Design and Evaluation of a Technological-enhanced Lab Environment for a Systems and Network Administration Course

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Statement of Originality

I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision. The thesis contains no material which has been accepted, or is being examined, for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968 and any approved embargo.

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I hereby certify that the work embodied in this thesis contains published papers of which I am a joint author. I have included as part of the thesis a written statement, endorsed by my supervisor, attesting to my contribution to the joint publications.

Tareq M. Alkhaldi

By signing below, I confirm that Tareq Alkhaldi contributed to the following publications:

- Alkhaldi T., et al., "A review of contemporary virtual and remote laboratory implementations: observations and findings", Journal of Computers in Education, Sept. 2016, vol. 3, issue 3., pp.329-351.
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List of Acronyms

CA	Constructive Alignment
DBR	Design-Based Research
ELC	Experiential Learning Cycle (Kolb, 1984)
ICT	Information, Communication and Technology
LMS	Learning Management System
PLTs	Pedagogy and Learning Theories and Principles
SAT	Students Satisfaction
TAM	Technology Acceptation Model
TePF	Technology-enhanced Pedagogical Framework
VCL	Virtual Computer Laboratory
VM	Virtual Machine

Further details are presented where appropriate in the relevant chapters.

Abstract

Advances in technology are influencing all fields including education. Recently, we have observed a wide use of emerging technologies to support and facilitate the establishment of virtual laboratories with many benefits that overcome the constraints of traditional physical laboratories. These laboratories provide a number of advantages such as remote 24/7 access, flexibility, freedom to learn at one's own pace, to reset/retrial experiments without wasting resources in a safe environment and providing new opportunities for learning. Although virtual and remote laboratories provide many new opportunities for learning, they have not necessarily been shown to assist students in achieving higher learning outcomes. How do we design technology-enhanced lab environments for effective learning?

To answer this research question, this thesis conducts a comprehensive literature review on technology-enhanced lab environments. In the literature review, we observe that pedagogical techniques integrated with virtual lab environments provide the best outcomes for student learning. Based on the findings, a hypothesis is proposed that considers a holistic view of designing technology-enhanced lab environments taking into consideration learning context, curriculum, learning activities, assessments, technology artefacts based on pedagogical and learning theories and principles (PLTs).

To validate the hypothesis, a technology-enhanced lab environment is developed and evaluated for a particular learning context: a systems-level course in computing. A literature review on technology-enhanced lab environments in systems level courses in computing reveal that only a few studies consider pedagogy in the design of such lab environments.

In this thesis, we propose, design and evaluate a comprehensive pedagogical framework that incorporates both technological and pedagogical considerations for teaching in a network and system administration course. The framework incorporates learning theories and principles, such as Biggs's Constructive Alignment, Kolb's Experiential Learning Cycle (ELC), in its design and innovative technology tools such as virtual labs and feedback tool.

The proposed framework is developed in two iterations and evaluated in real-world classroom environments following a Design-based Research (DBR) methodology. The evaluation consists of student perceptions of the proposed framework using mixed methods and the impact on student learning. In the first iteration, two architectures for virtual labs implementation and a feedback tool are developed and evaluated. A quasi-experiment is conducted to evaluate the impact of the technology intervention. The results provided useful insights that guided the design of the second iteration.

In the second iteration, the proposed framework is implemented and evaluated in its entirety. A quasi-experiment was conducted and students' assessments scores were compared. The results showed that the students in the experimental group, who were subjected to the proposed framework, scored higher marks which was statistically significant than the students who did not use the proposed framework. Furthermore, the findings indicated that the learning process encouraged a deep approach to learning. These results not only provided evidence of higher learning outcomes by students but also that a deeper learning process was undertaken when using the proposed framework. The lab activities incorporated the PLTs in their design, and the benefit of this approach was validated, supporting the hypothesis. Furthermore, components of the framework were evaluated providing useful insights and suggestions for improvements in future.

Finally, we reflect on the overall process used in the design, implementation, and evaluation of the framework. From this activity, design principles are derived that provide guidelines/principles to designing technology-enhanced lab environments for effective learning in future.

List of Publications

Dissemination: Journal articles:

1. Alkhaldi, T., Pranata, I., & Athauda, R. I. (2016). A Review of Contemporary Virtual and Remote Laboratory Implementations: Observations and Findings. *Journal of Computers in Education*, 3(3), 329-351.

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Chapter I

1. Introduction

This chapter introduces the thesis with a background on the use of technology to provide many opportunities for developing lab environments but limited guidelines to do so. The broad research question addressed in this research is presented next. Integrating pedagogical techniques in the design of technology-enhanced labs such as virtual labs have motivated the research. Significance and benefits of this research project are presented. The research approach to address the research question and evaluate the proposed solution are then explained. Finally, an outline of the thesis structure is given.

1.1 **Background**

In today's society, we have various emerging technologies that impact our lives in different ways. Technologies change how we communicate and interact and, importantly for this thesis, the way we learn and teach. Information and Communication Technology (ICT) is providing us with new opportunities to access and gain knowledge. Technology-enhanced learning experiences are becoming the norm for today's learner. Many, if not all, higher education students use the Internet to: access learning materials; interact with the content, instructors and other learners; and obtain support during the learning process. ICT is also transforming pedagogy by providing new ways to involve learners with different forms of content and activities in their learning experiences. Different learning environments, including blended learning, online learning, computer-based instruction and web communities have all created new opportunities for learning.

In many fields such as the natural sciences, engineering and computing, practical work and laboratory activities are paramount to learning. These types of activities provide opportunities for in-depth learning through application (learning by doing) and observation. Tuysuz (2010) found that laboratory activities increase student achievements and interest in the subject matter and further help them to learn and grasp new knowledge (Ma & Nickerson, 2006; Chen et al., 2010; Lustigova & Novotna, 2013).

In a traditional laboratory environment, learners conduct experiments physically in a laboratory. This type of lab is known as a physical or hands-on lab. Advances in technology have resulted in technology-enhanced laboratory environments. Technology-enhanced lab environments can be broadly classified into two categories: remote labs which allow learners to access physical equipment via networks (e.g., the Internet) and conduct experiments remotely (Chaos et al., 2013; Marques et al., 2014; Hossain et al., 2015); and virtual labs which allow learners to conduct experiments in computer-simulated environments, which are also called simulated labs (Woodfield et al., 2005; Ding & Fang, 2009; Alharbi et al., 2012; de Jong et al., 2014; Razvan et al., 2012 and others).

The main limitations of hands-on labs are the high cost of the initial set up of the lab and that the students must be located in the lab in order to perform experiments. The students cannot access the physical lab when it is being used by another class or during closed periods. This limited accessibility associated with physical labs is avoided in remote and virtual labs. In remote and virtual labs, students usually have the freedom to access and conduct experiments 24/7 from remote locations. This provides flexibility and availability over physical labs. Students also have the freedom to learn at their own pace, to re-set, repeat or re-trial experiments and to explore at their own convenience with minimal restrictions. Virtual and remote labs allow learners to experiment in a safe environment especially if the experiments use hazardous materials (Woodfield et al., 2005). Physical labs are geared towards on-campus students. However, with the ever-increasing numbers of distance learners, remote and virtual labs often provide the only means for such learners to access lab environments. Moreover, virtual environments provide new opportunities for learning, such as simulations focused on pedagogical aspects and scaffolding learners, that are not practical in physical lab settings (Chaos et al., 2013; Hossain et al., 2015).

Although virtual and remote labs have many advantages, in the literature many studies (Nickerson et al., 2007; Helps & Ekstrom, 2008; Li et al., 2009; Brinson, 2015; Heradio et al., 2016) argue that physical labs are important for learning in different educational contexts. Other studies state that virtual and remote labs have similar learning outcomes to physical labs (Anisetti et al., 2007).

Some studies point out that one type of lab does not replace the other, but rather they can be used to complementarily, taking advantage of the strengths of each lab type to enable rich learning environments (Razvan et al., 2012; Chaos et al., 2013; Alkhaldi et al., 2016).

With the rapid evolution of technology, new possibilities for designing lab environments are constantly being created. In the literature, many studies implement technology-enhanced labs for different educational contexts. However, a generic model, methodology or framework for developing lab environments to take advantage of technology to enhance learning is not yet documented in the research. This thesis therefore aims to address the following broad research question: *How do we design a lab environment to take advantage of technology for effective learning?*

1.2 **Motivations, Significance and Benefits**

Today millions of people learn in online environments, and technology-enhanced classrooms and virtual settings are becoming the norm. The rise in Massive Open Online Courses (MOOCs), which provide free online courses available for anyone to learn in a flexible way (e.g., http://mooc.org/) is a testament to this fact. It is not uncommon to have classes with many thousands of distance learners. In many fields of study, practical work and hands-on activities are paramount to learning. It is typical to do experiments in laboratory settings to conduct such practical work. Technology advances have enabled the development of innovative labs such as virtual and remote labs for learning. These technology-enhanced labs often provide the only means for distance learners to participate in laboratory activities while also giving flexibility and freedom to on-campus learners. Thus, it is becoming increasingly important to research how such lab environments can be effectively designed, developed and utilised for learning. This thesis aims to address this question and contribute towards filling this research gap. Developing such effective laboratory environments can have significant contributions and impacts on society.

1.3 **Research Approach**

This research project aims to address the broad research question by firstly conducting a comprehensive literature review of technology-enhanced labs. This analysis of the literature provides insights as to what strategies are effective for learning when innovative labs are implemented. This analysis also reveals areas of focus and gaps in the field of application of technology-enhanced labs.

The literature review and analysis produced a number of helpful insights with regard to implementing technology-enhanced labs. An apparent gap in the literature that was identified is that there are no clear guidelines, methodologies or frameworks to follow when integrating technology-enhanced labs into different educational contexts. Rather the literature provides studies which develop and apply technology-enhanced labs in specific educational contexts and sometimes provide an evaluation.

An observation of the analysis is that technology-enhanced labs and related technologies provide new opportunities to learn for both on-campus and distance learners. However, technology-enhanced labs are tools like any other tool. Integrating such tools effectively in learning requires careful consideration and appropriate decisions to meet educational goals. Considering the labs in isolation, without considering the context, is not sufficient. From the analysis, it is clear that it is the combination of tools, such as technology-enhanced labs, learner support, effective curriculum design and tutor interaction which are all essential components, that create a rich learning environment to achieve learning outcomes. Thus, in order to answer the overall research question, the thesis postulates that design decisions should not only consider the capabilities and opportunities that the technology provides but take a holistic approach that also considers the educational context, learning goals and design learning environments based on sound pedagogy and learning theories and principles to create an effective learning environment. This has led to the following hypothesis posed in the research project:

Design of technology-enhanced lab environments taking a holistic view of learning incorporating the learning context, curriculum design, lab activities, assessments, resources and technology artefacts based on sound pedagogical and learning principles and theories have a higher potential for effective learning.

