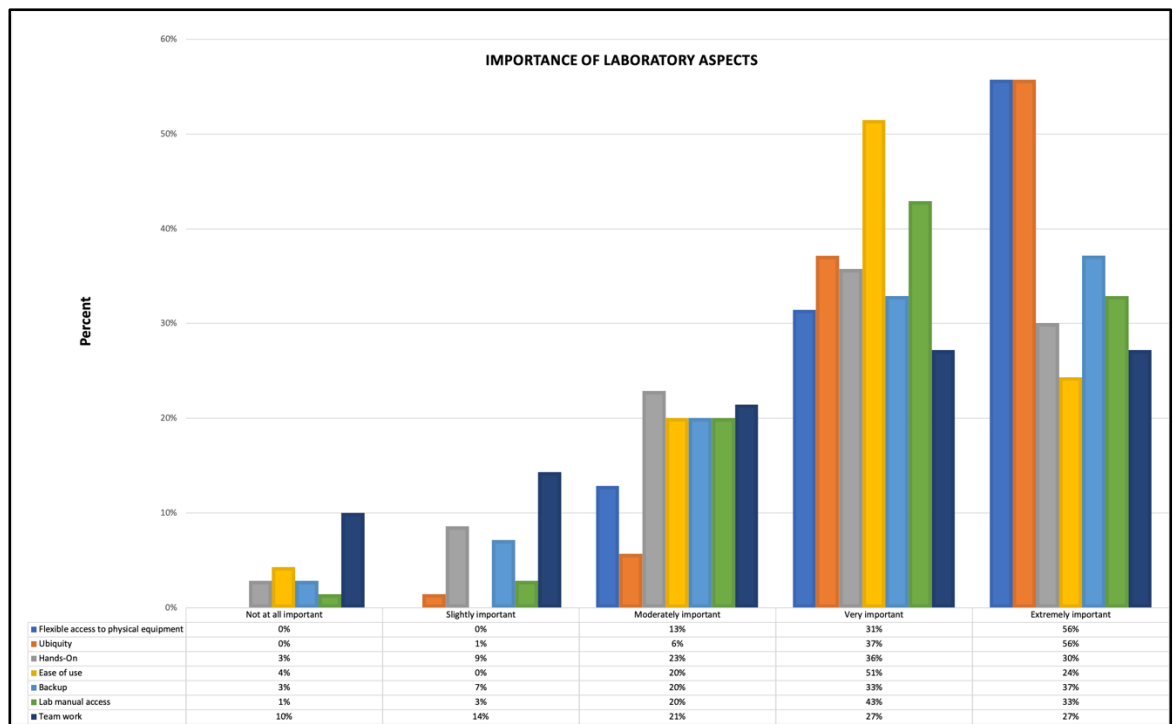


Figure 6-1 - Student's ratings on how important each aspect is in successfully undertaking labs

As can be seen in Figure 6-1, majority of students believe that the flexibility of access to physical laboratory equipment is important and over 80% considered this as very important or extremely important. This follows by time and location flexibility aspects of the laboratory with a 93% response rate of high importance (very important + extremely important). This indicates the significance of a flexible laboratory environment for science and engineering. 66% of students selected the high importance level (very important + extremely important) for interacting with physical equipment. The question was “to rate the importance of physically interacting with the equipment” and there was no comparison with online laboratory. Therefore, it just shows the importance rate of working on laboratory equipment.

Ease of use is an essential requirement for any system and the results of this survey show no difference with 95% supporting its importance by selecting moderately, very, and extremely important options.

The ability to backup work completed and accessing lab manuals during the experiment performance are features of the laboratory environment assisting users for effective utilization of the system. Over 90% of users considered



these features significant (moderately, very, and extremely important) in laboratory performance activities.

However, collaboration and teamwork did not receive high attention from participants as an important aspect of the laboratory environment.

The overall responses on rating the importance of laboratory environment aspects denote the significance of flexibility and ease of use features. It also indicates that users are not considering the collaboration as an essential part of the environment and autonomy of the system is more significant for students. While learning the skill on how to work in a collaborative environment is a necessity in today's job market, having insufficient work experience among participants contributes to the outcome of this question.

The next part of the survey asked participants to rate their satisfaction level on main COLab features. Figure 6-2 shows the percentage of satisfaction level on each key aspect of COLab.

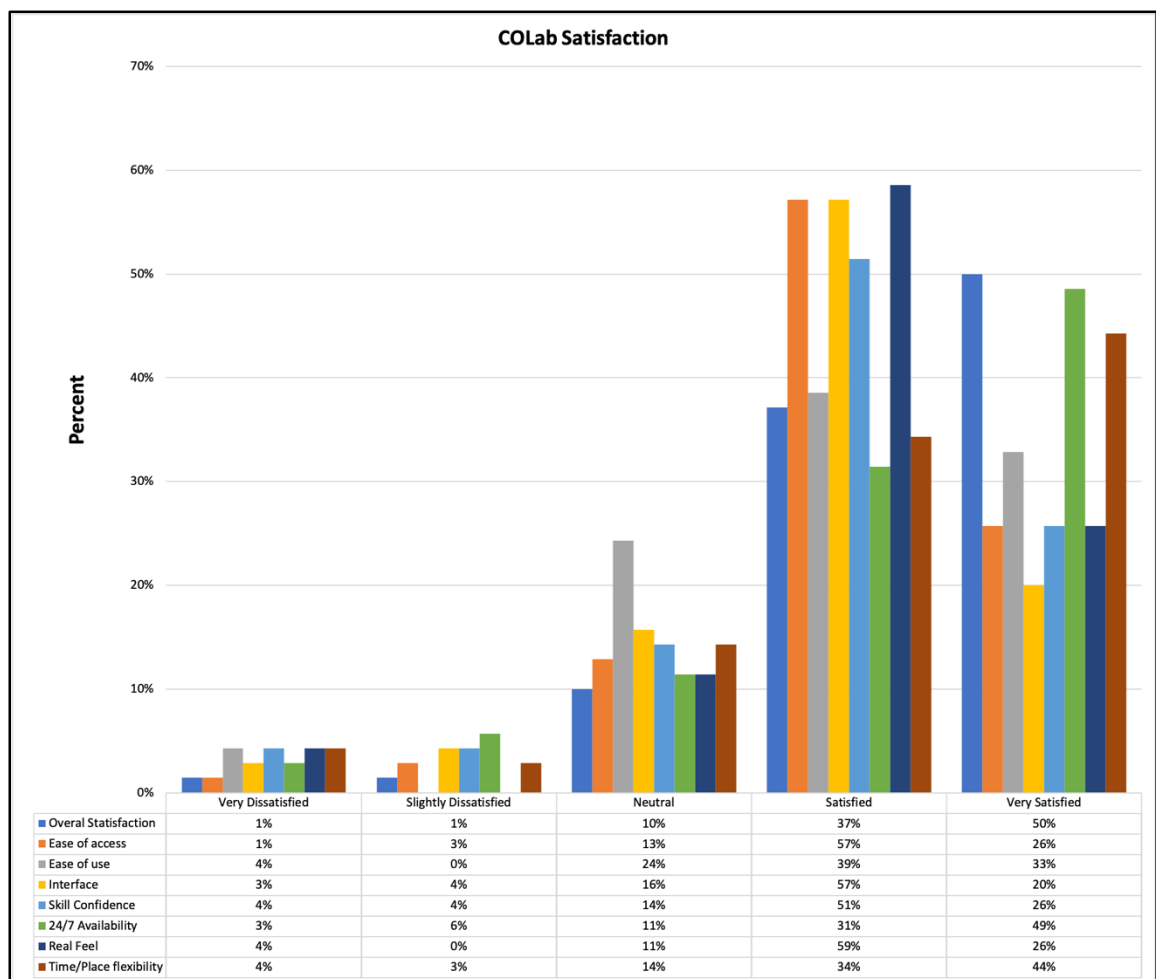


Figure 6-2 - Student's satisfaction level using COLab

The overall satisfaction is 83% with a great score on ease of access, 24/7 availability, and real-feel features of the system (over 80%).

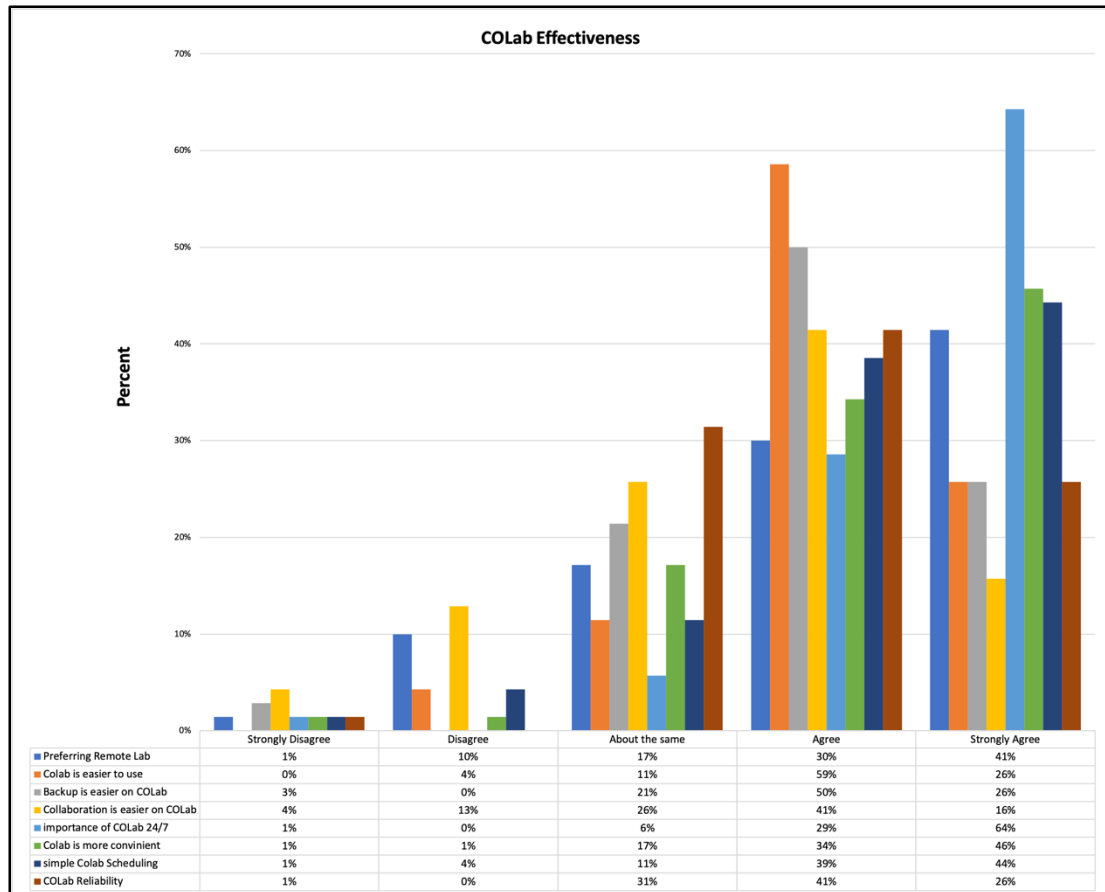
That follows by the time/location flexibility aspect of COLab which with the aforementioned features indicates the satisfaction level on the flexibility of COLab as an online laboratory environment.

The next highest satisfaction level is related to COLab interface and skill confidence aspects. Students rate about 7% dissatisfaction for these features which is not greatly significant and about 15% were not either satisfied or dissatisfied.

24% of participants rated neutral for the ease-of-use feature. With a 72% satisfaction level and only 4% dissatisfaction we can conclude that majority of students found COLab easy to use. However, there is some room for improvement to reduce the neutral percentage and increase the satisfaction level.

Overall results show a low dissatisfaction level on all the features of COLab (less than 10%). The features with the least satisfaction level are COLab interface, skill confidence, and ease of use (still over 70%). All these aspects can be considered as system usage procedure or how to use COLab. Therefore, some technique should be employed to improve the student learning experience in system usage.

The questionnaire also asked participants for their opinion on the effectiveness of COLab by rating functionalities of this system (Figure 6-3).



*Figure 6-3 - Effectiveness of COLab*

The participants' responses indicate user's overall satisfaction with the COLab functionalities.