To validate this hypothesis, the thesis implements and evaluates a technology-enhanced lab in a particular educational context. A system level course in an undergraduate computing program was selected. A virtual lab was designed and implemented. A number of pedagogy and learning theories and principles (PLTs) are reviewed and selected to design the integration of the virtual lab. Also, many other technology tools and artefacts are utilised to support learning. Overall, a technology-enhanced pedagogical framework (TePF) for a lab environment integrating a virtual lab is implemented and evaluated. The research project follows a Design-based Research (DBR) methodology to develop, implement and evaluate the framework. The success of the approach helps us derive "design principles" that can guide in the development of such technology-enhanced lab environments in future. The next section provides an overview of the thesis chapters and its structure.

1.4 Thesis Structure

This thesis is organised into the following chapters: Chapter 1 provides an introduction to the thesis, the overarching research question, the hypothesis addressing the research questions and provides a summary of the approach taken in the thesis. Chapter 2 is divided into two sections. The first section provide a review of the technology-enhanced labs in different fields. This analysis helped us to come up with a hypothesis addressing the research question. In the second section, a particular learning context (i.e. systems-level courses in computing) is selected to validate the hypothesis. A literature review for this context (i.e. virtual labs in system-level courses) is conducted next. Chapter 3 presents a framework for a technology-enhanced laboratory environment in a systems-level course in computing. The DBR methodology is utilised to implement and evaluate the framework in two iterations. Chapter 4 discusses DBR methodology while the two iterations used to develop and evaluate the proposed framework are discussed in chapters 5 and 6. Chapters 7 derives reflects upon the entire project and derives "design principles" addressing the broad research question. Chapter 8 concludes the thesis with a discussion on future research directions. Figure 1.1 depicts the organisation of the thesis.

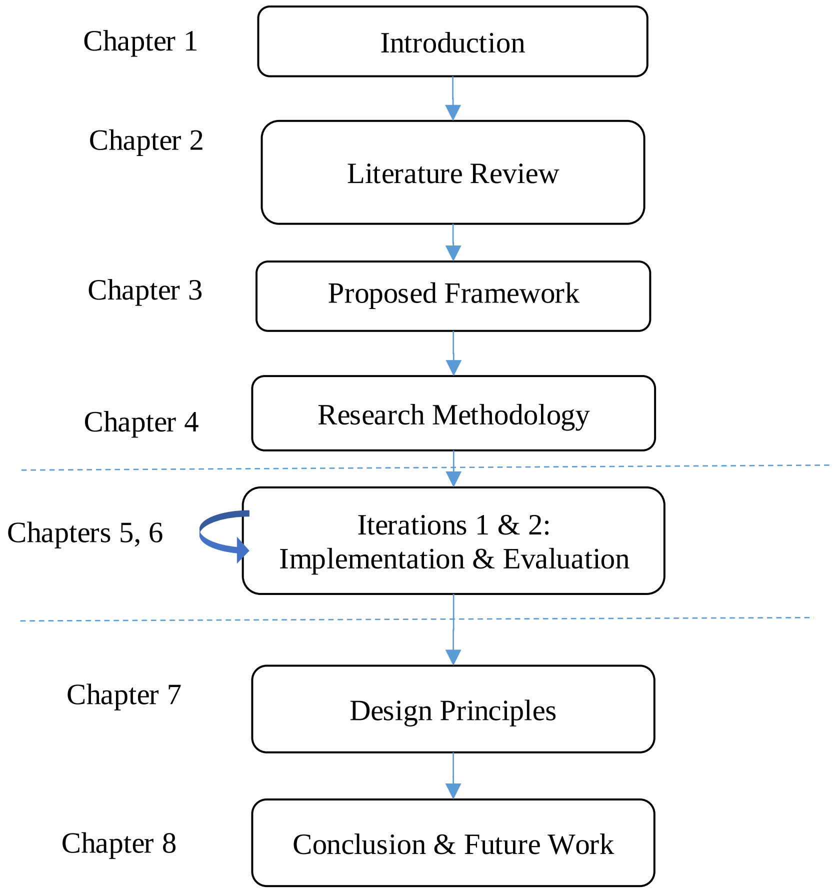


Figure 1.1 The Overall Structure of the Thesis

1.5 **Summary**

Hands-on activities play an essential role in student learning in many fields. Technology provides many opportunities to develop effective lab environments. Methods of designing and developing effective technology-enhanced lab environments to enhance learning are still in their infancy. This thesis takes a holistic view to designing technology-enhanced lab environments based on sound pedagogical and learning theories and principles. A technology-enhanced lab environment for a system level course in computing is implemented and evaluated iteratively with pilot studies. The evaluation provides useful insights to the effectiveness of the proposed approach.

The following chapter presents a literature review of related work.

Chapter II

2. Literature Review

This chapter presents a literature review which builds the foundation for the thesis. Firstly, in section 2.1, a review of technology-enhanced labs (remote and virtual labs) implemented in different disciplines are presented and analysed. The analysis provides us with a number of observations, findings and insights which are discussed in section 2.2. A key insight that helps us answer the main research question presented in Chapter 1 is that taking a holistic view to design technology-enhanced labs by taking into account learning context, curriculum design, resources, assessments and technology artefacts following sound PLTs can result in learning environments for effective learning. Thus, the hypothesis which will be evaluated in the thesis is presented in section 2.2.2. To validate the hypothesis, this thesis develops and evaluates a technology-enhanced lab environment for a selected learning context. Recently, system level courses in computing have developed virtual labs, taking advantage of virtualization technologies. Therefore, a review of the literature in this domain is carried out in section 2.3. The analysis revealed a research gap as most implementations of virtual labs focus mainly on the technical aspects and very few take a holistic view with a PLT focus. Finally, in section 2.4, a summary of the chapter is presented.

2.1 Virtual and Remote Lab Implementations in Different Disciplines

This section reviews remote and virtual laboratory implementations in different disciplines. The analysis uncovers a number of interesting observations, findings and insights into virtual and remote laboratory implementations. Several research initiatives have been undertaken in various disciplines demonstrating how these laboratories could work in their respective areas.

2.1.1 **Virtual and Remote Laboratories for Programming Robots**

Based on a study by Chaos, Chacon, Lopez-Orozco and Dormido (2013), both virtual and remote laboratories were developed for an Autonomous Robots subject in the Master of Systems Engineering and Automatic Control at the Spanish National University for Distance Education (UNED) and at the Complutense University of Madrid (UCM). These laboratories were set up for distance and online education. Students are given access to control the robot both manually and/or through programmed interfaces. The difference is that students interact using a simulated environment in the virtual laboratory while they interact with a real robot in the remote laboratory. A number of sensors are incorporated into the robot which allows students to program based on sensor readings. Students are first given access to the virtual laboratory environment to attempt their tasks and once a mastery of the interface and programming is achieved, access is given to the real robot environment through the remote laboratory. Although the interface is the same in terms of manipulating the robot in the simulated environment, manipulating the robot in the real world has additional complexities. For example, the motor may suffer from nonlinear effects, such as saturation on acceleration and dead zones. Moreover, sensors may be affected by noise, outliers in measurements, delays and failures in communication. Students are given a time-slot to test their solutions in the remote laboratory and it is moderated by lab assistants who are able to solve issues (such as collisions, mechanical failures, etc.) that cannot be remotely addressed by the students. The hands-on real-world experience provides a rich source of knowledge to enhance the learning process of students so they can deal with practical problems usually neglected in theory.

These virtual and remote laboratories have been operating in the program for two years. They have proven to be extremely useful for teaching the role that sensors play in robotics. A student satisfaction survey has shown that they either agree or completely agree with the fact that these laboratories are necessary for a complete understanding of robotic sensors.

In Chaos et al. (2013), it is shown that both virtual and remote laboratories are effective and useful. Virtual laboratories provide a safe, easily accessible environment for students to master their skills prior to applying them in a real-world environment through remote laboratories. Also, by applying their knowledge and skills in a real-world environment, students are exposed to the complexities of real-life situations which are hard to emulate in virtual environments and typically are ignored in theory. The authors state "*using the virtual laboratory like the remote one has been a success:*

students can get confidence in their work before testing in the real robot and they can make a first debug of the code before testing it in the real robot; 74% of the students feel more comfortable if they can use the virtual laboratory before connecting with the real robot". Overall, this study successfully integrated both virtual and remote laboratories in a robotics subject to provide a rich learning experience for students.

2.1.2 **Remote Lab in Biology**

Hossain et al. (2015) presented an architecture and implementation for a remote laboratory in biology. A specific set of experiments based on P. polycephalum, which is a single celled, multi-nuclei, cytoplasmic organism, were conducted. Initially, a system administrator would start an experimental session by preparing Petri dishes inoculated with P. polycephalum in the centre unless a special initial condition was specified by a student ahead of time. Students were notified with access keys once all experiments were loaded. A student then accessed experiments remotely using a web interface. This experimental session would last two to three days in which time there would be no further manual intervention. During this time, students were able to manipulate and investigate the state of their experiments through a web-based UI at any time and from any place without having to book a time slot. All experimental data were archived when the session expired and students were able to investigate these later at any time using the same UI. Students also could share their experiments and data with others.

The remote laboratory was used in a graduate bio-physics course. Four students conducted eleven online experimentation sessions. Student activities were logged and three one-on-one interviews were conducted in weeks 2, 5 and 10. Both the student activity and the feedback were analysed. The student feedback indicated that this platform lowered the threshold of entry to biology experimentation in three ways: it empowered non-biologists to perform real experiments without concerns about wet lab training and safety. The system abstracted away all of the wet lab details and allowed the students to concentrate on experimental strategies and data analysis. The system provided convenience by allowing students to remain engaged with their experiments from any place at any time. Also, the logs provided data that could be used in learning analytics to provide useful insights.

Hossain et al.'s (2015) proposed platform considers the development of an innovative Biotic Processing Unit (BPU) to handle specific types of experiments and automation in biology. The current implementation is proof of concept for a particular type of experiment in biology. This paper demonstrates the benefits of such a remote laboratory.

2.1.3 **The Virtual Chemistry Lab (ChemLab)**

Woodfield et al. (2004) and Woodfield et al. (2005) discuss the Virtual ChemLab project which is a simulated lab that allows students to simulate chemistry experiments in a number of ways. Virtual ChemLab simulation does not replace physical wet labs where students learn how to conduct a chemistry experiment (such as cleaning test tubes, setting up experiments, etc.). Rather, the goal of each Virtual ChemLab simulation is to provide students with an intuitive, safe, open-ended, unrestricted simulation environment, similar to a hands-on experiment, where they can create experiments, perform tests and view their results. The general features of a ChemLab simulation includes 26 cations that can be added to test tubes in any combination, 11 reagents that can be added to the test tubes in any sequence and any number of times, necessary laboratory manipulations including centrifugation, flame tests, decanting, heating, pH measurements and stirring, a lab book for recording results and observations, and a stockroom window for creating test tubes with known mixtures, generating practice unknowns or retrieving instructor-assigned unknowns. The simulation uses over 2500 actual pictures to show the results of reactions and over 220 videos to show the different flame tests. ChemLab provides a truly exploratory open-ended experiment framework as the 26 cations that can be combined in any order or combination and the 11 reagents that can be added in any order, create in excess of 10^{16} possible outcomes in the simulation.

The research team evaluated ChemLab’s Inorganic Qualitative Analysis simulation using online surveys sent to over 1400 students enrolled in freshman level chemistry courses between January 2001 and April 2002 at Brigham Young University. The surveys consisted of Likert-type questions and free response questions. Additionally, interviews and observations of students were conducted. Data was analysed through descriptive statistics and several analyses of variance (ANOVAs) and linear regressions. The most interesting observations and findings occurred when the student’s opinion and performances were correlated with each student’s personality profile. The personality profile of each student was determined by the Herrmann Brain Dominance Instrument (HBDI) (Herrmann, 1995).

Woodfield et al. (2005) found that creative learners (higher cerebral score) are more likely to explore and experiment in ChemLab simulations than structured learners (higher limbic score) not because they were less capable but because of their individual learning preferences. The study also found that students who are structured in their thinking and more precise (left-brained preferences) were more satisfied with the simulation than the students who are intuitive, nonlinear and experientially oriented (right-brained preferences). Perhaps the largest educational benefit of the inorganic simulation is that students can focus on the principles of general chemistry rather than focusing on troubleshooting aspects in a wet laboratory setting. This does not mean that wet labs are unimportant as skills to conduct real experiments remain important and the use of the ChemLab simulation in conjunction with wet labs provides the best learning experience. Students like the fact that they can repeat, so can use trial and error, in a safe, convenient and flexible manner that is not practical in a wet lab.

2.1.4 **Virtual Laboratory for Physics**

Ding and Fang (2009) investigated the effectiveness of a simulation laboratory on teaching and learning of physics concepts. Students usually have a set of opinions about physical phenomena derived from their everyday experience. However, these assumptions are normally incorrect and create misconceptions. To address these misconceptions, the authors aimed to produce an alternative constructivist teaching approach that could facilitate active engagement in learning and effectively allow students to apply physics concepts and principles in various situations. The authors created a simulation laboratory using C++ Builder. The laboratory was able to simulate the diffraction and reflection of light and allowed students to configure parameters for experiments and observe the rules of physics. In addition, its powerful display environment enhances an understanding of physical concepts and analysis of scientific knowledge. Hence, it promotes a better understanding of physical models.

In this study (Ding and Fang, 2009), 64 college students at Hubei University were selected to undertake the experiment. Data were collected through interviews with 6 students in the experimental group and 32 anonymous written testimonies of the same (control) group. The result of the study shows that this method indeed improved research skills and the capacity for exploration in the experimental group. The findings suggest that simulation laboratories have potential to improve teaching and learning of physical processes and encourage students in physics to engage in exploratory learning.

2.1.5 **VISIR Remote Labs in Engineering**

Marques et al. (2014) present a study on the implementation of Virtual Instrument Systems In Reality (VISIR) remote labs in a range of engineering courses; in particular they focus on the impact of such labs on achieving learning outcomes. A VISIR (Tawfik et al., 2013) developed by the Blekinge Institute of Technology in Sweden provides a flexible environment to construct and test different electrical and electronic circuits. It has been widely used to create remote laboratories. The authors examined the VISIR implementations against various aspects, such as achievement of learning objectives, implementation and user access, student academic results and teacher and student perceptions. The authors used a multi-case research study methodology, with each case representing a different course where VISIR was integrated. The study was carried out during two successive semesters in 2010 and 2011 covering seven courses, one course in the first semester and the remaining six courses in the second semester. These courses were drawn from various engineering degrees representing various student educational backgrounds. Two dimensions were used to analyse the results: a didactical approach and results obtained. The former looked into learning outcomes, integration design, teacher supervision and implementation problems while the latter looked into the actual use of VISIR, teacher and student' perceptions of usefulness and student learning achievements. The paper addresses the research question *Is VISIR always useful, no matter how it is integrated into a course? Or are there certain conditions/characteristics that maximize student learning?* through analysis of a multi-case research study. The authors found that instructional support for VISIR is crucial. VISIR can always be useful for some students (those more motivated or with a learning style leaning more towards to this kind of tool), but it can be reinforced when a particular condition is put in place - that students have a hands-on practice session before they start to use VISIR. VISIR is more useful in introductory courses and in terms of learning outcomes, VISIR labs increase student confidence in labs, with students who use VISIR generally having improved lab reports, improved lab examination results, higher grade distributions, statistically significant correlations between the number of times VISIR was accessed and lab grade, and higher learning gains. VISIR is a good choice when combined with a hands-on lab as it diversifies students' methods of learning and enables them to practice freely, increasing their confidence in the lab and enhancing their lab skills.

2.1.6 Virtual Laboratory Project in Science and Engineering

The Virtual and Accessible Laboratories Universalizing Education (VALUE) project (Achuthan et al., 2011) was initiated by Amrita University in support of the National Mission on Education through Information and Communication Technology Scheme in India. Amrita University's goal was to provide college and university students throughout India with access to virtual laboratories, allowing them to experiment, discover and have learning experiences similar to colleagues who had access to physical laboratories. The virtual experiments were all developed using the same coordinated processes. Firstly, an experiment was selected based on the All India Council for Technical Education and the University Grants Commission model curricula. Next, virtual lab research assistants reacquainted themselves with the experiment. They then worked with one of the Amrita University e-learning teams to create storyboards, provide suggestions for the experiment design, and test and evaluate interim versions. The virtual lab research assistants also collected reference materials and assisted the subject matter faculty members with the development of the theory and procedure discussions, assignments and self-evaluation quizzes. Amrita University's e-learning team, the Center for Research in Advanced Technologies for Education (CREATE @ Amrita) was responsible for creating the virtual lab interactive animations and simulations. After the experiments were completed, they underwent extensive beta testing in the hands of the virtual lab research assistants and were reviewed by the faculty involved. Each experiment had a standard format with seven components: Theory, Procedure, Self-Evaluation, Simulator, Assignment, Reference and Feedback. By 2011, ninety-eight experiments had been completed in physical sciences, chemical sciences and biotechnology. All are available online (http://vlab.amrita.edu/). A workshop was conducted to disseminate the use of these virtual labs among faculties across a number of higher education institutions. At the end of each workshop, exit surveys were given. The survey contained several questions regarding the perceived effectiveness of the virtual labs. The survey results indicated that the faculties felt that virtual labs could be an effective tool with more than 94% of the responses to be either good, very good or excellent, with over half of those respondents responding with excellent or very good. In response to the question “Do you feel such a virtual lab site aids/assists you in your job as a teacher?” 97% of the respondents answered yes. Overall VALUE virtual labs showed that incorporated guided labs with theory, procedure and static and dynamic simulations, as well as in some cases remote labs, self-assessment, assignment, references and feedback in a single portal, is easy for students and faculty to use and allows for self-directed experimentation.

2.1.7 Online Labs for STEM Education

de Jong, Sotiriou, and Gillet (2014) created the Go-Lab project. The main aim of the Go-Lab project is to provide school children with a motivating environment to acquire scientific inquiry skills and undertake engaging guided science experimentation. To meet this objective, Go-Lab provided a platform that incorporates remote and virtual labs as well as dataset analysis tools (collectively called online labs). In Go-Lab, the central pedagogical approach is inquiry learning. In inquiry learning, students are not directly offered information but rather are guided through an investigation process whereby a research question/hypothesis is derived, investigations are conducted via experimentation, results are observed and conclusions are made. This approach has proven to be more effective than other lab approaches using “cookbook” procedures or discovery approaches. Teachers are one of the main stakeholders in the project. Go-Lab provides teachers with authoring facilities to create and share their own Inquiry Learning Spaces. The Go-Lab portal (www.golabz.eu) provides many tools and facilities for creating and sharing inquiry-based labs in science and technology fields. This project has developed a number of labs and expects to pilot across 1000 schools within Europe in the future.

2.1.8 VPLab: Virtual Programming Laboratory

Prieto-Blazquez, Herrera-Joancomarti and Guerrero-Roldán (2009) mainly focus on designing the Virtual Programming Laboratory (VPLab). It identifies several critical components required to ensure the success of VPLab in enhancing student knowledge and skills in computer programming language. The critical components are categorised into three types of resources: technological resources; pedagogic and strategic resources; and academic staff resources. The technological resources focus on the technology artefacts that can be used to simulate virtual laboratories and assess student knowledge and understanding. These technology artefacts are the Virtual Communication Environment (VCE), the SIMulator (SIM), the REMote Laboratory (REM), the

Virtual Machine (VM), and the Automatic Assessment Tool (AAT). The pedagogic and strategic resources focus on the theory and the pedagogical approach and methodology that allow the understanding and/or creation of knowledge. The pedagogic and strategic resources used in VPLab are learning methodology, supporting documentation and other materials, and evaluation. The academic staff resources focus on the teachers or members of academic staff who help students reach their individual objectives and personalise learning by giving attention to each student. The authors also conducted a questionnaire type survey across 284 participants who were distance learning students to evaluate the relevance of the proposed structure and their critical components. The survey is divided into two parts where the first part obtains a profile of survey respondents and the second part analyses the significance of each critical component. The components that score highly in the survey are:

- The teacher component of academic staff resources;
- The evaluation and learning methodology of pedagogic and strategic resources; and
- The VCE, SIM, VM and AAT of the technological resources.

An interesting finding in the study was that although technological resources were rated highly by the students, the distance learning students appeared to place more importance on the pedagogical and human factors.

2.1.9 **Virtual Computing Lab**

Alharbi, Athauda and Simon (2012) provided a virtual computer lab for students in an IT undergraduate course. A virtual computer was provided to each student as a pre-configured Virtual Machine (VM) that was hosted on a private cloud environment. Students accessed a virtualised desktop that had the look and feel of accessing a local machine. A pilot study was conducted to evaluate the feedback of students about the virtual computing lab in a course consisting of laboratory-based individual tutorials, and assignments which included group work. The authors conducted a survey on 33 students to evaluate their satisfaction and experience. The survey was divided into four sections: assistance in learning, accessibility and ease of use; virtual labs vs physical labs; and overall experience. Students were highly positive about the flexibility, accessibility and ease-of-use of the VCLs from any location and at any time without any need to install and configure software for use in their tutorials and assignments. It was clear that students when working individually preferred to use the VCLs, however, when they needed to meet group members, have tutor interactions or for social purposes, they preferred to come to physical labs. Having access to virtual computing labs while also having regular physical labs for tutor and group interactions provided the best learning experience in this study. Another large scale virtual computing lab deployments mentioned in the paper was Schaffer et al. (2009).