In the first section, students were asked if they prefer a remote laboratory compared to the in-class physical environment. Out of all responses, 11% of participants prefer an in-class laboratory environment, 71% vote in favour of remote laboratory, and for 17% of users, an online environment is just as good as in-person classes. Although the majority of users preferred online laboratory, there is still a significant number of students (about 30%) who either prefer in-class experiment setup or do not have any preferences. This can result from the fact that remote laboratory is a new and unfamiliar environment for many users. It might require a longer time for some users to build enough confidence to adopt the remote environment over the traditional class setup.

Although in the previous question COLab ease of use feature did not receive a very high satisfaction level, according to the response rate shown in Figure 6-3 students considered it easier to use compared to in-class setup.

Technically the backup process in NETLAB+ setup is straight forward compared to in-person classes and the outcome from the questionnaire also support this fact with 76% agreement on the effectiveness of the remote laboratory backup system.

According to the survey, outcome collaboration is the least effective feature on COLab with only 57% considering it as an easier way for group work compared to the in-class laboratory.

The 24/7 availability of the system received 93% agreement supporting the same concept asked in the satisfaction question.

Students also recognized COLab as a more convenient option for laboratory experiments by 80% agreement level.

The NETLAB+ scheduling system received an 83% effectiveness level compared to only 5% disagreeing on its functionality.

Students denoted that reliability of COLab is either better than the in-class setup or the same.

To check the availability of the remote system, compared to the number of students, participants were asked if they managed to schedule a session when they were willing to experiment. The results are shown in Figure 6-4.

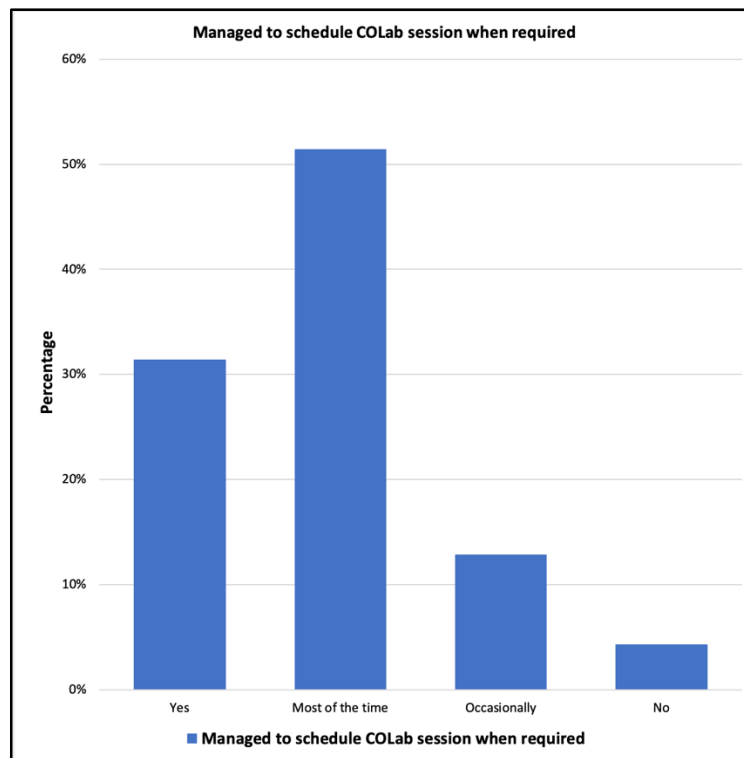


Figure 6-4 - availability of COLab compare to the number of students

Almost half of the students managed to book the system most of the time, 31% all the time, 13% occasionally, and 4% were not successful in scheduling the system when required.

There was an optional comment section at the end of the questionnaire for participants to write any improvement suggestion. Almost 86% of the comments were about technical issues and the system usage process.

- 37% of feedbacks are emphasized the necessity for additional laboratory pods on COLab. The number of laboratory bundles was increased and a Storage Area Network (SAN) was added to COLab for additional VMs. Also, the number of reserved sessions were monitored to determine the high demand period so restriction rules on the number of booking session per person could be applied to guarantee the fair condition for all users.
- Students suggested changing the setting so they can perform multiple laboratories in one session and decrease the waiting period between scheduling the time slots. These are all part of NETLAB+ server

features which was adjusted to student requirements and the issues were resolved.

- Several comments were about problems with the NETLAB+ server interface usability especially its dependency on JAVA. Fortunately, most of these issues were fixed in the NETLAB+ VE version.
- Students also complained about the long process of initialisation of pods at the beginning of the session. In the earlier versions, all of the pod devices had to start up at the beginning, however, after the updates, the system only initializes the required devices for the intended laboratory experiment. Students are still required to wait for the initializing period on laboratory devices included in the topology and this time cannot be decreased any further same as using the devices in the in-class laboratories.
- Some of the feedback indicated the requirement for an introductory session on how to use the system in the form of a workshop, and instructional manual or video as not all students are aware of the features of the COLab system. For example, one of the participants suggested adding an option for sending the configuration files to the local machines that could be done by turning on the second interface on the VMs and share it online (e.g., email, Dropbox, Google Drive, etc). Moreover, all sessions configuration is saved on the user folder that existed in NETLAB+ sever and can be directly downloaded from there.
- The COLab maintenance was another area of concern especially during weekends and public holidays when students have more time to study. The majority of these problems were addressed by upgrading equipment and implementing effective monitoring and alert system on servers.
- Students in the SLIIT campus experienced a bandwidth problem that remained for two semesters until it was resolved by local IT staff.

According to all the survey responses, it can be concluded that students are generally satisfied with COLab but some areas require modification for improvements. The survey participants indicated flexibility and availability features as key elements in the success of COLab.

### 6.3.1.2 COLab usage observation

The information gathered from the NETLAB+ server log system indicated the statistics of laboratory system attendances. This data can be categorized based on the community, user/accounts, class, or pod usage (Figure 6-5). Since all students are enrolled under the same community group, the data were extracted in this category shows a full usage of the laboratory system. More options were included in recording usage statistics for the NETLAB+ VE version. Figure 6-5 shows an example of the usage report interface in both NETLAB+ PE and NETLAB+ VE and options available for categorizing the data.

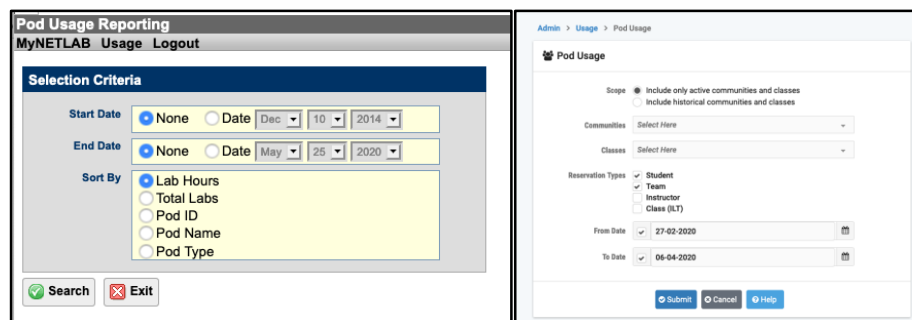


Figure 6-5 - usage reporting interface in NETLAB+ PE (left) and NETLAB+ VE (right)

Figure 6-5 shows the hours that students spent on COLab for 5 years. This system utilization graph shows a great increase in 2016 and a declining slope from 2016 to 2019. Due to various changes applied by Curtin University to the programs used in this study including, laboratory redundancy, course restructure, and course combining, the input data was distorted. Therefore, the outcome of hours that students spent on COLab shown in Figure 6-6 lack the authenticity to be used directly for analysing the actual utilization pattern.

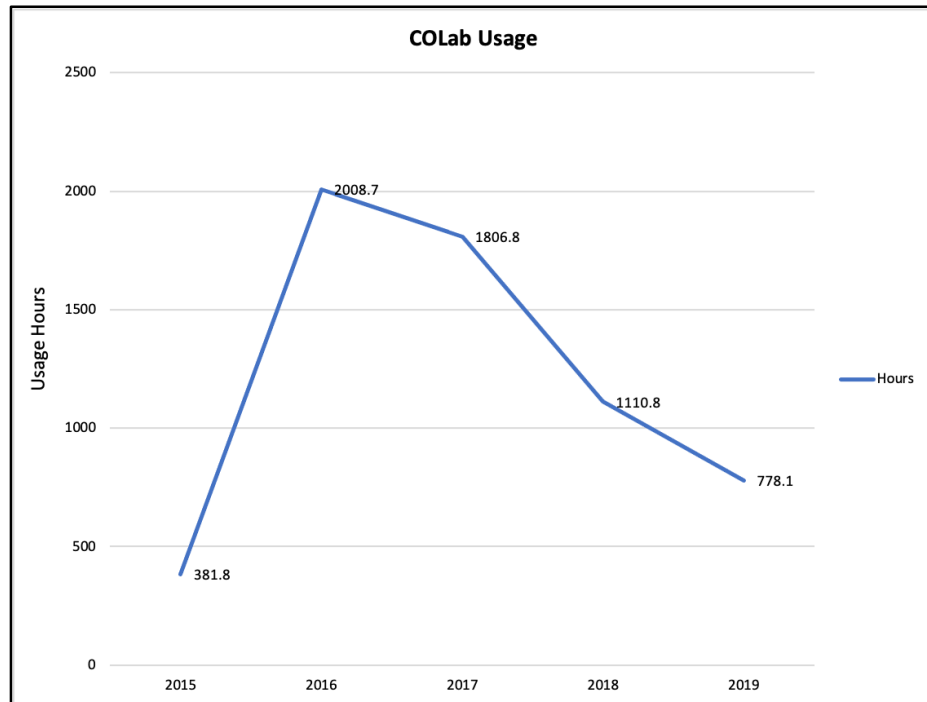


Figure 6-6 - COLab Utilization Graph

The majority of time spent on COLab is associated with CCNA laboratory pods including both CCNA and CCNA security.

The high number of utilization hours in 2016 is mainly the results of having a greater number of laboratory-types in this year. As shown in Figure 6-6 five different laboratories were running on COLab in 2016 including; CCNA, Communication Engineering (SDR), GEEP, Embedded Systems, and Wireless.

In 2016 students could reserve sessions one after each other without back-off time. The length of each session was up to 4 hours and some students booked the number of 4-hour sessions continuously to have more ability for performing the laboratory tasks when they needed resulting in many unused sessions. Also, it limited the options for other students to schedule a laboratory time slot on COLab and decreased the efficiency of the system. Hence, in 2017 a back-off time was enforced between the scheduled laboratory sessions for each user account. This contributes to the differences in COLab utilization hours between 2016 and 2017.



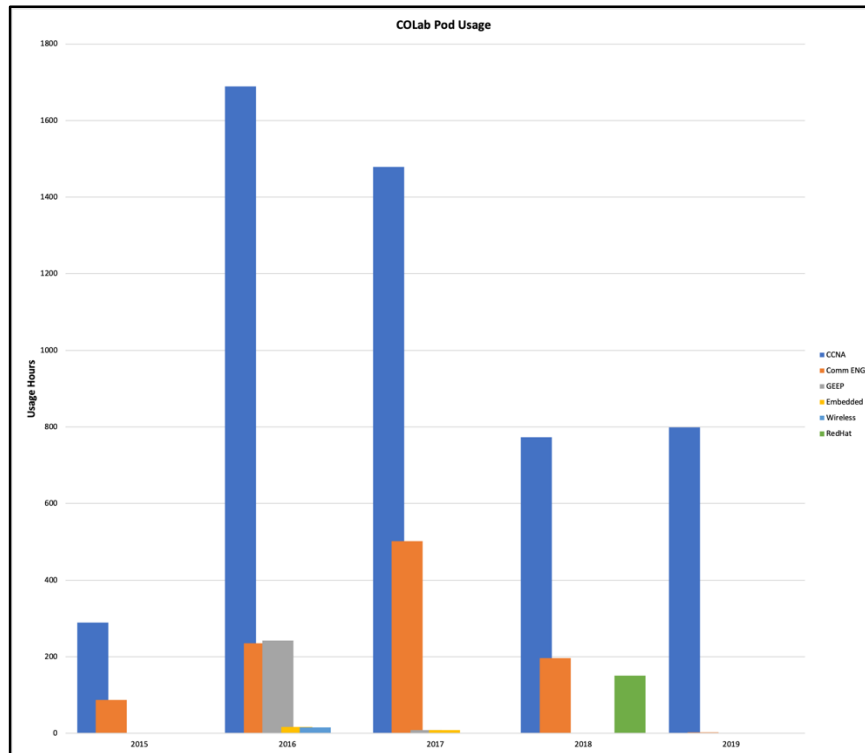


Figure 6-7 - Pod Utilizations on COLab

Communication Engineering pods were under evaluation in 2015 and fully operational from 2016. In 2017 it was offered to more campuses that increased the number of students using the COLab for Software Defined Radio (SDR) based experiments. However, from 2018 the units with SDR laboratory component changed and the number of students decreased (Figure 6-7). SDR laboratories were cancelled in 2019.