2.1.10 **NVBLab: The Virtual Collaborative Networking Lab**

Hwang, Kongcharoen and Ghinea (2014) discuss an experiment where students in a networking class work on a number of ICT network-based assignments from basic to advanced labs using two platforms. The control group use VMs installed on their PC to do assignments while the experimental group of students are given access to guest Operating Systems (OSs) with a web-based GUI interface featuring a web terminal, a command search window, laboratory materials and chat windows – group and individual. The platform is called the Network Virtualization - Based Laboratory (NVBLab).

The experiment was conducted during the summer semester (2013) at Kasetsart University with a total of 35 students, the control group having 15 students and with 20 students in the experimental group. The experiment had four steps: 1) Lab orientation and pre-test 1; 2) Experimental treatment and post-test 1 for basic labs; 3) Pre-test 2 and experimental treatment for advanced labs; and 4) Post-test 2 and a questionnaire. The basic labs were conducted individually for both experimental and control groups, while the advanced labs were conducted individually for the control group and in groups of 5 for the experimental group who had access to chat windows for collaborations which allowed for communication between group members, teaching assistants and the lecturer when doing assignments. In the advanced labs, control group conducted collaborative work and used online chat window of NVBLab following Online Collaborative Learning (OCL) (Harasim 2011) principles.

The pre-test results revealed no statistically significant difference between the experimental and control groups indicating they had similar background skills in both basic and advanced labs. In addition, post-test 1 showed no statistically significant difference between the control and experimental groups. However, there is a statistically significant difference between the results of the experimental group and those of the control group with post-test 2 showing improved student learning achievements among the experimental group. The paper also evaluated the command count and chat message count in the experimental group. It concluded that the group interaction and immediate feedback and support from other group members had increased student interest with the result that the experimental group completed more assignments and achieved higher learning outcomes (scores).

2.1.11 **Virtual Networking Lab**

Razvan, Wilson, Winckles, Cirstea and Jones (2012) proposed and implemented an architecture for a cloud-based virtual networking lab. The networking lab experiments required students to configure and test complex network scenarios using network hardware and software. Typically, such network labs are constrained by the hardware resources available in a lab. However, by creating a virtual networking lab, students are able to configure complex network scenarios using virtual networking hardware and resources. A virtual networking lab requires students to configure multiple VMs and other virtual hardware such as routers, switches, etc. The authors of the paper present an architecture for a virtual networking lab and implemented it by employing virtualization technologies such as VMWare and NetLab+. The networking lab was successfully deployed with over 900 labs and over 1700 hours of lab work used to test the described NetLab+ solution, conducted by over 260 students. The survey evaluations surpassed expectations as almost all students believed that their study experience was enhanced by the proposed virtual infrastructure. Some suggestions for improvement included providing better mobile access to the virtual labs as well as access to physical networking hardware. As all labs were conducted in a virtual environment, students still lacked the experience of working with real physical hardware devices.

Related observations from the literature review are discussed below.

2.2 **Observations and Findings**

A number of observations and findings from the above review are discussed below.

- *Complementary nature to physical labs*: With all the advantages that remote and virtual labs provide, it has been observed that they do not still replace physical/hands-on labs. In many disciplines, such as chemistry and biology, wet lab training is an essential part of learning to conduct experiments which cannot be obtained by virtual and remote labs alone. However, these different types of labs are complementary in nature and may be combined in ways that provide a rich and engaging learning experience for the learners. For instance, in the virtual chemistry lab (Woodfield et al., 2005), the authors clearly state the importance of using wet labs: "*We believe that learning the how is vitally important, which is why we believe Virtual ChemLab is best used with a 'wet' laboratory*". In Marques et al. (2014), the authors concluded in their multi-case study that a VISIR lab was a good choice when combined with a hands-on lab. In Razvan et al. (2012), the authors found that when using a virtual networking lab, lack of experience with real hardware was one of the suggestions for improvement.

- *Different types of labs and technologies developed for different contexts:* In addition, another observation is that different types of labs have been developed for different contexts (i.e., discipline, learning outcome, lab experiment objective, type of experiment, etc.). For example, Chaos et al. (2013) developed both virtual and remote laboratories to teach students to control robots in virtual and remote settings. In Hossain et al. (2015), the authors developed a remote biology laboratory to create experiments on P. polycephalum. Woodfield et al. (2005) provided a virtual environment allowing students to simulate chemistry experiments. In the study carried out by Prieto-Blazquez et al. (2009), students were provided with a set of tools and an environment to learn programming. Similarly, Razvan et al. (2012) provided students with a virtual network lab that allowed students to configure and test networks. It is evident that we cannot generalise the remote and virtual robotics lab developed in Chaos et al. (2013) for students to do biology experiments on P. polycephalum. Additionally, even if we consider a single discipline such as biology, the remote lab for P. polycephalum discussed in Hossain et al. (2015) may not be relevant for other types of biology experiments.

- *Different types of labs may cater to different learner personalities and preferences*: An interesting finding from Woodfield et al. (2005) was that personality profiles and learning preferences had an impact on opinion, performance and exploratory use of Virtual ChemLab. Woodfield et al. (2005) found that, to within a 99.9% confidence interval, the higher someone's cerebral score (creative learner), the less help they feel they need in using the inorganic simulation while the higher someone's limbic score (structured learner), the more help they need. Also, structured learners, with a confidence interval of 95%, report that they spent a smaller percentage of time exploring or conducting what-if experiments in Virtual ChemLab. Woodfield et al. (2005) show that structured learners have a much harder time experimenting in Virtual ChemLab, and also indicate that these students may have difficulty learning in any loosely structured learning environment, not because they are incapable, but because of their individual learning preference.

According to the literature, there have been many technologies used and tools developed for remote and virtual labs. For example, the above review came across a range of innovations and technologies available: Easy Java Simulations and LabView in Chaos et al. (2013); virtualization technologies such as VMWare in Alharbi et al. (2012); VISIR in Marques et al. (2014); and biotic processing units (BPUs) in Hossain et al. (2015). Some of the literature also focuses on technology that can be used to develop virtual and remote laboratories. Table 2.1 summarises the literature review on virtual and remote laboratory implementations.

Table 2.1: Virtual and Remote Lab Implementations in Different Disciplines

Subject	Paper	Sample Size	Lab Technology	Description
Engineering	Chaos et al. (2013)	n = 30	LabVIEW MATLAB Easy Java Simulations	Both virtual and remote laboratories are effectively used to provide a flexible, safe, easily accessible environment for students to develop their skills prior to applying them to a real robot using remote laboratories.
	Marques et al. (2014)	n = 1272	VISIR	VISIR remote labs are popularly used in engineering. This study aims to find what factors impact integration of VISIR labs to courses. It found that instructional support for VISIR is crucial.
Sciences	Hossain et al. (2015) – Biology	n = 4	BPU	This remote biology laboratory provided convenience by allowing students to remain engaged with their experiments from any place at any time. Also, a log provided data that can be used in learning analytics to provide useful insights.
	Ding & Fang (2009) - Physics	n = 64	C++ Builder	Students were provided with a simulation environment to explore topics in diffraction and reflection of light. Both research skills and exploratory learning are encouraged.
	Woodfield et al. (2005) - Chemistry	n = 1400	Java	A virtual chemistry lab (ChemLab) provides students the freedom to conduct chemistry experiments in an exploratory manner which is not practically possible in a physical lab. The authors observed that creative learners are more likely to explore and experiment in ChemLab simulations than structured learners because of their individual learning preferences.
Information Technology (IT)	Prieto-Blazquez et al. (2009)	n = 284	VPLab	VPLab proposed a general structure on virtual labs for undergraduate courses in computer programming language. It identifies several critical components required and evaluates student views on different

Subject	Paper	Sample Size	Lab Technology	Description
				resources. An interesting finding is that teacher interactions are highly rated by distance learners along with technology artefacts.
	Hwang et al. (2014)	n = 35	Network Virtualization - Based Lab NVBLab	A networking class work on a number of network-based assignments in basic and advanced labs with individual and group work. The group-based advanced labs with communication between tutors and peers had a statistically significant impact on learning outcomes.
	Razvan et al. (2012)	n = 260	VMWare/ NetLab+	Use of cloud computing in network course labs to implement and test complex networking and security scenarios. The students believe that their study experience is enhanced by the proposed virtual infrastructure.
	Alharbi et al. (2012)	n = 33	VMWare	A private cloud and VMWare virtualization platform id used to design VMs that can emulate computer labs which are accessible from anywhere. The aim of the experiments was to analyse student satisfaction with VCLs.
STEM	Achuthan et al. (2011)	Not stated	Web technologies	Provide labs to experiment in virtual and remote lab settings provided through a web interface for students who are unable to access physical labs. Each experiment is developed with Theory, Procedure, Self-Evaluation, Simulator, Assignment, Reference and Feedback to provide the pedagogical framework and context for each experiment.
	de Jong et al. (2014)	n=0	Web technologies	The Go-Lab project provides an engaging and motivating environment for students to experiment through online labs using an inquiry-based learning pedagogical approach. The Go-Lab aims to trial in over 1000 schools across Europe in the near future.

2.2.1 Advantages of Technology-enhanced Labs

A number of the benefits of using technology-enhanced labs are summarised below:

- *Accessibility and availability:* A major advantage of both remote and virtual laboratories over hands-on labs are their accessibility from remote locations and availability at any time. Remote labs provide learners with remote access to physical laboratories. For instance, in Hossain et al. (2015) students are able to log in 24/7 from any device and observe their experiment. Students using virtual ChemLab (Woodfield et al., 2005) can work on simulations any time from any device connected to the browser. Marques et al. (2014) show how VISIR labs allow students to gain confidence by letting them practice their lab experiences outside of the physical laboratory, eventually achieving higher scores and increasing student engagement. Also, virtual laboratories and remote laboratories may be the only option for laboratory experience available for distance learning students. The virtual and remote robotic laboratories in Chaos et al. (2013) are used by distance learning students at UNED and UCM. Finally, remote laboratories allow sharing of valuable lab resources among institutions (iLab - Harward et al. (2008), LabShare project - Mujkanovic et al. (2011); Seiler, (2013)).

- *Flexibility:* Learners in virtual laboratories have the freedom to explore, repeat experiments and learn at their own pace which is not practically possible in a physical lab or even in a remote lab. Students are able to access and experiment in a virtual lab at their own convenience at any time from any location without the need to schedule or be restricted to a timetabled slot. The freedom to explore without restrictions or consequences is rarely afforded in physical labs. For instance, in ChemLab (Woodfield et al., 2005), students have the freedom to explore a vast range of experiment simulations with 26 cations that can be combined in any order or combination and 11 reagents that can be added in any order. Students can reset and repeat experiments as they wish and learn at their own pace.

- *Cost-effectiveness:* virtual and remote labs are cost-effective when compared with physical labs. This is one of the greatest advantages for developing remote labs as expensive equipment can be shared by many learners remotely (Harward et al., 2008). For some types of laboratories, the running cost for virtual labs is much lower as simulations are conducted in virtual environments. For example, a virtual chemistry lab does not use actual chemical resources.

- *Safety:* Virtual and remote laboratories provide a safe environment for learners to conduct experiments. For instance, in a chemistry simulation environment such as ChemLab (Woodfield et al., 2005), learners are able to create experiments without the worry of chemical explosions or using hazardous materials. Another example is that students conducting biology experiments in a remote biology lab do not need to be concerned with safety issues (Hossain et al., 2015).

- *Newer opportunities for learning:* Virtual environments enable new opportunities to perform simulations and experimentations that sometimes are not possible to be performed in physical or even remote labs. For instance, in the virtual network lab (Razvan et al., 2012), students have the opportunity to configure complex network scenarios and hardware devices which are difficult to source in a physical lab environment. In Woodfield et al. (2005) and Ding and Fang (2009), it is clearly shown that exploratory investigation which is not practical in a physical lab is available to students in virtual labs.

In the next section, we focus on analysis of the literature review with a view to answer the research question posed: *How do we design a lab environment to take advantage of technology for effective learning?*

2.2.2 Revisiting the Research Question

The main aim of practical activities in labs is to achieve learning goals. Technology advances have enabled lab environment designs to overcome limitations of physical labs as well as providing new opportunities for learning. Answering the research question posed in Chapter 1 - *How do we design lab environments to take advantage of technology for effective learning?* requires further analysis. This section aims to addresses this broad research question based on the analysis of the literature above.

Technology-enhanced labs can create learning environments that focus on the topic or pedagogical objective of the experiment while abstracting away complexities that may occur in a real-world experiment and also scaffold and guide the learner to achieve learning goals. This is clearly shown in Chaos et al. (2013). In this remote laboratory for robotics, students are first given a virtual environment whereby they manually operate a robot in a virtual environment. The objective is to introduce students to the control interface of the robot and to build their interest by interacting with it. In the next phase, students write a program to control the robot based on sensor inputs and mapping goals in order to develop their knowledge and skills in developing algorithms to manipulate the robot. Finally, when their expertise and confidence has been developed, students are exposed to a remote laboratory, which has real robots in action. By this time, students have already gained the expertise, knowledge and skill to face the intricacies and complexities of the real world situation. Had students been first exposed to the remote/hands-on lab, these complexities could have been distracting, complicating or even overwhelming for students, which potentially could lead to a failure in achieving the learning outcomes. In this instance, by effectively incorporating virtual and remote laboratories using an appropriate pedagogical structure, it allows students to perform experiments with a focus on the learning objective at hand while abstracting the real-world complexities. The labs are designed to scaffold the learner to develop student expertise to achieve their learning goals. Implicitly, these labs apply scaffolding theory and zone of proximal development (Lev Vygotsky, 1978) where students are guided to higher level tasks by first completing simpler tasks prior to attempting more complex tasks (from simulations to real-world manipulation of robots in remote labs).

Abstracting complexities can allow the learner to reach learning goals, especially novice learners. This is observed in the remote biology lab in Hossain et al. (2015) and the virtual chemistry lab discussed in Woodfield et al. (2005). Hossain et al. (2015) discussed how a non-biology student with no wet lab training is able to conduct biology experiments using a remote lab. This allows the student to focus on the P. polycephalum experiment by abstracting away from the wet lab training which is not the objective of the lab experiment. This sentiment is re-iterated by Woodfield et al. (2005:1674):

> *"…the largest educational benefit of the inorganic simulation is that students can focus on the principles of general chemistry, rather than focusing on troubleshooting aspects in a laboratory setting. These troubleshooting aspects imply more than just laboratory technique. Laboratory technique focuses on how to do something, whereas the troubleshooting aspects focus more on why something does not happen the way it should. One of the reasons beginning chemistry students feel overwhelmed in their first laboratory class is because, we believe, they are consumed by the details of lab technique and the troubleshooting aspects in the laboratory."*

Other studies have also used PLTs in their design. In Hwang et al. (2014), students who collaborated in NVBLab achieved higher learning outcomes in comparison to the control group. The authors designed tools and laboratory activities for collaborative work based on Online Collaborative Learning (OCL) theory (Harasim, 2011), resulting in improved learning outcomes.

Ding and Fang (2009) combined constructivist teaching approaches and a simulated lab environment where students are able to explore diffraction and reflection of light by configuring parameters in experiments in order to learn physics concepts. The Virtual ChemLab (Woodfield et al., 2005) also allowed students to explore in an unrestricted simulation environment where they can create experiments, test and view their results.

Exploratory learning (Njoo and de Jong, 1993) was enabled through simulated lab environments. In de Jong et al. (2014), students are guided and supported to learn by following an inquiry-based learning approach. Students are not directly offered information but rather taken through a guided investigation process whereby a research question/hypothesis is derived, investigations are conducted via experimentation using remote and simulated labs, results are observed and conclusions are made.

In the VALUE project (Achuthan et al., 2011), rather than providing a simulation or virtual experiment environment by itself, each experiment is guided by Theory, Procedure, Self-Evaluation, Simulator, Assignment and References for further information. This approach combines each experiment with background context and learning materials taking a holistic approach to the design of virtual labs and lab activities. Prieto-Blazquez et al. (2009) argue that rather than simply providing a virtual lab, a number of critical components, including technological resources, pedagogic and strategic resources, and academic staff resources should be developed to enhance student knowledge and skills in programming. They conclude with students rating pedagogical and human factors highly in addition to the technological resources in VPLab (Prieto-Blazquez et al., 2009). It is clear from the above analysis that in order to achieve learning goals the above studies did not present the technology-enhanced labs by themselves but provided supporting tools and resources for learning and followed sound PLTs (e.g., inquiry-based learning) in their design.

This analysis provides us with evidence to answer our research question - "*How do we design lab environments to take advantage of technology for effective learning*?". It reveals that the design of such lab environments for effective learning needs to integrate technology artefacts (such as virtual and remote labs), leveraging their benefits while also providing the necessary support, tools and resources for effective learning guided by sound PLTs. Thus, this thesis postulates the following hypothesis to answer the above research question:

<u>Hypothesis</u>: *Design of technology-enhanced lab environments taking a holistic view of learning incorporating learning context, curriculum design, lab activities, assessments, resources and technology artefacts based on sound pedagogical and learning principles and theories have a higher potential for effective learning.*

The design of a technology-enhanced lab environment that includes curriculum design, lab activities, support tools, resources and technology artefacts based on sound PLTs is referred to as a *Technology-enhanced Pedagogical Framework* (TePF) for lab environments in this thesis. A TePF for a lab environment needs to be implemented in a particular learning context. Thus, this thesis implements and evaluates a TePF for a lab environment in a system level course in computing education to validate the above hypothesis. The next section discusses related work in technology-enhanced labs in system level courses in computing.

2.3 **Technology-enhanced Labs in System Level Courses in Computing**

Similar to other disciplines, lab work is critical for student learning in computing and information technology fields. In particular, system level courses in computing education, such as information security, networking, system administration and operating systems, use hands-on activities that require students to configure hardware and system level software (operating systems, firewalls, security settings, etc.) with administrative privileges in complex networked environments. Such laboratory activities require specialised physical labs with equipment isolated from other campus networks. This can be prohibitive, both financially and practically, and this approach inherits other constraints of physical labs such as restricted access.

Virtualization and related cloud computing technologies have provided the means to implement virtual computing labs that enable students to create, configure and deploy virtual IT infrastructure (e.g., VMs, switches, routers, etc.) and conduct experiments without the need to have specialised physical labs for system level courses in computing. In the literature, a number of virtual lab implementations using virtualization s have been researched. The following sections presented a discussion of virtualization technologies and virtual computing labs in general followed by a review of related work.

2.3.1 **Virtualization Technologies and Virtual Computing Labs**

Virtualization technologies have provided capabilities to virtualise hardware, software and network infrastructure. These technologies are fuelling cloud computing infrastructure and newer IT service delivery models. Organisations can now provision virtual IT infrastructure on demand hosted in centralised data centres accessible remotely via networks. The physical infrastructure can be managed within an organisation (private cloud environments) or hosted external to the organisation by third party cloud providers (public cloud).

Virtualization is a group of technologies that allows configuration of virtual infrastructure over physical resources. Thus, with virtualization technologies, we can configure multiple virtual machines (VMs) with configured hardware (such as disk space, RAM, CPU, etc.) to run on a single piece of physical hardware (which is called the host). Similarly, we can configure complex network resources (e.g. virtual switches, virtual routers, storage, etc.), in this virtual environment. These capabilities have been exploited and revolutionised the delivery and deployment of IT services today – generally known as cloud computing. IT organisations (such as Google, Amazon, Microsoft and others) have used these technologies in their data centres to virtualise and deliver IT resources as IT services to organisations and communities. These service providers are commonly known as public cloud service providers. Nowadays, a person or an organisation can rent computing resources (e.g. servers, storage, computing power, etc.) through the Internet from these cloud providers. Additionally, internal IT departments of organisations have taken advantage of these technologiesand provide IT resources to their organisations which are generally known as private cloud environments. Cloud service providers offer different levels of IT services. These services are broadly classified as: Infrastructure as a Service (IaaS); Platform as a Service (PaaS); and Software as a Service (SaaS). In IaaS, IT infrastructure resources such as storage and CPU are provided. Examples of such providers are Amazon Web Services (AWS) and Microsoft Azure. In PaaS, developers are provided with an environment to develop and deploy web applications in cloud environments. An example of this is Google’s App Engine. In SaaS, rather than installing software on local machines, users rent IT applications from cloud providers. Examples include Google Docs (from Google), Office 365 (from Microsoft) and other offerings.

At the heart of virtualization is the hypervisor technology. This is a software layer that enables the deployment of different re-configurable virtual resources (storage, memory, CPUs, etc.) on physical hardware. There are two main types of hypervisors – Type 1 are bare-metal hypervisors and Type 2 are embedded hypervisors. In the Type 1 (bare metal) hypervisor, the hypervisor runs on the hardware and provides a virtualization platform. In Type 2, the host’s operating system runs on the hardware while the hypervisors run as an application on the host Operating System allowing a virtualization platform. Figure 2.1 provides an overview of Type 1 and Type 2 hypervisors. Examples of Type 1 hypervisors include Hyper-V (from Microsoft) and ESXi (from VMWare). Examples of Type 2 hypervisors are VMWare Workstation/Fusion, VirtualBox and others.