GEEP laboratories were offered on COLab for two campuses in 2016 and 2017.

In 2018 the number of students enrolled in CCNA courses increased by almost double and it was challenging to organize skill assessments on the remote system and in-class setup for all students. To address this issue, it has been decided to conduct skill assessments on COLab and in-class setup for students enrolled in computer networking focused courses and Master degrees.

While students enrolled in non-computer networking focused courses were asked to use Packet Tracer for skill assessments with the option of using the

in-class or COLab setup based on the availability of the system with given priority to master and computer networking students.

Therefore, almost all students in the second group preferred Packet Tracer and performed laboratory experiments on this system to get familiar with the environment. This resulted in a great drop-in COLab usage in 2018.

As shown in Figure 6-7, there is a small increase in CCNA pod usage hours in 2019 compared to the previous year (2018). However, the overall laboratory usage illustrated in Figure 6-6 dropped by 332.7 hours in 2019. This is the direct result of the RedHat laboratory that was only offered in 2018 and almost all the usage hours in 2019 were simply from CCNA courses (Figure 6-7).

In the first study period of 2020, the COLab utilization increased to almost 600 hours over three months that may be the result of the impact created by the COVID 19 pandemic when students were not able to attend the in-person laboratories.

From observing the COLab usage log system based on the accounts, there is a high number of international students attending the laboratory experiments using this remote environment. Therefore, it can be concluded that COLab was successful in sharing the resources and enforcing the same standard level across all campuses even where there is no local supply of equipment.

Also considering that Packet Tracer was a convenient option for many students to perform laboratory tasks and assessments, the level of COLab utilization is still significant.

### **6.3.2 Data Analysis**

According to the responses from survey participants, access, time, and place flexibility, and ease of use are rated as the most important features in the laboratory environment. They also signified a high satisfaction level in most of the COLab features, remarking the real feel, 24/7 availability, and ease of use aspects. The overall questionnaire outcome approved the effectiveness of COLab with a 93% agreement rate on its convenience of use. Also, the majority of participants preferred online laboratory over in-class or simulators.

The general view of the graph presenting the COLab usage pattern captured in five years shows a decline in usage from 2016 (Figure 6-6). However, many factors including various study program changes by university and adjustment technical configuration applied to COLab design contributed to the time that students spent in the remote laboratory. By observing the individual pod usage, number of laboratories bundles available for each study period, number of enrolled students per units, and unit delivery changes, it can be concluded that COLab usage had a sustainable growth.

The majority of the comments and feedback presented by participants were targeted at technical issues that are mostly related to the first versions of COLab.

There was also some feedback associated with COLab instructional training and adaptation with the system. This signifies the importance of developing and conducting initial step-by-step training on how to use the COLab for more effective and efficient utilization of the environment.

Generally, the comments and feedbacks are supporting the COLab as a worthwhile laboratory environment while suggesting some adjustment to the system to achieve more efficiency. The implementation of an optimal back-off time between the booking sessions is an example of adjustment based on the student's feedback.

Both deductive and inductive analysis performed on the collected data and explained in this section demonstrates that COLab is an efficient, effective and practical remote laboratory environment model for science and engineering. Also, the features implemented on this experimental model and teaching approaches are the key factors for achieving the efficiency, effectiveness, and practicality of the system. The COLab interface design, ease of use, 24/7 availability, initial training sessions, and reliability are some of these factors.

The best practice system design and pedagogical framework for achieving an efficient, effective and practical remote laboratory environment are explained in the next section.

## 6.4 Online Laboratory Infrastructure

An online laboratory infrastructure is a combination of equipment and network setup, educational contents, and human interaction with these systems.

Great attention must be paid to the technical and educational aspects for the effective and flawless operation of this infrastructure.

The design of this infrastructure can be divided into two major parts: 1) the online laboratory setup that requires an attempt for best practice engineering design and Human-Computer Interaction (HCI), 2) online science and engineering educational content.

### 6.4.1 Best practice model

To attain the best practice model of an online environment for science and engineering laboratories, an empirical research method is required that involves the design, test, refine, and implement the procedure. Accordingly, COLab has been through this process number of times until the optimal design is reached.

Also, the HCI study was performed for identifying the most effective way users can interact with the online laboratory environment. Studying and analyzing the user's feedbacks, questionnaire responses, and COLab usage observation identified several HCI related issues in the first versions of the design.

Developed on the experience of implementing and studying the COLab setup, and the research on general online laboratory design, the following criteria are identified as essential requirements in creating the best practice model for online laboratory environment:

#### 6.4.1.1 Authenticity

While simulators are effective educational tools for teaching the fundamental concepts, laboratories are providing an environment for students to learn the procedure of equipment set up, configuration, troubleshooting, and measurements. Student experience of interacting with the online laboratory devices must be as close as possible to the conventional or in-person experiment environment.

- The feeling of working in a real environment assists educators in teaching experimental concepts and increases the student's satisfaction level compare to other virtual environments such as simulators. Also, the real data extracted from online laboratories encourage learner's motivations [10].
- The results produce by simulators are artificial and do not represent the same outcome from real devices. By using simulators as the only laboratory tool, topics such as environmental safety and laboratory ethics education are missing, students do not develop skills in operating the real devices, and limited scenarios and features are available. As a result, simulators are not capable of providing a comprehensive teaching environment in many cases [3].
- The authenticity of the environment was reflected in COLab laboratory implementation by providing maximum control to the devices such as direct console connection and power management.
- Virtual machines on COLab are all configured with the same format, OS, software, and applications same as the physical laboratory machines to provide an accurate learning environment.

#### **6.4.1.2 *Autonomy***

Any educational environment must motivate students and keep them active throughout the course and reduce the dropout percentage. There are higher possibilities for students to withdraw from the course and have lower interaction with learning activities in an online educational environment compare to conventional classes where there are more controlled factors involved [102]. Educators in online classes do not have the same level of control and student satisfaction monitoring ability compare to traditional classrooms. Therefore, the online learning environment must be designed in a way that students enjoy the learning activities and feel satisfied with the educational achievements. Student's engagement with the online learning environment increases their motivation for participating actively in the course. According to Deci and Ryan's Cognitive Evaluation Theory (CET), autonomy and self-determination are one of the main factors relating to intrinsic

motivation in individuals [103]. Autonomy gives students control over their action, responsibilities, and the feel of independence that results in a higher level of motivation and effective engagement in learning material [102].

Lee, et al, discussed that support for autonomy in the learning environment should be accompanied by instruction and structured guidance to assist students' self-regulation and avoid the feeling of being lost [102]. They also suggested three strategies to develop an effective autonomous learning environment including

- Provide choices- while providing choices and freedom in course activities encourages students' engagement, too much of it can overwhelm students. Therefore, well-balanced learning choices and instructional control must be implemented in the educational environment [102]. In the COLab system number of choices are implemented to help student autonomy such as individual or collaborative laboratory performance, continuing the last session using the previously saved configurations, scheduling laboratory sessions based on individual's availability, and more.
- Provide rationale – where providing choices is limited due to the course nature, giving rationale will encourage autonomous motivation [102]. These more relates to the course material perpetration. An example is the GEEP laboratory on COLab where there is a limited number of choices however the rationale is provided to students by instructors during the laboratory sessions, activity instructions, and course material.
- Provide opportunities for personalization- this attribute suggests that the learning environment must be developed in a way that students can establish a personal connection to the educational environment [102]. for example, while students are following a set of instruction to perform laboratory tasks on COLab setup for CCNA courses, they have the opportunity to explore other possibilities and scenarios for computer networking that are beyond the classroom.

The nature and characteristics of the online educational environment make it possible to create an autonomous learning system where students have more independence and control in their engagement with course material.

However, autonomy without guidance and provision from the course instructor can confuse and affect the student learning experience.

Also depending on the requirements for each course, different level of instruction and guidance must be available. For example, in the COLab setup, a higher level of guidance is required for GEEP laboratories compare to CCNA courses.

In the process of designing and implementing the COLab system, great attention was given to the autonomy of the learning environment. The COLab system provides the opportunity to implement different types of course delivery methods including instructor-led, self-study, and a combination of both in an autonomous learning environment.

#### **6.4.1.3 Manageability**

The remote laboratory is a complex system formed by heterogeneous components that require a mechanism for comprehensive management [104].

The COLab management system is performed on different level based on components functionalities. NETLAB+ server acts as the main point of management that monitors and organizes the laboratory equipment, user profiles, log system, authentication, course contents, class arrangement, and many other user interaction requirements. The laboratory equipment management can be divided into three sections, Console connection managed by Console switch, Power managed by PDU, and VMs managed by ESXi server.

#### **6.4.1.4 Scalability and adaptability**

With the rapid change of science and technology, the ability to update the set of experiments implemented in the remote laboratory is vital. Also, as the demand for online education is increasing, there is a requirement for an additional set of laboratories to accommodate new online courses as well as adding extra bundles for increasing demand on existing courses. Therefore,

the online laboratory environment must adapt the regular changes to the content whether it is the implementation of a new course, increasing the existing laboratory bundle, or updating the old course [104].

These changes must be performed with minimum alterations on the online laboratory setup for agility and efficiency purposes.

In the COLab setup, two areas are influenced by any update or addition of a course; laboratory devices and course content.

While all the devices are connected to a managed system, the update and addition of equipment is a simple and straightforward process. For the supported academy courses such as CNAP, any update or addition of course content is managed in an uncomplicated procedure via the NETLAB+ server. Similarly, the customized laboratory content and required equipment are configured using the NETLAB+ server after material development and hardware implementation.

#### **6.4.1.5 Security**

Security measures are an essential requirement for any system and an online laboratory is not an exception. Similar to the management mechanism, a comprehensive security mechanism is required to ensure the confidentiality, integrity, and availability of an online laboratory as a complex system.

These measures are applied to the COLab system at various level by implementing strategies such as secure connection, user authentication system, password protection mechanism, privilege levels enforcement, firewall rule applications, etc.

In COLab set up the internal network that includes all the laboratory devices, software, and licensing is isolated from the outside network. Users log in to the interface that communicates with the laboratory system without having access to the internal network so laboratory software and licensing are protected in the secure environment.

#### **6.4.1.6 Promote flexibility**

The design of the online laboratory system should support flexibility in the learning environment both for course delivery methods and technical design.



For instance, the laboratory system should accommodate users' ubiquitous access to the system. Therefore, the network connection should be compatible with existing communication standards, and users should be able to interact with the system using any computer platform.

Attributes such as 24/7 availability, choice of individual or collaborative work, and providing instructor-led and self-study teaching methods, promote flexibility in the learning procedure.

#### **6.4.1.7 Ease of use**

The time spending on learning how to use an educational system must be minimized to increase student effective engagement otherwise it becomes a negative effect driving users away from utilizing the environment. In section 3.1 based on the feedback and survey contribution provided by students, it has been concluded that ease of use is an essential attribute of the online laboratory.

Therefore, an online laboratory environment must be easy to use with minimum instructions requirement.

Based on the outcome of this study, it is beneficial and practical to present the 'how to use' instructions in the form of video and document for convenience.

#### **6.4.1.8 Reliability**

The reliability and consistency of the online laboratory environment must be proven to students for effective engagement and experiment performance. Students are motivated to utilize the online laboratory system if they find it reliable.

For instance, if the system fails to keep the connection throughout the session or laboratory equipment experience a constant technical problem, it will have a great effect on student experiment performance and they might need to repeat one task multiple times. These types of inconsistencies have a direct relationship with the student's trust and motivation.

A comprehensive evaluation mechanism is required to ensure reliability and consistency in the online laboratory system.

In COLab an evaluation period is defined for any new laboratory setup. During this time the intended laboratory tasks will be performed multiple time to confirm the reliability and detect any irregularity on the setup. In many cases, after the initial evaluation, the online laboratory is offered along with an in-person model for the first semester as a backup plan.

utilizing high-quality equipment, using a reliable network connection, and implementing stable power connections are some of the essential strategies to ensure the consistency of the system.

#### **6.4.1.9 Cost-effectiveness**

While an online laboratory creates a convenient environment for students to perform experimental tasks, it should be economical for investment justification.

In most cases, the online laboratory environment is a cost-effective design since equipment are available 24/7 and their utilization is not limited to the defined laboratory sessions.

An effective learning environment and best practice model will be created by considering all the above criteria while designing and implementing online laboratory infrastructure for science and engineering. The course learning objectives in this environment is similar to in-person classes with the addition of more elements of knowledge for working with remote systems such as:

- Building confidence to use remote operation.
- Planning for remote backup and disaster recovery and learning methods of transferring the backup files to local machines.
- Understanding the nature of network connection in the online environment and learn basic computer networking knowledge.
- Learning to perform group work and improve collaboration skills in a virtual environment.

The outcome of the teaching methods study and pedagogy framework created based on the results of this research is presented in the next section.

### 6.4.2 Framework and pedagogies for online laboratory

The main objective of this study is to develop a framework and pedagogies for science and engineering online laboratories through examining and evaluating an experimental model. Frameworks and pedagogies set structure and standards to define learning objectives, outcomes, and activities to attain knowledge in the educational environment.

The educational frameworks are constructed based on epistemological learning theories. In Chapter2:Background Study and Literature Review- the four major learning theories were explained in details including behaviourism, cognitivism, constructivism, and connectivism.

Bloom's Taxonomy is an educational framework that received great attention from educators to classify the learning objectives based on the cognitive process required to attain knowledge. The learning objectives are placed in the two dimensions Bloom's Taxonomy table with one dimension presenting the cognitive processes in increasing complexity level and the other dimension representing the categories of knowledge from concrete to abstract (Chapter4:Experiment Design).

While learning objectives describe the educational goals, learning activities are the tasks designed to achieve those goals, and assessments are the methods of evaluating the learning outcomes. Organizing the learning objective based on Bloom's Taxonomy, assist educators in curriculum development by

- Providing student's point of view on objective evaluations
- Presenting the education possibilities
- Clarifying the relationship between cognitive processes and knowledge
- Making it easier to decide on the type of learning activities and assessments for the specific objective
- Evaluating the consistency of educational materials based on the objective category

- Increasing precision in describing the objectives for better communication [105].

In term of epistemological learning theories, Bloom's Taxonomy is based on cognitivism and constructivism. The cognitive process dimension addresses the cognitive development stages in cognitivism theory. Also, the knowledge categories support teacher and learner's constructivist approach [106].

The laboratories are the learning activities designed as educational methods to achieve the learning objectives. Therefore, it is imperative to categorize the course objectives based on an educational framework before deciding on the type of laboratory content and design.

The focus of this study is on the science and engineering online laboratories as an essential learning activity. To design a comprehensive framework and pedagogies for this learning activity, a study of related learning theories is required.

Based on the previous discussion the online laboratories are complex systems that a single theory is not capable of addressing all aspect of it. Therefore, to simplify the theory evaluation the system is divided into two sections:

1. Science and engineering characteristics of the laboratory
2. Online nature of the system

The first part relates to the science and engineering course objectives that can be categorized based on the structural framework with relation to cognitivism and constructivism theories such as Bloom's Taxonomy. These learning theories support the active learning environment that satisfies the science and engineering education particularly the laboratory activities as the essential component of the course.

However, cognitivism and constructivism are not capable of presenting all aspects of online nature in remote laboratories. The Internet-based technological education created an environment that relates to the four theories of Chaos, Complexity, Self-regulated learning, and Network learning.

### **6.4.2.1 Online Laboratory and Chaos, Complex, Self-regulation and Network theories**

Chaos theory focuses on the unpredictability and non-linearity of a complex system' chaotic behaviour. This theory is based on the two principles, 1) the effects of an event is not predictable and 2) although Chaos has a random characteristic there is a pattern that if discovered can make the order and prediction [107]. Complexity theory is also emphasizing the non-linear and unpredictable situations in a complex system [108].

In a conventional laboratory classroom, students follow the set of instructions and are guided by educators. This instructional procedure is performed under a controlled environment and considered as initial conditions with predictable results of students' laboratory task performance. However, in online laboratory learners are required to form their instructional procedure by accessing resources that are not structured in the same way as conventional classrooms. For example, students are required to form an interaction with educators and receive guidance by locating an instructional video/document on the educational platform or utilize an online conversation method. Also, since all laboratory equipment is situated in a remote environment, students need to establish remote communication with devices for intended experimental task performance. An example procedure is a remote power cycle or remote console configuration that requires the learner to access a specific interface for experiment performance. These reflect the initial conditions in a complex system where knowledge is accessed in a non-linear method and results are not predictable. However, in this system learners are encouraged to identify the connection and pattern between these events to form their learning procedure.

Therefore, the online laboratory for science and engineering is identified as a complex dynamic system producing chaos events.

The self-regulation and network learning theories are emphasizing on the autonomy of the learning procedure.

Self-Regulated Learning is a subsection of self-regulation theory in social psychology where learners regulate their emotions, thoughts and actions to form the learning process and achieve the learning goals. This is related to

natural learning where the learner decides on what knowledge or skill to learn.

Self-Regulated Learning supports the student-centre learning approach where students use the feedback from their previous experience to adjust the current learning process. This forms an open-loop feedback system where the learning is taking place in a cyclical process. The three changing factors of personal, behavioural, and environmental conditions are driving the feedback in this learning system (Figure 6-8) [109].

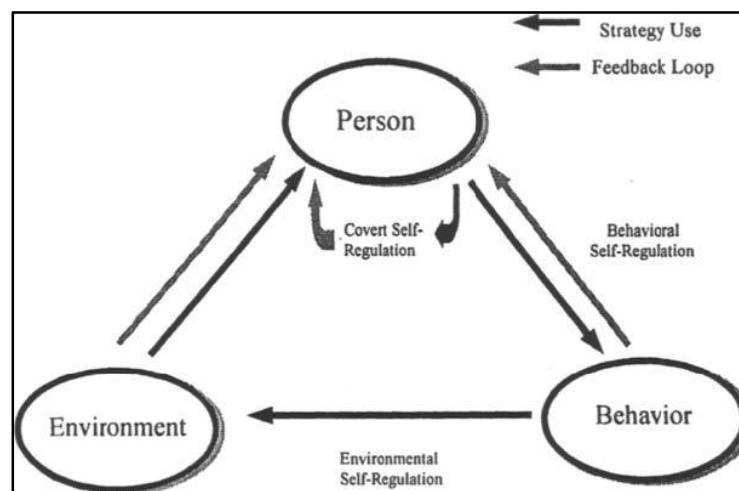


Figure 6-8 - Triadic process of self-regulation [109]

Zimmerman explains that in the behavioural self-regulation process between person and behaviour factors, performance is adjusted strategically through self-observing. Also, the outcomes and conditions in the learning environment are adjusted in the environmental self-regulation process. And lastly, the covert self-regulation process achieves the adjustment of the cognitive state [109].

In online laboratory activities, learners adjust their interaction with the laboratory system and devices by performing behavioural self-regulation. Although the environment in an online laboratory system is set and preconfigured, learners are still able to make some adjustment such as scheduled time, configuration interface format, device's power status, and backup system. In the covert self-regulation process, learners observe their learning experience and adjust their thoughts on how to perform the laboratory experiments using the online system more effectively.

According to Zimmerman, the self-regulated learning process takes place in three cyclical phases. First is the **forethought phase** where learners analyse the task and work on their motivation toward learning. Setting up goals and planning strategies for learning a skill or knowledge is part of task analysis. Also, self-efficacy, outcome expectations, intrinsic interest/value, and goal orientation enhance self-motivation belief [109].

When students are first exposed to an online laboratory experiment, analysing the tasks is the initial step they go through by setting goals and strategies on how to use the online environment most effectively. Then they regulate their efficacy in performing the experiments and evaluate expected goals and outcomes for self-motivation. For example, log in to the system and connecting to the laboratory bundle enhances the motivation to engage with the task.

The second stage in self-regulated learning is the **performance or volitional control phase**. In this phase learner using self-control and self-observation processes to attend to the learning task and refine their experience. In the online laboratory environment, students complete the self-control stage by studying and attempting the laboratory tasks instructional process, using imagery methods to create personal strategies for remembering and focusing on the experiment performance and system interaction steps [109].

The third and last stage in self-regulated learning is the self-reflection phase. In this phase student review and evaluate his or her performance and react based on the satisfaction level on goal achievement outcomes [109]. For example, after laboratory task performance, students evaluate the results and compare them with the defined goals and outcomes in previous phases to measure the satisfaction and decide on the adjustment in the next cycle of learning.

Networked learning is a theory that was developed to recognize the impact of technology in the educational environment. This theory focuses on the learner's relationship with other learner, communities, educators, and educational resources.

Hudgson and McConnell summarised the pedagogical ideas in networked learning in the following eight principles:

1. "The focus is on learning which has a perceived value to the learners.
2. Responsibility for the learning process should be shared (between all actors in the network).
3. Time has to be allowed to build relationships
4. Learning is situated and context-dependent
5. Learning is supported by collaborative or group settings
6. Dialogue and social interaction support the co-construction of knowledge, identity and learning.
7. Critical reflexivity is an important part of the learning process and knowing.
8. The role of the facilitator/animator is important in networked learning" [110].

Many of these principles and ideas are shared between self-regulated learning and studying in chaos and complex system. The networked learning pedagogical ideas are directly associated with online laboratory educational requirement.

Connectivism theory developed based on the cooperation of chaos, complexity, self-regulated learning, and networked learning theories. In the next section, the application of connectivism to designing a pedagogy framework for online laboratory education is explained.

#### **6.4.2.2 Online laboratory and Connectivism**

Fundamentally the meaning of education is explained as processes of learning knowledge or skill. According to Stephen Downes, in connectivism, knowledge is a set of connections between nodes and learning is creating, removing and improving these connections [111].

The pedagogy model proposed by connectivism assumes that the networked connections between people, machines, and educational content is ubiquitous. Therefore, technology has a great influence on educational development based on connectivism theory [112].



Connectivism theory highlights the two main characteristics of knowledge in the modern learning environment: 1) knowledge has a short life 2) the amount of knowledge available in each field is massive. Based on these characteristics, learners are not expected to learn and memorise the knowledge but attain the ability to identify and apply it as required [112].

The learning process takes place in two stages, first is the sense-making which is an internal process where learners attempt to identify the pattern in a complex system and the second stage is meaning-making which establishes the knowledge outcomes and impact [101].

In connectivist learning, educators are also nodes in the network. As classroom control shifted from exclusive teacher controlled toward learners and the role of educators changed accordingly. The transferring of knowledge from educators to the learner is replaced with teaching students how to form a meaningful network and identify the connections [101].

Massive Online Open Courses (MOOC) is commonly used as an example of a connectivist learning environment. The MOOC course contents are fully online and students have full control over their learning process with minimum guidance from educators.

However, the online laboratory is the course activity component and not the full course. Also, while it offers a great deal of autonomy to students, educators are still actively involved in the learning process and their level of guidance is depending on the laboratory structure. For example, GEEP requires more guidance and instructions from teachers compare to CNAP courses.

The learning procedure of conventional in-class science and engineering laboratories are mainly based on the cognitivism and constructivism theories. Students undergo cognitive processes organized from easy to difficult to attain knowledge from concrete to abstract in a classroom setup with a high level of guidance. However, the online laboratory modifies the learning environment by shifting the control toward students and providing more freedom in a ubiquitous network setup. With the combination of science and engineering core concepts and a technology-based online environment, it is not possible to create pedagogies based on a single theory.

A combination of learning theories must be considered for a comprehensive teaching model.

### **6.4.2.3 Online laboratory pedagogy and framework**

While the concepts of cognitivism and constructivism learning theories presented in the form of an educational framework such as Bloom's Taxonomy are applicable in developing a great part of the pedagogies for online laboratories, the addition of connectivism perceptions must be considered in creating a comprehensive model.

As it was explained in Chapter 4: Experiment Design, the Bloom's Taxonomy table consists of six cognitive processes and four types of knowledge.

The first cognitive process is remembering, which relates to students' ability to retrieve learnt knowledge in the same format that was presented to them previously. The sub-processes of remembering are recognizing and identifying where students are establishing the similarities between the new problem and what they learnt before. However, in an online laboratory, the first cognitive process is to explore the environment and establish a connection to utilize the system. If an online laboratory is considered as a chaos/complex system, in this process students will try to identify the pattern in the system and form sense-making information. The remembering processes can be seen as part of the explore and connect procedure for the online laboratory environment.