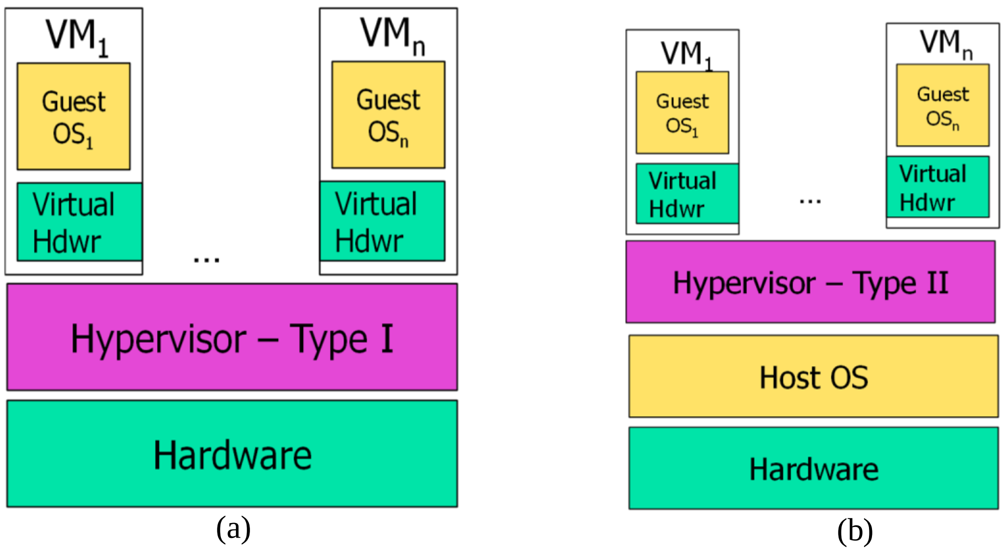


Figure 2.1 (a) Type 1 hypervisor (b) Type 2 hypervisor

Virtualization technologies and services provide opportunities to configure complex IT infrastructure and access this from anywhere using the Internet. In the literature, a number of implementations of deploying general computing labs using virtualization technologies can be seen (Averitt et al., 2007; Schaffer et al., 2009; Alharbi et al., 2012). In virtual computing labs, students log into remotely hosted VMs which have all necessary software configured for their learning.

It is interesting to note that virtual computing labs which provide access to a remote desktop have little distinction between remote labs and virtual labs as discussed in Chapter 1. The virtual computing lab can be classified both as a remote lab or a virtual lab as per the definition. The actual VM is hosted on a remote server and thus can be classified as a remote lab. Likewise, it can be classified as a virtual lab as the VM is actually running on a simulated hardware layer so, in essence, is a virtual simulated environment. It can be configured so that the users of a virtual computing labs may look and feel exactly as if the VM is run as a local machine so that there is little distinction between a physical computer lab machine and a VM. Thus, virtualization technologies allow the centralisation of management of computing resources to provide virtual computing labs which combine the advantages of remote and virtual labs (i.e., access to the computing lab from anywhere at any time while also having the look and feel of a local machine).

The virtual computing labs discussed above use a centralised approach to deploying labs whereby VMs are hosted and managed centrally and students connect to them remotely. This approach is also called centralised labs. Another deployment approach is decentralised deployment of labs. In the decentralised approach, VMs are configured and hosted on each student's computer and not hosted centrally by the university/organisation. Each student installs a hypervisor and hosts the VM on his or her computer. This provides more flexibility to the student as s/he can configure the VM as needed, however they do require technical know-how to install and configure VMs and run hypervisors, and it also takes up resources on the host VM on student computers.

Virtual computing labs are typically implemented to access a single VM for students to meet their learning needs. System level courses in computing, such as networking and system administration, information security, require access to multiple networked resources such as multiple VMs, switches, routers, in complex networked environments to meet the students' learning needs. This requires more complex IT infrastructure deployments than standard desktop environments. The following section provides a review of the implementation of virtual laboratories for system level courses in computing.

2.3.2 **Virtual Labs for System Level Courses in Computing**

This section reviews implementations of virtual labs using virtualization technologies in the literature for system level courses in computing. Table 2.2 provides a list of related work on virtual labs in system level courses in computing that use virtualization technologies. The table outlines the author(s) of study, the subject area (such as computer networks, operating systems, system administration and/or information security), the type of lab (virtual, remote or physical), a description of the study and the results, whether any technology tools were developed for teaching and learning, the virtualization platform used for the virtual lab, whether the study had an evaluation and if any PLTs were explicitly used in the study.

Table 2.2: Virtual Labs (based on virtualization technologies) for System Level Courses in Computing

Paper Author and Year	Subject	Type of Lab	Description	Tech. Tools	Virtualization Platform	Evaluation	Pedagogy Theories
Anisetti et al., 2007	Computer Networks and Information Security	Virtual	The paper describes Open Virtual Lab (OVL) - a virtual lab for networking and information security that uses a para-virtualization approach and an open source Xen platform. To evaluate, two case studies were conducted. In both case studies, students unanimously reported their satisfaction with the OVL environment. In the second case study, results show online students exposed to OVL achieved better results than those attending the traditional laboratory course. In the second case study, on-campus students used physical labs while online students used OVL.	No	Xen	Yes	None
Border, 2007	Computer Networks, System Admin and Information Security	Virtual	The author develops the Remote Laboratory Emulation System (RLES) to facilitate access to the virtual laboratory environment through the Web for both distance and local students at Rochester Institute of Technology. RLES implements four technologies: Microsoft Windows Terminal Services, Microsoft Remote Desktop Communications, Microsoft Remote Assistance and VMWare Workstation to deliver virtual labs. Students use this environment to complete labs in Principles of System Administration course in Winter quarter 2005.	No	VMWare Workstation	No	None
Ramalingam, 2007	Computer Networks, System Admin and Information Security	Virtual	This paper presents a decentralised lab environment where a Virtual PC platform is used to create VMs for different courses and store them in lab PCs allowing students to work on their images with administrative privileges and to be able to save the state throughout the term. The limitation is that the VM images are stored on the client lab machine and students need to attend the lab to access the client machine that hosts their VMs.	No	Virtual PC	No	None
Wannous, et al., 2007	Computer Networks	Virtual	This paper describes the design of a virtual lab for networking. It is a hands-on lab using the Xen virtualization platform and VNC Server for remote access.	No	Xen	No	None
Duignan & Hall, 2008	Operating Systems	Virtual	In this paper, the authors consider a constructivist approach to teaching operating systems. A number of pedagogy theories (such as activity theory, active learning, sociality, collaboration, etc.) are considered. A group project spanning the entire term is provided whereby the students work on the project throughout the term using virtualization to meet the course objectives. Overall the students rated the labs higher, and the use of virtualization technologies provided a lab environment that contributed to a positive student learning experience.	No	VMWare	Yes	Constructivist approach
Hu & Wang, 2008	Information Security	Virtual	In this paper, the authors present the xSec lab environment which uses the Xen platform and both Linux and Windows VMs to teach network security. A number of labs in the xSec	No	Xen	No	None

Paper Author and Year	Subject	Type of Lab	Description	Tech. Tools	Virtualization Platform	Evaluation	Pedagogy Theories
			course project involve students extending/modifying the source code of Linux to enhance security features.				
Gaspar et al., 2008	System oriented courses	Virtual	The paper discusses three projects that consider open-source virtualization technologies and how they can be applied to teaching different system level courses in computing education: 1) XenWorlds which provides a free modifiable virtualization platform based on Xen (hypervisor for Linux); 2) V-Net Lab which is developed for cybersecurity courses that require students to be given administrative access to entire networks. V-Net can provide hands-on activities for the student to develop and configure defensive technologies such as firewalls and intrusion detection systems and attack these defences using live exploits and malware including viruses and worms; and 3) The SOFTICE project (Scalable, Open source, Fully Transparent and Inexpensive Clustering for Education) aimed at leveraging open-source virtualization and clustering technologies to support innovative pedagogies for system level courses such as operating systems and networking.	No	Xen	No	None
Li & Mohammed, 2008	Information Security	Virtual	This study describes the use of decentralised labs in teaching an intrusion detection course. In the decentralised labs, student machines use VMs deployed on their own computers to conduct labs. VMs, related packages and trace files are provided for students to conduct lab activities. Two iterations of the course in Fall 2006 and Fall 2007 were delivered and evaluated with both on-campus and distance education students. Students acknowledge the usefulness of the virtual labs to understand lecture topics and gave positive feedback. Decentralised labs had advantages over centralised labs and could be used as a complement to centralised labs in system level courses.	No	VMware	Yes	None
Li, 2009	Information Security	Virtual	This paper describes the use of decentralised labs to teach intrusion detection courses. The decentralised labs use student machines to deploy VMs, packages, trace files, etc. The lab activities are conducted on the student machines, decreasing the load for resources on the institution's centralised labs. The intrusion detection course was delivered and evaluated 3 times over 3 years with different virtualization platforms. The platforms were VMWare Player (2006), VMWare Workstation (2007) and VirtualBox (2008). The student experience was positive in all years. Usability was similar between platforms. Students felt that VMWare used more resources than VirtualBox. Also, in 2008, students were provided an opportunity to use the centralised VCL for 2 bonus lab projects. Most students used the decentralised lab for the project work. No clear correlation was found between the lab grade averages and the virtualization options (VirtualBox vs VMWare) used by students.	No	VMWare VirtualBox	Yes	None