The meaning-making or second stage of the learning process in connectivism take place in the rest of the cognitive processes included in Bloom's Taxonomy.

This process of exploring and connecting along with Understand process is considered as the **forethought** or first phase of the self-regulated learning theory.

Students accomplish the second phase of self-regulated learning theory or **performance/volitional control phase** in the third (Apply) and fourth (Analyse) cognitive processes of Bloom's Taxonomy. And the last phase or **self-reflections** occurs in the Evaluate and Create cognitive processes. Figure 6-9 illustrates the cognitive processes in online laboratory learning.

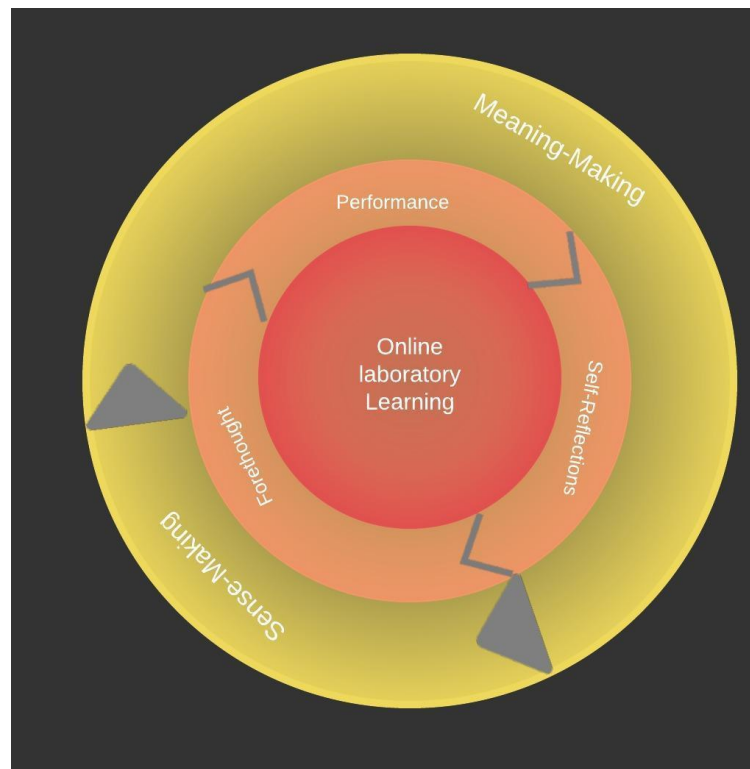


Figure 6-9 – Online Laboratory Cognitive Process

The second dimension of Bloom's Taxonomy consists of four types of knowledge starting with Factual knowledge that relates to basic information about the subject matter. Factual knowledge is divided into two sub-sections, *terms and terminologies* and *specific details and elements*. However, the first knowledge that students are required to attain during activity performance in an online laboratory environment is **Collective Knowledge**. The collective knowledge refers to all the information that needs to be collected when working with a complex system to create a sense and meaning of the setup and technologies used in the environment. For example, in the first experience of using the COLab system, users collect different information related to the online system and the methods on how to perform laboratory tasks in this environment. These can include knowledge on account setup procedures, user interface, scheduling laboratory sessions, device types, connection methods, backup system, and many more. As it can be concluded some part of the factual knowledge appears in the collective knowledge the rest of that is more related to the conventional educational environment delivering theoretical concepts.

After students collected the information about the environment and laboratory tasks, they will identify the basic elements. The next knowledge will be related to categorizing and classifying these basic elements which are very close to the Conceptual knowledge in Bloom's Taxonomy. This is followed by Procedural and Metacognitive knowledge.

Table 6.2 summarizes all the above and presents the detailed educational framework model for online science and engineering laboratories.

Knowledge	Cognitive Process					
	Sense Making	Meaning Making				
	Forethought		Performance/volitional Control		Self-Reflections	
	1. Explore and Connect	2. Understand	3. Apply	4. Analyse	5. Evaluate	6. Create
Collective Knowledge						
Conceptual Knowledge						
Procedural Knowledge						
Metacognitive Knowledge						

Table 6.2 - educational framework model for online science and engineering laboratories

Generally, laboratories are designed to assist students in understanding the theoretical educational material presented in the lecture while developing skills and practical competencies [113]. Therefore, they are the supportive teaching methods of the same concept. That is why Bloom's Taxonomy uses the same classification of subject matters and objectives for both lecture and laboratories to cognitive processes and knowledge. However, the addition of the online environment to laboratories changed some part of the delivery method and pedagogies mainly in the first stages of the learning experience where students are required to adjust to the environment. After this

adjustment stage, the rest of the learning experience is similar to conventional laboratory experiments.

The proposed framework presented in Table 6.2 is an alteration to Bloom's Taxonomy for responding to the online environment pedagogical requirements.

## 6.5 Summary

In this chapter, the effectiveness of the online science and engineering laboratory was evaluated based on the COLab user's feedbacks collected over the four years. Then the pedagogies were developed that reflects the existing learning theories and available educational taxonomies.

Respondents predominantly identified the availability and flexibility of the remote laboratory as the most important aspect of the system. They showed a high satisfaction level in the ubiquity, ease of use, and the real feel of the COLab. The effectiveness of the online laboratory prevailed among the responses while recognizing 24/7 availability and convenience of COLab as the most satisfying elements by over 80%.

However, it was not possible to extract the accurate usage pattern and growth from the feedback and survey outcomes, as other factors such as teaching curriculum changes influenced the COLab utilization.

Driven from the users' feedback, the design of the online laboratory system must consider factors including authenticity, autonomy, manageability, scalability and availability, security, flexibility, ease of use, reliability, and cost-effectiveness to create a best practice model.

Studying the users' learning pattern and their feedback confirmed that pedagogies and framework for online laboratories cannot be developed on any single learning theory and a combination of cognitivism, constructivism, and connectivism must be utilized for a comprehensive view.

To create a pedagogical framework, the Bloom's Taxonomy, a well-recognized model for science and engineering discipline was adopted as the base model. However, elements of this model were altered to incorporate the requirement for the online teaching environment. As a result, the first section of Bloom's Taxonomy in both knowledge and cognitive process sections were replaced by related components addressing the connectivism theory.

## Chapter7: Conclusions and Recommendations

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This chapter includes the conclusion and recommendations for future works.

### 7.1 Conclusion

This research aimed to identify the effective, efficient and practical methods of teaching online laboratories in science and engineering. This is done by creating an experimental environment and collecting user's feedback and observation. Based on the qualitative and quantitative analysis the elements related to the best practice model for online laboratory design was identified and an educational framework was developed. Following are the summaries that reflect the finding in this thesis:

- The research commenced with the study on the process of learning as a general requirement for any educational program. Then it focused on science and engineering education and the significance of the laboratory role in teaching the concepts in this area. It has been stated that science and engineering laboratory education methods are based on a combination of learning theories.
- An experimental model called COLab was developed to implement various online laboratories and study the user learning experiments while interacting with this setup. COLab was created based on the engineering design process and refined several times to create the best practice model. The main factors identified as the requirements for the design of the science and engineering laboratory were summarised in Chapter 6 Analysing and Results.
- While there are many similarities between teaching methods in a conventional laboratory setup for science and engineering and online version, it is important to note the key differences. The characteristics of the interaction between the educators in an online environment encourage the use of self-regulated learning methods. However, the results from data analysis on this research showed that while users are interested in performing the laboratory experiments in the time and

place independent environment, they are also requiring an effective method of online instructions to efficiently interact with the setup.

- The traditional laboratory classrooms are usually considered as a controlled environment where students are asked to perform a task under supervision. They following provided instructions and interact with laboratory devices while receiving real-time assistance from educators. However, the online laboratory environment is identified as a non-linear and complex system. Students are required to establish a connection to the system and instructor to perform the required task. They need to interact with the online platform before working with laboratory devices. Also, collaboration with classmates and receiving instructions and assistants are done through online applications. These together add to the complexity of the learning process that requires a different skill set. As a result, the stages of learning are not the same as traditional in-class activities. When students first interact with the online laboratory, they need to analyse the system, then via self-observation, the learning task is refined. Throughout the whole laboratory experiment, the learning process can be divided into sense-making and meaning-making phases.
- Teaching in a controlled environment such as traditional classrooms are simpler compared to a complex system such as online laboratories. In creating the teaching methods for online laboratories, it is essential to create learning objectives in a classified manner. This classification must be based on learning theories and assist educators to identify the objectives for educational materials.
- Bloom's Taxonomy is a practical example of an effective classified system that educators use to create learning objectives. This taxonomy was used as the foundation to create and develop pedagogies for online laboratories. According to the outcome of this research on the learning theories for online laboratories, the non-linearity and complexity of this system alter the learning process compared to traditional education. It has been identified that a combination of the three learning theories including Cognitivism,

Constructivism, and connectivism must be utilised to build the new framework. The new framework created by modifying the Bloom's Taxonomy to include aspects such as self-learning processes that are sense-making and meaning-making. It also reflects the characteristics of the Connectivism theory in cognitive processes and knowledge along with the existing Cognitivism and Constructivism structures. The final proposed framework is presented in Chapter6: Analysing and Results.

This thesis illustrated that using the online laboratory as an inseparable part of science and engineering education is a necessity for the current remote/blended educational model. Therefore, while the online educational environment is adopted for teaching the theoretical part of these types of courses, there must be an online platform to facilitate students in experimental activities. The findings on the aspects involved in the science and engineering online laboratory learning process are summarised and explained in Figure 6-9 to assist educators and course developers to understand the steps that students take to acquire knowledge while interacting with the environment. The outcome of this study will help educators to create an effective environment and develop science and engineering laboratory materials by classifying the teaching objectives using the model presented in Table 6.2.

## **7.2 Limitations of the Study**

The methodology of this study required implementing different laboratory setups on the remote system (COLab) and examine the user experience recorded in the form of surveys, feedback, and system usage information. However, there were some limitations.

For several courses, the structure has been altered during the research period affecting the enrolment number and delivery methods.

With the merge of some teaching units, the number of students increased significantly. The laboratory assessment method changed to adopt the requirement for a large number of students. To address this matter, the tests were conducted using the simulator for fast marking and the ability to examine more students in each session. As a result, while students had a



more effective learning experience in working with real equipment, the simulator usage received more attention for exam environment preparation and this impacted the COLab usage pattern.

Also due to course restructure and staff constraints the laboratory experiments for some units were reduced in numbers or completely removed affecting the COLab attendance number.

The other limitation is related to the type of courses examined in this research. The courses available to study were from the engineering discipline and there was no opportunity to perform the research on diverse science laboratories.

### **7.3 Recommendations for Future Works**

The following recommendations are suggested to further extend this study:

- To better understand the results on the accessibility of the science and engineering online laboratories, the two separated systems (CAVI and COLab) could be converged so there are more variety of laboratory experiments are available for both sighted and vision-impaired students. This requires the development of an accessible web interface.
- Further study for identifying the methods to assist users in establishing confidence while interacting with the online laboratory system. The aim is to increase learning efficiency by minimizing the time users spent on how to work with the online system.
- It is also recommended to research into a new initiative that makes the online laboratories accessible for all users with various assistive requirements.
- Implement and examine the proposed framework for online laboratories in other science and engineering disciplines.
- Develop and implement a server using open-source resources that replicates the NETLAB server functionality for cost reduction.



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## Appendix A

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### Engineering Australia Policy on Accreditation of Programs Offered in Distance Mode

#### ENGINEERS AUSTRALIA

##### ACCREDITATION BOARD

##### ACCREDITATION MANAGEMENT SYSTEM

##### EDUCATION PROGRAMS AT THE LEVEL OF PROFESSIONAL ENGINEER

Document No. P04

Title Engineers Australia Policy on Accreditation of Programs Offered in Distance Mode.



ENGINEERS  
AUSTRALIA

##### DOCUMENT STATUS

Revision	Prepared by	Authorised by	Issue Date
2	Associate Director – Accreditation. Professor Alan Bradley.	Chair of the Accreditation Board. Professor Mike Brisk.	11/01/06



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## 1. Introduction:

Engineers Australia recognises that educational techniques are continually advancing. It wishes to encourage and promote new approaches to learning and teaching, limited only by the requirement that the knowledge and attributes appropriate for entry to professional engineering practice can reliably be shown to have been attained by all graduates of the program. Engineers Australia reserves the right to investigate in depth how stated outcomes are actually achieved in practice.

Accordingly, Engineers Australia does not wish to be unduly prescriptive about particular criteria that might apply to distance education, or any other mode of flexible delivery. The preferred approach is to examine any program on its merits and in light of the criteria common to all programs. However, when approaching any variety of program in which it does not have an existing body of experience, Engineers Australia will attempt to seek out and be guided by current best practice.

## 2. Policy Statement:

- (a) Engineers Australia will evaluate, for accreditation, programs leading to the professional engineering degree which are conducted partly or principally in distance mode.
- (b) The accreditation criteria and process are those set out in the Accreditation Management System in particular, document G05 Alternative Implementation Pathways deals with offshore, remote campus and distance based delivery, in which the process specifically requires that the criteria be met and the evaluation be conducted for all modes and pathways by which the program can be completed.
- (c) Engineers Australia will expect to modify these guidelines from time to time and will welcome all input to that end.

(\* See Website for modules within this publication:

<http://www.engineersaustralia.org.au/membership/accreditation.html>

### 3. Guidelines:

Engineers Australia has developed the following guidelines as a basis for the evaluation of engineering education programs delivered in distance mode. These guidelines will be progressively reviewed with the development of learning technologies and as further convergence occurs between traditional on-campus and external delivery approaches. The guidelines are not prescriptive, but where they are not followed, the evaluating panel will wish to be convinced that any alternative approach is equally effective.

1. A distance mode offering should be built on an existing engineering education program, concurrently offered in traditional mode to on-campus student cohorts, so that academic staff members are kept constantly face-to-face with how people actually learn. Even for experienced staff it is difficult to operate solely in distance mode. Distance delivery should thus be one of a number of possible implementation pathways for a particular program. Accreditation of the program must take account of all possible implementation pathways.
2. Electronic and face-to-face opportunities must be provided for on-campus and distance mode students to interact, particularly to ensure that group and team based learning experiences are equitable for both on-campus and distance mode cohorts. It is desirable that on-campus students make some use of materials developed for distance learning.
3. The educational design, learning activities, learning resources and assessment measures for a distance mode implementation of a program must be purpose built to support the external student in a comprehensive and independent manner. Therefore a distance education program should be designed explicitly for external students, not just adapted from on-campus materials.
4. Distance mode learning must be underpinned by a sound delivery platform using electronic and print-based resources that satisfy defined standards of quality, consistency, effectiveness of learning support and performance monitoring, ensuring educational outcomes equivalent to those of on-campus students. When developing or enhancing study materials, academic staff should have access to instructional design, multi-media and editorial consultants.
5. There must be in place an overarching quality system that fully embraces the distance mode and engages the external student as a key stakeholder within the educational system. Appropriate mechanisms should be in place to ensure timely and adequate feedback on matters such as assessment and queries within this quality system.
6. The academic staff team must be committed, equipped and adequately resourced to support implementation of the distance based learning mode. A distance education program cannot be built on the work of a minority of dedicated staff, however innovative or passionate. Everyone involved must be a committed contributor.
7. Academic policies and regulations should be framed so that they recognise and support the academic and administrative requirements of a distance education program, such as student enrolment, and program delivery mechanisms.




8. There must be equitable access to student services, academic and administrative support for distance and on-campus students alike such as library, counselling and study skills.
9. Distance mode students must be required to participate in residential on-campus learning activities equivalent to a minimum duration of one full academic week for every semester of effective full time study. In this way the school can ensure that graduates have attained the specified attributes and capabilities. Residential schools enhance student-staff and student-student interactions as well as enriching the learning experiences of both students and staff. Also, although most or all practical experience may have been gained off-campus, it is important that staff be convinced of students' practical capabilities at first hand.
10. Provision must be made for laboratory and practical learning, project work and exposure to professional engineering practice that is demonstrably equivalent to those experiences delivered to the on-campus student cohort.
11. There must be specific and adequate mechanisms for tracking the development of personal and professional skills in the distance study mode to ensure the satisfactory delivery of the generic attributes in graduates.
12. The bandwidth, performance and accessibility of electronic communication systems must be adequate to ensure the quality and effectiveness of learning support and performance monitoring, equivalent to that experienced by on-campus students.



## Appendix B

### Survey Questions


Curtin University

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**Which of the following units are you enrolled in?**

Data Communications and Network Management (B.Tech)

Distributed Networks

Renewable Energy (any)

Network Design

Other unit that uses Netlab (eg projects)

Data Communications and Networking (B.Eng)

Advanced Communication Engineering

Network Engineering/Data Network Security

**Please rate how **IMPORTANT** each of the following aspects are in successfully undertaking labs.**

Not at all important	Slightly important	Moderately important	Very important	Extremely important
1	2	3	4	5

Flexibility of access to physical equipment (in the laboratory 207:117)

Flexibility in time and place (anywhere/anytime access)

Physically interacting with the equipment (hands on)

Ease of use

Saving your work (backup)

Ease of access to lab manuals

Collaboration (team work)

**Please rate your level of SATISFACTION with the following aspects of the remote laboratory (NetLab)**

Very Dissatisfied 1      Slightly Dissatisfied 2      Neutral 3      Satisfied 4      Very Satisfied 5

NetLab overall



Ease of Access



Ease of use



NetLab Interface



Confidence with the overall skills learned using NetLab



24/7 Availability of NetLab



Authenticity of the NetLab system (how real does it feel?)



Flexibility in time and place (anywhere/anytime)



**Please rate the EFFECTIVENESS of remote labs in comparison to in class laboratories**

Strongly disagree 1                      Disagree 2                      About the same 3                      Agree 4                      Strongly agree 5

I prefer to use NetLab over in person labs

It is easier to use NetLab

Saving my results is easier with NetLab

Collaboration with my peers is easier with NetLab

The 24/7 availability of netlab is important

NetLab is much more convenient

Scheduling NetLab is simple

Netlab is reliable

**Did you always manage to book a NetLab session when you wanted one?**

- Yes  
 Most of the time  
 Occasionally  
 No

**What can be done to improve the NetLab system**

## Appendix C

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### Equipment Specifications and Setup

#### Control Switch

The following Control Switches were implemented in COLab:

- Two Cisco Catalyst 2960G 24TC-L (Figure A - 1)



Figure A - 1 - COLab Control Switch-Catalyst 2960G 24TC-L

- One Cisco Catalyst 3550 series 48 port (Figure A - 2)



Figure A - 2 - COLab Control Switch - Catalyst 3550 series 48

NETLAB+ server dynamically manages and configures the Control Switch. However, the initial configuration must be performed by the administrator via direct connection to the device. These initial settings include:

- clearing any existing configuration
- configuring *netlab* as an SNMP server community string with read/write permission. SNMP or Simple Network Management Protocol is a widely accepted Internet standard protocol to manage network devices. In the case of this remote laboratory setup, the NETLAB+ server uses the SNMP communication to manage the Control Switch. SNMP is installed and configured on the NETLAB+ server with the community string "*netlab*". The community string is an ID or password sent with SNMP messages to access network devices for monitoring and management purposes[114]. Therefore, it should

be configured on the Control Switch for SNMP communication with the NETLAB+ server[78].

- assigning the IP Address to VLAN 1 interface. The IP address and subnet mask are provided in NETLAB+ documentation. The IP address is in the same subnet as the NETLAB+ server's internal interface.
- Check the connectivity between Control Switch and NETLAB+ server's internal interface.
- Now that the NETLAB+ server is connected to the Control Switch it will automatically push the rest of the configurations using SNMP.

Every time a new laboratory pod added to the system, devices are connected to the Control Switch and will be configured through the NETLAB+ server. This is applicable for laboratory setup included in the NETLAB+ course content list. The list includes templates to design laboratory pods for educational academies such as Cisco, CSSIA, Palo Alto, VMware, and more. However, for a customized laboratory setup, after connecting devices to the Control Switch, the connected ports must be configured manually via a direct console connection.

Through the automatic configuration via NETLAB+ all ports connected to the devices are assigned as access mode for carrying traffic for one VLAN only and ports connected to other control devices and VM server are configured as a trunk to carry the traffic from more than one VLAN.

## **Access Server**

The use of asynchronous interface and cable is a Cisco solution for converting a router to a terminal server. An asynchronous interface is a 68-pin network module with up to 134.4 kbps speed, supporting either 16 (NM-16A) or 32 (NM-32A) ports for data terminal equipment (DTE) serial connection. Figure A - 3 shows a 32 port async interface. These interfaces are either built into the router or attach to the router as an interface module [115]. In the COLAB setup, there are two Cisco 2600 series routers operating

as access server, one with an NM-16A interface module and the other one with an NM-32A interface module together providing 48 console connections.



*Figure A - 3 - COLab Access Server Async Connection*

The 68-pin OCTAL Cables or CAB\_OCTAL\_ASYNCY cables shown in Figure A - 3 attach to the async interface on the router and each provides eight RJ-45 ports for connecting to the laboratory device console ports [[116].

The following steps explain the full process of laboratory device console connection using NETLAB+ server and Access Server:

1. NETLAB+ server connects and authenticates to Access Server via Ethernet link through Control Switch.
2. Through this connection, the NETLAB+ server automatically configures Access Server using SNMP, so it can open Telnet session to each laboratory devices. A sample configuration is shown in figure 5 and the full Assess Server configurations are presented in Appendix A
3. Every time a user accesses a laboratory pod, the NETLAB+ server opens Telnet connections to all the devices on the pod by sending commands to Access Server. A sample command is:
4. NETLAB+ server performs as a Telnet proxy for users to open a terminal connection to laboratory devices

Similar to Control Switch the initial configurations are required on the new Access Server for NETLAB+ server automatic management.

When the laboratory session is terminated NETLAB+ server sends the command to Access Server for closing the Telnet sessions and clear the tty (async) lines.

## Power Distribution Unit (PDU)

The PDUs installed in the COLab setup is shown in Figure A - 4.

The IP address configuration is the only initial setting required for the PDUs to communicate with the NETLAB+ server.

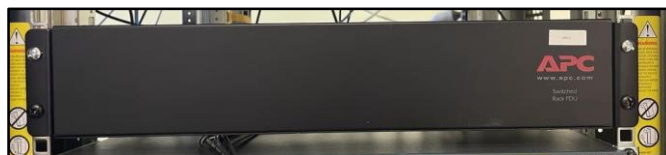


Figure A - 4 Power Distributed Unit- APC in COLab

Similar to Control Switch and Assess Server, the IP address must be in the same subnet as the NETLAB+ server's internal interface.

## VM Server

The VMware ESXi environment is installed on a separate server/s. A VMware ESXi server must be configured to perform management operations by using vCenter applications and database. The laboratory pod VMs can also be hosted on a management server or another VMware ESXi server/s.

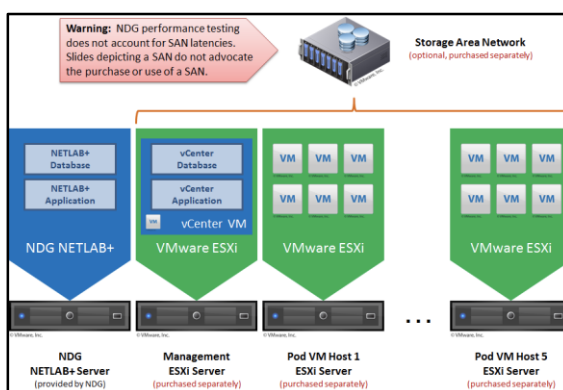


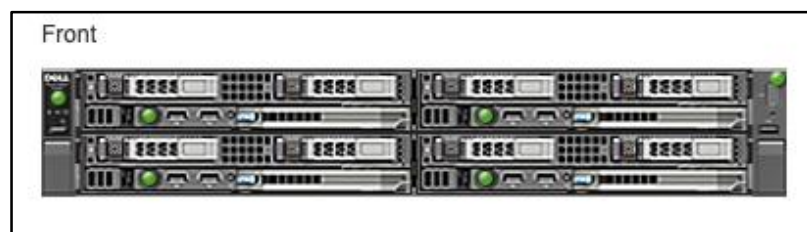
Figure A - 5 - NETLAB+ infrastructure [81]

## Hardware Specification

In the first version of COLab implementation, all VMs were hosted by the management server. However, as laboratory infrastructure was expanded and more VMs were added to the system, extra servers were added.

At the time of the first installation of NETLAB+ setup, the recommended server hardware by NDG was Dell R710/R720 [81]. However, the newer generation (Gen 12) was implemented as the initial ESXi server. As more laboratory pods were added to COLab setup, and accordingly more VMs were required, the original server failed to operate efficiently.