Paper Author and Year	Subject	Type of Lab	Description	Tech. Tools	Virtualization Platform	Evaluation	Pedagogy Theories
Li, Toderick & Lunsford, 2009	Computer Networks, Information Security	Virtual	This paper describes using VCL (Averitt et al, 2007) to provide centralised labs for system level courses at East Carolina University. The VCL was used to provide centralised labs for 3 courses (2 information security and 1 networking course). Evaluation of the centralised labs was positive, however only a small percentage of students preferred to use the centralised labs. This may be due to a lack of familiarity given that most labs were conducted using decentralised labs while the VCL was provided as an option. Centralised and decentralised labs have different strengths and can be used to complement each other.	No	VMWare, VirtualBox	Yes	None
Stewart, Humphries & Andel, 2009	Computer Networks, System Admin and Information Security	Virtual	This paper describes an architecture to deploy sandboxed decentralised virtual labs for students (with the constrained memory requirements of student machines) in networking, system administration and information security courses. The use of open-source software platforms and packages (such as Linux kernel with OpenVZ, libvirt, etc.) and a centralised image library for instructors to deploy images for lab activities are discussed.	No	Linux kernel with libvirt, OpenVZ or QEMU/ KVM, or VMWare	No	None
Li & Toderick, 2010	Networking and System Admin	Virtual	This paper describes and implements different cloud in cloud architectures (i.e. virtual data centres). Three different architectures to create and deploy virtual data centres useful for teaching and research purposes are described. Then the implementation of these architectures using different virtualization platforms is described. A VCL (Averitt et al., 2007; Dreher et al., 2009) is used to deploy virtual data centres as system images from a library.	No	VirtualBox VMWare, ProxMox VE, OpenVZ, Xen	No	None
Wannous & Nakano, 2010	Computer Networks	Virtual	NVBLab incorporates a virtual lab-based Xen virtualization platform where students can create multiple VMs and access network resources – routers, switches, etc. VNC server and clients are used to access the VMs remotely. In addition, two new tools – Designer and Builder were developed. In Designer, students can graphically design a network to be deployed in the NVBLab environment. Once the designed network scenario is finalised, it can be deployed to the virtual lab using the Builder tool. A case study was conducted to evaluate NVBLab as a part of a computer network course. In addition to student feedback on NVBLab, pre- and post-tests were completed to discover the impact on learning. Students had positive feedback for the tools and the virtual lab with some feedback for improvements for the user interface and performance. Also, student learning had improved.	Yes – Design-er, Builder	Xen	Yes	None
Wang, Hembroff & Yedica, 2010	Information Security, Computer Networks	Virtual	This paper describes the implementation and experience of a virtual lab using VMWare platform tools including VMWare Lab Manager, vCentre, ESX and related technologies. A number of features of Lab Manager are discussed along with ways to deploy virtual labs for different requirements and scenarios in system administration and information security courses. The authors' experience, the resource implications and training needs are presented.	No	VMWare	No	None

Paper Author and Year	Subject	Type of Lab	Description	Tech. Tools	Virtualization Platform	Evaluation	Pedagogy Theories
Yan, 2011	Computer Networks	Virtual	This study presents the design of a centralised cloud-based lab environment, NLS-Cloud, where both on-campus and distance students can freely practice in a network scenario. NLS-Cloud leverages the Xen Cloud Platform (XCP) and consists of several components. A practical assignment workflow on NLS-Cloud for reference is presented and a typical assignment that can be given using the NLS-Cloud but would be difficult to conduct in a physical lab is discussed. To evaluate NLS-Cloud, two surveys were completed by both instructors and students. The feedback was encouraging and provided directions for future work.	No	Xen	Yes	None
Chan & Martin, 2012	Computer Networks	Physical and Virtual	The paper discusses the use of both physical and virtual resources to develop a network infrastructure laboratory for third year undergraduate students to conduct practical hands-on activities at La Trobe University's Bendigo Campus. The infrastructure includes both physical networking equipment and a virtualised platform. A detailed discussion of configurations for advanced network labs is presented. The virtual networking infrastructure offers a significant advantage in delivering a cost-effective, highly flexible and scalable hands-on learning experience and allows for large scale, complex and advanced networking experiments or demonstrations that would not otherwise be possible.	No	VMWare	No	None
Dinita et al., 2012	Computer Networks, Information Security	Virtual	This paper describes the architecture of a virtual lab implementation using VMWare and NetLab+ for networking and information security courses. Student feedback is highly positive with suggestions for improvement including better support for mobile access.	No	VMWare	Yes	None
Willems & Meinel, 2008; 2011; 2012	Information Security	Virtual	The Tele-Lab platform provides a comprehensive web-based training system incorporating a virtual lab for information security learning. The tutoring system provides information security learning units with information, multi-media presentations, practical exercises and assessments. The platform architecture consists of many modules to enable the dynamic deployment of VMs and complex network scenarios for practical hands-on activities. A number of practical information security hands-on activities are available on Tele-Lab (such as MITM attacks, etc.). In Willems and Meinel (2012), the authors have extended Tele-Lab to be able to provide dynamic parameterised assessments.	Yes	KVM-Qemu	No	None
Ruiz-Martinez et al., 2013	Computer Networks	Virtual	This paper provides results on the use of virtualization tools to teach basic and advanced computer network concepts through hands-on experience. The authors developed VNUML-UM - a customised Virtual Network User-Mode Linux (VNUML) distribution for the practical learning of computer networks - which is a virtual desktop infrastructure and runs multiple VMs on a single Linux host. The VNUML-UM approach is used to set up labs involved with advanced concepts such as mobility, load balancing or high availability. This virtual environment was used for three academic years (2009-2012) with successful results.	No	User–Mode Linux	Yes	None

Paper Author and Year	Subject	Type of Lab	Description	Tech. Tools	Virtualization Platform	Evaluation	Pedagogy Theories
			In particular, students who completed the practical work scored substantially more in the theoretical exam than students who had not attempted the practical work. The usefulness of the practical work based on VNUML-UM is further validated through student opinion surveys.				
Hwang, Kongcharo-en & Ghinea, 2014	Computer Networks	Virtual	In this paper, the authors evaluate the impact of collaborative learning in learning networks. An experiment is conducted whereby students are divided into control and experimental groups. The control group works individually and install VMs on their machines to conduct labs. The experimental group uses Network Virtualization -based Laboratory (NVBLab) to conduct labs (Wannuos et al., 2010). An Online Synchronous Discussion (OSD) chat feature is provided for group discussion between class members and the teacher for the experimental group. The labs are divided into basic and advanced labs. Firstly, the basic labs are conducted individually and pre- and post-tests are conducted. There is no statistically significant difference between the control and experimental groups in the basic labs. In the advanced labs, experimental group worked in groups while control group individually. There is a statistically significant difference with post-test scores of the experimental group performing better. Also, survey results confirm collaboration and the OSD helped students to complete tasks and stay engaged.	No	Xen	Yes	Online Collaborative Learning
Konak et al., 2014	Information Security	Virtual	The authors observed that using virtual labs in information security with lab activities have resulted in cook-book style instructions which do not necessarily increase student performance. To address this, the authors apply Kolb's Experiential Learning Cycle (ELC) to redesign hands-on lab activities in the information security course and evaluate student learning outcomes, challenges, engagement, competency and interest. The evaluation provides evidence of improved student interest and competency when compared to cookbook style lab activities. Also, student-to-student interaction was found to have a significant positive effect on competency development. This paper goes beyond the traditional approach of focusing only on technical design to applying pedagogy theory to redesign hands-on activities with virtual labs for improved outcomes with a comprehensive evaluation.	No	VMWare	Yes	Kolb's Experiential Learning Cycle
Xu, Huang & Tsai, 2014	Computer Networks, Information Security	Virtual	This study designs and implements V-Lab, a virtual cloud lab that utilises open-source technologies - Xen and KVM. The study uses V-Lab for teaching networking and information security labs. The labs are organised in a progressive three-phase teaching model taking students from hands-on activities aimed at gaining fundamental knowledge and skills to complex activities and working in groups to advanced topics that require students to research, build and evaluate secure systems collaboratively. The study evaluates the platform and its effectiveness in improving learning for students. The evaluation consists of: 1) a six-	No	Xen, KVM	Yes	None explicitly (implicitly the labs are organised from basic to advanced and collaborative

Paper Author and Year	Subject	Type of Lab	Description	Tech. Tools	Virtualization Platform	Evaluation	Pedagogy Theories
			factor pedagogical model for experiments (motivation, knowledge, collaboration, creativity, demonstration and feedback); 2) teaching phases (basic, intermediate and advanced experiments); 3) observations with and without V-Lab in terms of increases in the number of hands-on experiments with V-Labs, reduced hours for lab setup and configuration, and increased percentage of students finishing experiments on time; 4) improved positive feedback and better grades for students who used V-Lab compared to traditional laboratories. The evaluation clearly summarises the benefits of using V-Lab.				work is incorporated)
Salah et al., 2015	Information Security	Virtual	This study highlights and summarises several major challenges and limitations of practical cybersecurity in traditional labs. It shows how the Amazon Web Services (AWS) cloud can be used as a platform to carry out various lab exercises for local and remote students. In particular, they show how Amazon can be used to allow students to manage, monitor, analyse and configure subnets, network hosts, devices and protocols. For example, in a traditional laboratory, the network lab requires a number of network devices including routers, switches and relevant network software packages. With the existence of local and remote students taking the same course across multiple university campuses, they would need to replicate the physical setting. The cloud computing model solved most (if not all) of the problems experienced by having physical lab set ups. The cloud can provide on-demand, flexible, isolated, scalable, (virtually) unlimited and easily configurable labs. This study compares and contrasts the AWS cloud lab for teaching cybersecurity exercises. The majority of networking lab exercises were carried out effectively in the cloud with the exception of a few activities that required physical hardware. The cloud-based labs were highly educational and motivational for students. They were able to gain significant cybersecurity skills as well as additional understanding of using cloud resources and services.	No	AWS	Yes	None
Zhu, 2015	Computer Networks	Virtual	The paper aims to support hands-on network programming projects to develop Internet applications, routing algorithms, and to understand protocol layers in computer network courses using VMs hosted on a public cloud in comparison to the previous approach where students were running multiple VMs on the same computer. The Amazon Web Services (AWS) cloud platform was used to provide hands-on network programming projects and lab exercises. A survey was conducted to understand student satisfaction when using cloud-based VMs. Most students agreed that using the AWS cloud was helpful for their learning in this course and career development and were in favour of using the AWS cloud not only in this course but also in other computer science courses.	No	AWS	Yes	None

Paper Author and Year	Subject	Type of Lab	Description	Tech. Tools	Virtualization Platform	Evalu ation	Pedagogy Theories
Caminero et al., 2016	Computer Networks and other topics	Virtual	This paper describes the TUTORES system which provides VCLs for an engineering course. TUTORES uses VMWare's ESXi as the hypervisor and OpenNebula to manage the virtualization environment. A number of scripts and tools are developed to automate the request and deployment of virtual labs. TUTORES was evaluated in a computer network distance learning course. Control and experimental groups were used for the evaluation. The control group used a decentralised lab where students used their own machines to configure VMs to conduct the labs while the experimental group used VRLabs deployed by TUTORES to do lab activities. The evaluation survey considers three dimensions: perceived usefulness; perceived ease of use; and perceived interaction. TUTORES was positively viewed by students although local labs also scored well. An evaluation of teachers also was performed, and it is clearly seen that teachers prefer TUTORES over local labs. The TUTORES environment provided a centralised environment for them to view and support students. A number of future enhancements are also discussed.	No	VMWare	Yes	None
Gercek, Saleem & Stell, 2016	Computer Networks	Physical, Virtual	In this paper, the authors describe a phased approach that the MIS department of University of Houston – Clear Lake took to implement a networking lab from physical in 2005 to virtual (private cloud deployment). The challenges, pitfalls and experience of implementing a virtual network lab are discussed. The authors point out that the physical lab continued to operate while implementing the virtual lab which has advantages of remote access and scalability.	No	Not mentioned	No	None
Konak et al., 2016	Information Security	Virtual	This study examines whether collaborative hands-on activities are more effective than individual settings in a VCL. The authors consider collaborative learning principles such as Bayer's model of Collaborative-Apprenticeship Learning (Bayer, 1990) to redesign lab activities for information security which use the Collaborative Virtual Computer Laboratory (CVCLAB). To evaluate this intervention, a case study involving both individuals (IW = 45) and small groups (CW = 52) completing laboratory versions of the activity were assessed and surveyed. The findings showed that students who performed the activity in groups benefited more than students who completed the activity individually. The group students achieved a better level of learning, felt more competent, demonstrated more interest and observed a lower level of variability in the perceived learning outcomes. The authors encourage collaborative learning strategies to be considered in the design of virtual computer laboratories and hands-on activities.	No	VMWare	Yes	Bayer's model of Collaborative-Apprentice-ship Learning (Bayer, 1990)
Perez et al., 2016	Computer Networks, System Admin and	Virtual	This paper discusses NETinVM which describes a User-Mode Linux (UML) configuration nested in a single VMWare or VirtualBox VM. The configuration uses nested virtualization and provides a scenario of VMs that is applicable in many educational scenarios (on internal, DMZ and external networks). NETinVM has a small footprint that allows it to be installed	No	VMWare or VirtualBox	Yes	None