Consequently, a Dell PowerEdge FX2/FX2s server was implemented as an addition to the laboratory server set up in response to VMs high resource demand. The Dell PowerEdge FX2/FX2s implemented in COLab is a chassis that includes four PowerEdge FC630 servers as compute sled. Figure A - 6 shows the front view of COLab four-bay chassis with PowerEdge FC630 operating as ESXi servers. In the original COLab setup with NETLAB+ PE implementation, the first FC630 server was selected as the management server with the rest of the FC360s as pod's ESXi server. However, in the current and upgraded COLab setup, NETLAB+ VE was installed and configured on a separate server with other management applications. As illustrated in Figure A - 6 the original Dell R720 is now the management ESXi server that includes NETLAB+ VE, vCenter applications, and vCenter database. Then the all four FC630 servers included in the Dell PowerEdge FX2/FX2s are operating as ESXi servers hosting pod VMs.



*Figure A - 6 - Dell PowerEdge FX2/FX2s Front View [117]*

Each Dell PowerEdge FC360 server operates independent of the other FC360s and has two network interfaces for internal and external connections. These Ethernet connections are managed by I/O modules installed at the back of the chassis as shown in Figure A - 7.



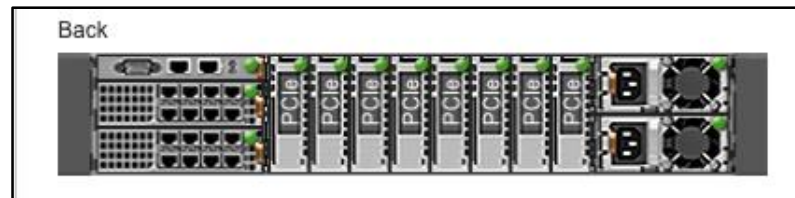


Figure A - 7 - Dell PowerEdge FX2/FX2s Back View [117]

There are two I/O modules installed in the Dell PowerEdge FX2/FX2s server that communicates to FC360 serves through the network switch embedded in the compute sled system board [117]. As it is shown in Figure A - 8 each I/O module includes two quad-port NDCs (Network Daughter Card) and each compute-sled is mapped to two ports of I/O modules.

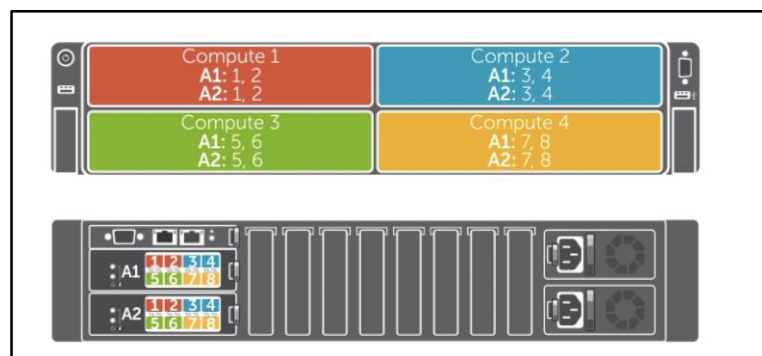


Figure A - 8 - Dell PowerEdge FX2/FX2s 4 Compute-Sled I/O Module [117]

Table A - 1 illustrates how each port on the I/O modules map to compute sleds [117].

Compute sled	IO Module A1 (Top)	IO Module A2 (Bottom)
1	1, 2	1, 2
2	3, 4	3, 4
3	5, 6	5, 6
4	7, 8	7, 8

Table A - 1 - I/O module port mapping for compute-sleds [117]

At the back of the Dell PowerEdge FX2/FX2s server, there are PCIe expansion slots mapped to the PCIe mezzanine cards mounted on compute-sleds (Figure A - 9). In the model used for COLab, for each compute-sled, there are two pre-configured PCIe slots [117].

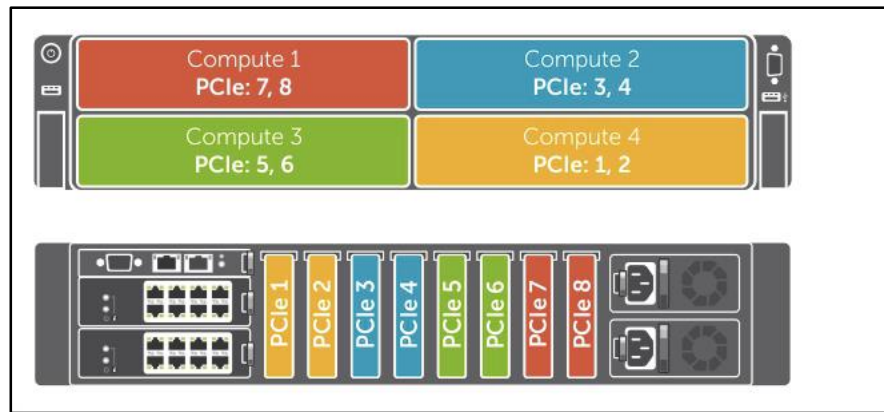


Figure A - 9 -PCIe mapping in Dell PowerEdge FX2/FX2s four-bay chassis [117]

To add more devices via Ethernet connection the switch expansion cards were added to all PCIe slots on the server (picture 11).

## Hypervisor- ESXi

A Hypervisor is also known as Virtual Machine Monitor (VMM) is software that isolates the virtual machine's applications and operating systems from the underlying host computer hardware. So multiple operating systems can run as VMs (guest machine) on ESXi hardware (host machine) simultaneously and independent from each other [118]. There are two types of hypervisors: type 1 also called *native* or *bare-metal* hypervisor installs and runs on the host hardware, and type 2 or *hosted hypervisor* is software that installs and runs on the host operating system.

ESXi is a type 1 hypervisor that deploys and manages the VMs without underlying OS or software application requirements [82].

The management server in the COLab environment is an ESXi server installed on a Dell PowerEdge R320 with the vCenter and NETLAB+ VE as its main components. The four Pod VM host ESXi servers are all installed on Dell PowerEdge FX2/FX2s compute sleds or Dell PowerEdge FC360s in the COLab setup running the VMs required for laboratory topologies.

## vCenter

As it has been mentioned to supply sufficient compute power, vCenter must be installed on a server dedicated for management requirement and pod virtual machines must reside in separate ESXi server/s.

VMware provides two types of vCenter: appliance (vCSA) and server (for Windows). NETLAB+ infrastructure uses the vCenter appliance (vCSA) that comes in the Open Virtualization Format (OVF) software package and based on SUSE Linux. The vCSA version includes an embedded PostgreSQL database that eliminates the additional license requirement for Microsoft Windows and SQL for the server version. Also, multiple databases and Active Directory setup is required for the vCenter server version. Therefore, the deployment of vCSA as an OVF appliance is quicker and easier compared to the vCenter Windows server [81].

After obtaining the VMware vCenter appliance OVF and license, it should be deployed on the ESXi management server using a vSphere web client. Through the deployment process, the IP addressing components are configured and a user account is created to be used by the NETLAB+ server for accessing the vCenter. Then the initial configurations are performed on vCenter via web browser access using the IP address assigned in the previous step.

After performing the initial configurations on vCenter it can be accessed directly through the vSphere web client. The additional settings are required for vCenter to centrally manage the pod ESXi servers [81]:

1. Create a Datacenter that is the primary container of pod ESXi host servers and VMs on vCenter.
2. Add pod ESXi servers to the Datacenter
3. Change the firewall setting for each pod ESXi server to allow remote PC viewer sessions.
4. Configure automatic start-up for vCenter on management ESXi server.

With the above configurations, all pod ESXi servers and virtual machines can be managed centrally by the vCenter server using the vSphere web client.

## **vSphere Client**

The vSphere client comes as standalone and web-based versions. The standalone vSphere client is a Windows application that installs on a PC and communicates to the vCenter server. Instead, the vSphere web-based client only requires a web browser to launch the GUI and communicate with vCenter [84].

In the first COLab setup, vCenter v5.1 and standalone vSphere client were in use for management tasks as the web-based version was not accurate in performing some of the operations. However, from vCenter v6 all the monitoring and management operations are performed using the current vSphere web-based client that uses the HTML5.

### Server Network Configuration

The inside IP addresses are provided by NDG setup. However, the outside IP addresses, subnet masks, and default gateways must be provided by the campus IT admin. It is recommended to record the IP addressing configurations in a table similar to Table A - 2 for reference and future system expansion.

Dual-Homed Model – Real Equipment Pods	
vCenter Outside IP Address	
ESXi Management Server Outside IP Address	
ESXi Host Server 1 Outside IP Address	
ESXi Host Server 1 Inside IP Address	169.254.0.241
ESXi Host Server 2 Outside IP Address	
ESXi Host Server 2 Inside IP Address	169.254.0.242
ESXi Host Server 3 Outside IP Address	
ESXi Host Server 3 Inside IP Address	169.254.0.243
ESXi Host Server 4 Outside IP Address	
ESXi Host Server 4 Inside IP Address	169.254.0.244
Outside Subnet Mask	
Inside Subnet Mask	255.255.255.0
Outside Default Gateway	
Inside Default Gateway	None
Primary DNS Server	
Secondary DNS Server	

Table A - 2 - Inside Network IP address Reference Table [85]

As shown in Figure 5-4 - NDG Dual-Homed Network Model [85] all the servers including management and pod ESXi host servers are connected to the control switch. These servers must be available for all the pods using the virtual machines regardless of the VLAN they are operating on. therefore, all control switch's ports connected to servers must be configured as a trunk port to allow all VLANs traffic. The NETLAB+ server connection to Control Switch must also be configured as a trunk port for the same reason [85].

However, since NETLAB+ VE is used in the COLab setup as a VM on a management server, connecting the server to the trunk port is sufficient.

The networking setup inside the ESXi server is designed to share the physical network interface card (NIC) with VM's virtual network interface card (vNIC). To accomplish this ability, ESXi uses a virtual switch (vSwitch), VMkernel port, physical adaptor (NIC), and Port Groups.

**Virtual Switch** is a software-based internal LAN created by ESXi kernel that forms the association between physical networks, virtual machines, and VM kernel to provide network connectivity. When dealing with VMs network traffic, vSwitch inspect the data packets and forward them to the right destinations [119].

VM kernel is an OS similar to POSIX that runs on an ESXi server and manages the physical recourses including network controllers. The **VM kernel port**, also known as the VM kernel network interface or adaptor, is responsible to provide services to the ESXi server for connectivity between VMware infrastructure and other networked components such as NETLAB+ server or Control Switch [119].

**Port Group** is used to apply the network policies to a set of vSwitch ports. It creates a Virtual LAN (VLAN) on vSwitch and assigns a group of ports to each VLAN [119]. Figure A - 10 illustrates an example of the ESXi server networking configurations. As it can be seen the diagram includes vmnic0 as the physical network interface card (NIC), VMkernel port with IP address configuration that works as a services provider for VM infrastructure classified under workgroup, workgroup 1 and 2 containing several VMs that are connected to different VLANs, and a virtual switch (vSwitch) that bridges between vmnic0, VMs, and VMkernel.

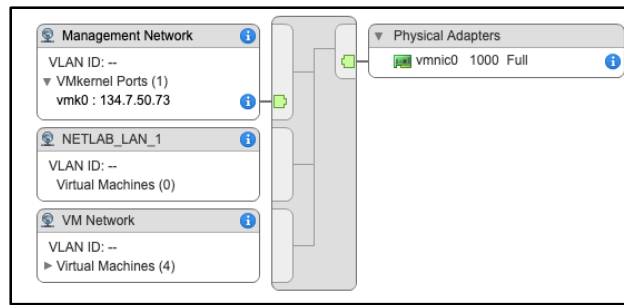


Figure A - 10 - ESXi server network configuration

In the NETLAB+ VMware infrastructure dual-homed network setting, three networks must be configured: outside, inside, and safe staging network.

The **outside network** uses vSwitch0 which is created automatically during the ESXi installation process. VMkernel port IP address is also configured as an ESXi installation and configuration step [81].

To verify the ESXi server network configuration, the vCenter server must be accessed through the vSphere client. The ESXi server can be selected from the vCenter host list for management and monitoring. Usually, there is no need for any configurations on the outside network as it is already configured throughout the server installation process [81].

However, the **inside network** must be configured. The IP address of the inside network interface is provided by NETLAB+ setup documentations.

The procedure steps are:

1. Creating a new vSwitch (e.g., vSwitch1) with the “VMkernel Network Adaptor” connection type.
2. Adding an adaptor or physical interface (e.g., vmnic1) to vSwitch1
3. Configuring the IP address from the list provided by NETLAB+
4. Verify the inside network setting

Virtual Machine’s network interface connects to the inside network.

NETLAB+ server communicates to the VMware infrastructure through the inside network and creates a port group for each pod on the ESXi host [81].

When VMs are assigned to a pod they are connected to the inside network on the port group specified by the NETLAB+ server.

The **Safe Staging Network** purpose is to provide a temporary network connection for new VMs and ones that are assigned to any pods. Since there is no physical adaptor connected to the Safe Staging Network vSwitch and

port group, it is a secure technique to keep new VMs traffic under control until they are assigned to a pod [81].

## Laboratory Setup

### CCNA Laboratory

The following devices are implemented on COLab for CCNA R&S laboratory pods:

- **Routers:** the two models of Cisco routers used in COLab are Cisco 2901/2911 S(0/0/x) and Cisco 2801/2811 S(0/0/x)
- **Switches:** Cisco Catalyst 2960
- **PCs:** All PCs in CCNA R&S laboratory topology are replaced by virtual machines running Windows OS, Windows 7 for Multi-Purpose Pod and Windows 10 for MDP. The image of the virtual machines can be downloaded from <https://www.cssia.org/cssiaresources/> for registered members. All the programs and software used in the CCNA R&S laboratory are included in the VM image. An academic subscription for *Microsoft Azure Dev Tools for Teaching Program* is required to maintain the Windows license. First, the image (OVF) is deployed as a master VM on an ESXi host server and Windows license is activated for it, then pod VMs cloned from the master VM using the same license.

The laboratory equipment is all connected to Control devices for remote access and pod configuration from NETLAB+ server.

The communication between virtual machines and laboratory devices occurs through the Control Switch.

Figure A - 11 shows the connections in Multi-Purpose pod including Control Switch links. This figure only displays the straight-through connections and omits the serial links between the routers. If compared with Figure 5-8, all the links connecting the laboratory devices to Control Switch are the PC connections. For example, port 4 on Control Switch connects to Ethernet 6 on S1 that is a communication link to PC-A.

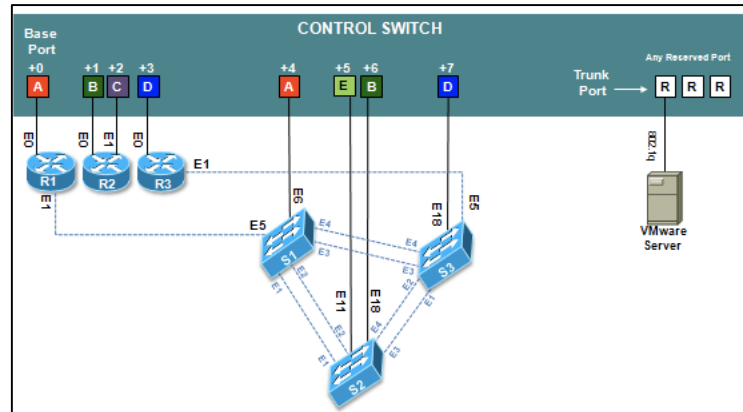


Figure A - 11 - Multi-Purpose Pod connections on Control Switch [89]

As it was explained above (Server Network Configuration), ESXi host server communicates to Control Switch via a trunk port so it can access all the VLANs for data transmission. When a VM is assigned to a pod by NETLAB+ server, it places the VM network interface on the VLAN for that specific pod using internal vSwitch configuration on the ESXi server.

The connections in Multi-Device pod are simpler than Multi-Purpose pod with only four devices and no serial connections between the routers. Figure A - 12 displays the Multi-Device laboratory equipment connections and their links to Control Switch.

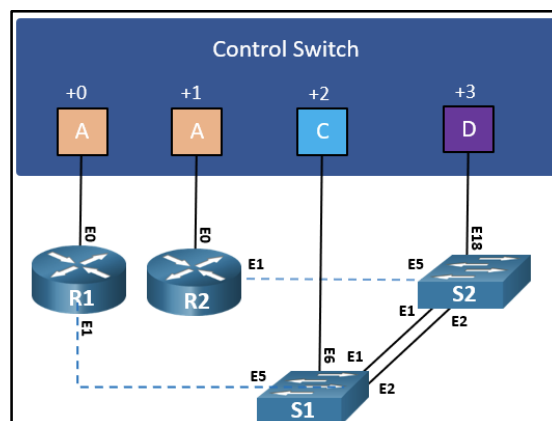


Figure A - 12 - Multi-Device Pod connections on Control Switch-CCNAv7 [90]

The VM communications are similar to Multi-Purpose pod setup.

The Access Server provides laboratory equipment console access to users for remote configuration task via async cable connection. Figure A - 13 and



Figure A - 14 shows the console connection from laboratory devices to the Access Server for both Multi-Purpose and Multi-Device pods.

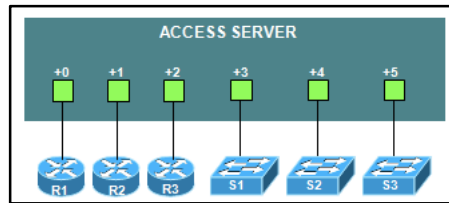


Figure A - 13 - Access Server Connection for Multi-Purpose Pod [79, 89]

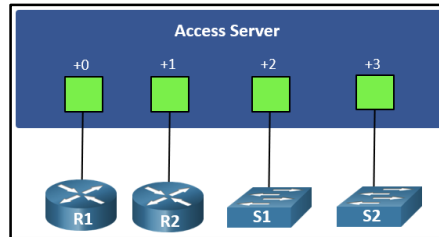


Figure A - 14 - Access Server Connection for Multi-Device Pod [90]

For laboratory equipment power management, the power cable of each device must be connected to a PDU controlled by NETLAB+ server (Figure A - 15 and Figure A - 16)

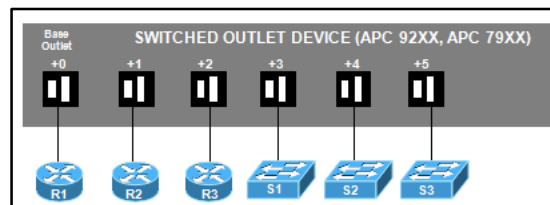


Figure A - 15 - Power connection to PDU for Multi-Purpose Pod [89]

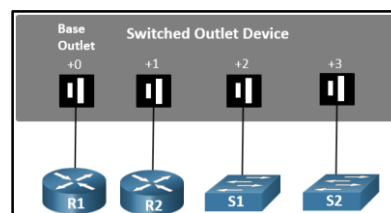


Figure A - 16 - Power connection to PDU for Multi-Device Pod [90]

The VMs power control and remote console access are performed through ESXi server managed by NETLAB+ server

Figure A - 17 displays the NETLAB+ server pod configuration interface.

The screenshot displays the NETLAB+ configuration interface for a pod named 'Pod01-CCNAwithASA'. The pod is currently in an 'IDLE' state with 'DISABLED' ACL and 'ONLINE' status. The interface is divided into several sections:

- Lab Devices:** A table listing physical devices connected to the pod.
 

Device	Type	Access	PDU	Action
R1	Cisco 2901/2911 (S0/0/x)	ATS 1, LINE 33	PDU 1, OUTLET 1	
R2	Cisco 2901/2911 (S0/0/x)	ATS 1, LINE 34	PDU 1, OUTLET 2	
R3	Cisco 2901/2911 (S0/0/x)	ATS 1, LINE 35	PDU 1, OUTLET 3	
S1	Cisco 2960	ATS 1, LINE 36	PDU 1, OUTLET 4	
S2	Cisco 2960	ATS 1, LINE 37	PDU 1, OUTLET 5	
S3	Cisco 2960	ATS 1, LINE 38	PDU 1, OUTLET 6	
ASA	Cisco ASA 5505	ATS 1, LINE 39	PDU 1, OUTLET 7	
- Remote PC:** A table listing virtual machines.
 

PC Name	VM	Operating System	VM Role	Runtime Host	Action
PC A	CiscoLabPC01	Windows 7	NORMAL	134.7.50.75	
PC B	CiscoLabPC02	Windows 7	NORMAL	134.7.50.75	
PC C	CiscoLabPC03	Windows 7	NORMAL	134.7.50.75	
- Control Switch Ports:** A table listing VLANs and their configurations.
 

Relative Port #	Default VLAN	Control Switch	Control Port	Port Role	Peer	Action
0	A (10)	1	GigabitEthernet0/1	LAB-ROUTER	POD 1 RCPN 0 (R1/E0)	
1	B (11)	1	GigabitEthernet0/2	LAB-ROUTER	POD 1 RCPN 2 (R2/E0)	
2	C (12)	1	GigabitEthernet0/3	LAB-ROUTER	POD 1 RCPN 2 (R2/E1)	
3	D (13)	1	GigabitEthernet0/4	LAB-ROUTER	POD 1 RCPN 3 (R3/E0)	
4	A (10)	1	GigabitEthernet0/5	LAB-SWITCH	POD 1 RCPN 4 (S1/E6)	
5	E (14)	1	GigabitEthernet0/6	LAB-SWITCH	POD 1 RCPN 5 (S2/E11)	
6	B (11)	1	GigabitEthernet0/7	LAB-SWITCH	POD 1 RCPN 6 (S2/E18)	
7	D (13)	1	GigabitEthernet0/8	LAB-SWITCH	POD 1 RCPN 7 (S3/E18)	
8	F (15)	1	GigabitEthernet0/9	LAB-FIREWALL	POD 1 RCPN 8 (ASA/E0)	

Figure A - 17 – NETLAB+ Device Configuration Interface

After cabling the laboratory equipment, all the pod configurations are performed using this interface.

## CCNA Cybersecurity Operations Laboratory

The detailed storage requisite is shown in Table A - 3 [92].

Virtual Machine	OVF/OVA	Initial Master Pod (Thin Provisioning)
CyberOps Workstation	2.4 GB	5.7 GB
Kali	3.6 GB	8.3 GB
Metasploitable	900 MB	1.8 GB
Security Onion	3.2 GB	9.7 GB
WinClient	6 GB	11.6 GB
<b>Total</b>	<b>16.2</b>	<b>37.1</b>

Table A - 3 - storage requirement for each VM on the master pod [92].

Similar to other CNAP courses on NETLAB+, Cisco networking academy membership

Is required to access the pod template for CCNA CyberOps laboratory topology. Also, Microsoft Imagine or Visual Studio program vendor membership and CSSIA agreement are essential to utilize features on the windows-based VMs.

VMs are deployed on an ESXi server once downloaded from <https://www.cssia.org/cssiaresources/>. Then VM MAC addresses must be manually configured according to Table A - 4 [92].

Virtual Machine	NIC	MAC
<b>CyberOps Workstation</b>	1	08:00:27:23:B2:31
<b>Kali</b>	1	08:00:27:CA:70:C6
<b>Metasploitable</b>	1	08:00:27:AB:84:07
	2	08:00:27:DE:6E:B0
<b>Security Onion</b>	1	08:00:27:8c:29:85
	2	08:00:27:2b:22:6e
	3	08:00:27:a8:ab:b6
	4	08:00:27:44:6c:a0
<b>WinClient</b>	1	00:50:56:82:da:48

Table A - 4 - CCNA CyberOps sandbox MAC address assignment [92]

When VMs are configured on the ESXi server, they can be deployed on the NETLAB+ server master pod. Then the other pods can be created by cloning the master pod. However, before starting the cloning process, licenses must be activated on the master pod so multiple VMs can use the same license [92].

## Appendix D

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### ATTRIBUTION OF PUBLICATION STATEMENT BY OTHERS

The purpose of this statement is to summarize and clearly identify the nature and extent of the intellectual input by the candidate and any co-authors.

**Article 1:** title: Developing methodologies for the presentation of graphical educational material in a non-visual form for use by people with vision impairment.

**Article 2:** title: Remote renewable energy laboratory: Green Electric Energy Park (GEEP)

Attribution of Prof. Iain Murray

Article	Literature Review	Concept Design	Configuration and Implementation	Experimental Results	Data Analysis	Discussion	Paper Writing	Thesis Chapters
1								4
2								5

Attribution of Geoffrey Hsiung

Article	Literature Review	Concept Design	Configuration and Implementation	Experimental Results	Data Analysis	Discussion	Paper Writing	Thesis Chapters
2								5

[Student]

[Supervisor]