Paper Author and Year	Subject	Type of Lab	Description	Tech. Tools	Virtualization Platform	Evaluation	Pedagogy Theories
	Information Security		on student machines. It has been evaluated in a computer security course with traditional lecture-based learning and a problem-based course in security. In both instances, students ranked the course with NETinVM higher than other courses. Also, the paper discusses the use of NETinVM in an enterprise web application course and also it is also used by parties external to the university for a number of scenarios in teaching hands-on activities.				
Soceanu et al., 2017	Information Security	Virtual	This paper describes Project DECAMP which aims to provide ICT security labs for European partner universities. DECAMP builds several components to allow labs to be shared and integrated to Learning Management Systems (LMS) in partner universities for seamless access by students. The solution has components that enable integration with Moodle and the use of a single sign-on from Moodle to access courses and labs. OpenStack is used as the platform to integrate cloud computing resources from all partner universities to provide virtual labs. An OpenStack-Moodle plug-in was developed for integrating the virtual labs with the LMS. The students can now directly deploy VM images for their course work on OpenStack platforms to complete these information security labs.	No	OpenStack	No	None
Kongcharoen et al., 2017	Computer Networks	Virtual	In this paper, the authors evaluate the effective collaboration mechanism— called Synchronized Pair Configuration (SPC) —in computer network labs to explain collaborative activities, and information transformation in the team. The proposed framework consists of three main components: Pair users, SPC, and VBLab (Virtualization-based Laboratory) which is shown in their previous version (Hwang et al., 2014). First, the VBLab provide four features to support lab activities namely (1) a synchronized web terminal allows the pair to exchange driver and navigator roles immediately (2) a chat feature that allows students to have both face-to-face and online synchronous discussion (OSD) for discussing and sharing ideas (3) Command search, and (4) lab materials. Second, SPC system aimed to reduce instructor effort and enhance interaction and collaboration between paired students to help them accomplish lab assignments through one shared synchronized terminal. This proposed system is based on Distributed Cognition theory (Flor &Hutchins, 1991; Hutchins, 1990). This allows the pair works only on their monitor while they communicate with their partner through three ways: face-to-face, online discussion, or synchronized terminal. However, this protocol differs from the original distributed cognition system in which the pair works on two separate terminals using only face-to-face communication. The finding of pre-test, post-test, and homework scores were positive. Both Basic and Advanced Labs, paired students in the experimental group performed better than the control group. Also, students' perceptions using the TAM model and interviews indicate that the experimental group had high motivation to use the proposed system.	Yes	Xen	Yes	Distributed cognition theory

It can be observed that many implementations of virtual labs focus on technical designs to provide improved access and new opportunities for teaching and learning. Although technology-enhanced labs provide significant benefits to learning, the combination of a good pedagogical framework, learner support, quality content and tutor interaction are all essential components to create a learning environment where students can excel and achieve higher learning outcomes (Alkhaldi et al., 2016).

In our work (Athauda et al., 2018), we classify the implementation of virtual labs for system level courses in computing into two levels of evolution as follows: Level I: Technology innovation and evaluation; and Level II: Technology, pedagogy and evaluation.

Level I: Technology innovation and evaluation: Most studies in the literature can be categorised as Level I. At Level I, the focus of study is on the technical design and evaluation. Capabilities of technology innovations to overcome existing limitations and to provide opportunities for new learning are discussed and demonstrated. The details of the technical design are presented. Evaluation is typically conducted using a case study where the technology intervention is implemented in real class environments. Level I studies can be further categorised based on their evaluation as follows: Technical Design (TD); Technical Design and Technical Evaluation (TD and TE) and Technical Design, Technical Evaluation and Learning Impact (TD, TE and LI).

In the TD stage, studies focus on technical design aspects of technology innovations and no evaluation is presented. For instance, the study by Hu and Wang (2008) focuses on creating a lab environment for a hands-on exercise in computer security using Linux and Xen. In Li and Toderick (2010), the authors describe three architectural approaches to deploy virtual labs using virtualization technologies. In Stewart, Humphries and Andel (2009), the authors present an environment using full and operating system virtualization that can be used in networking, systems administration and cyber security education. Other studies that fall into this category include Soceanu, Vasylenko and Gradinaru (2017), Gercek, Saleem and Steel (2016) and Wannous, Nakano, Kita and Sugitani (2007).

In the TD and TE stage, studies not only discuss the technical design but also present an evaluation of the technology intervention focused on technology acceptance and user experience. Typically, the technology innovation is applied in real class environments to conduct the evaluation. The evaluation could be either focused on technology evaluation only and/or focused on the technology innovation's impact on learning. In a technology evaluation, technology acceptance and user experience are examined. Technology evaluations typically demonstrate a capacity to provide new opportunities for learning and/or overcoming limitations. For instance, in Salah, Hammoud and Zeadally (2015), the authors use a public cloud environment (Amazon EC2) to implement cybersecurity labs. The advantages and detailed technical configuration of implementing a cybersecurity lab are discussed. The authors teach a cybersecurity course using the cloud lab and evaluate the acceptance of such labs using student surveys. Other studies that fall in to this category include Prieto-Blázquez, Arnedo-Moreno and Herrera-Joancomartí (2008), Li and Mohammed (2008), Duignan and Hall (2008), Li, Toderick and Lunsford (2009), Yan (2011), Dinita, Wilson, Winckles, Cirstea and Jones (2012) and Zhu (2015).

Some studies in Level I also evaluate the impact on learning due to the technology innovation, which is classified as TD, TE and LI. Often an experiment is conducted with a pre/post-test of student learning (assessment scores and survey results) or with control and experimental groups of students where only experimental group is exposed to the technology innovation. For instance, in Wannous and Nakano (2010), a virtual network lab is created along with two tools, Designer and Builder, which allow students to design a network scenario and deploy the scenario in a virtual environment. The tool is evaluated using pre- and post-tests to evaluate the impact on learning. Also, student perspectives on the tools are evaluated with survey questions. In Ruiz-Martinez, Pereniguez-Garcia, Marin-Lopez, Ruiz-Martínez and Skarmeta-Gomez (2013), hands-on lab activities to learn advanced network concepts (such as mobility, load balancing and high availability) are provided using a VMUML-UM tool and evaluated with pre- and post-test assessment results and surveys to determine the learning impact. Other studies in this category include Anisetti et al. (2007) and Xu, Huang and Tsai (2014).

Level II: Technology, pedagogy and evaluation: It has been observed that only a few studies in literature can be classified at Level II. Level II studies explicitly use PLTs when integrating or designing technology innovations to learning environments and also designing related teaching and learning activities. The evaluations in these studies consider technology acceptance, user experience and impact on learning through these interventions. The advantage of designing technology innovations based on PLTs is that the researchers have access to formal PLTs to guide the design teaching and learning activities and technology innovations rather than using a trial-and-error approach. Also, due to these formal theories/principles, researchers and educators have insights as to why certain strategies or approaches are effective in their learning environments.

For example, in Konak, Clark and Nasereddin, (2014), Kolb's Experiential Learning Cycle (ELC) (Kolb, 1984) is used to redesign hands-on lab activities incorporating a VCL into an information security course. Control and experimental groups of students were evaluated for their learning experience and outcomes. The control group conducted the lab activities individually following a "cook-book" approach to the hands-on activities, while the experimental group's learning activities were designed to follow each phase of Kolb's ELC. The teaching and learning activities were evaluated on learning impact and outcomes based on student surveys and quiz results. The students in the experimental group achieved higher learning outcomes and revealed a significant positive effect on competency development. In Konak and Bartolacci (2016), Collaborative Learning Theories (Bayer, 1990; Laal, 2013 and others) were applied to design collaborative teaching and learning activities for virtual labs in information security courses. This study evaluated the collaborative approach empirically in a real-class environment. A control group of students were provided with lab activities based on individual work and the experimental group conducted the activities in a collaborative manner. Data is collected using surveys, open-ended questions and quiz results. It was shown that students in the experimental group have higher and more consistent levels of competency and interest as well as higher post-test scores than the control group. Other studies that fall into this category include Hwang, Kongcharoen and Ghinea (2014) and Kongcharoen, Hwang and Ghinea (2017).

The studies in the literature are classified into the two levels are shown in Table 2.3. The stages of evolution in applying technology innovations in education can be observed as follows: firstly, studies that focus on the technical design of the technology innovation to take advantage of the opportunities that new technologies provide (TD); next, studies that focus on the technical design and empirically evaluate technology acceptance and user experience (TD and TE); and thirdly, those studies that also evaluate the impact on learning (TD, TE and LI). At Level II, studies consider theories and principles in education when designing teaching and learning activities (TLAs) and integrating technology innovations to take advantage of the opportunities that technology advances provide and empirically evaluate the impact on learning (TP&E). The goal in TP&E interventions are to utilise technology innovations and TLAs to improve learning. The use of theories and principles in education assist to guide the design/integration of technology and TLAs. The goal of TD, TD & TE and TD, TE & LI stages is to demonstrate the use of technology/technical designs to address limitations in existing learning environments or demonstrate new opportunities for teaching/learning.

Table 2.3: Classification of Related Work

Study	***Level 1 – Technical Design &/or Evaluation***			***Level 2 – Technology, Pedagogy & Evaluation***
	TD	**TD & TE**	**TD, TE & LI**	**TP & E**
Anisetti et al., 2007	√		√	
Ramalingam, 2007	√			
Wannous et al., 2007	√			
Duignan & Hall, 2008				√
Hu & Wang, 2008	√			
Gasper et al., 2008	√			
Li & Mohammed, 2008	√	√		
Li, 2009		√	√	
Li, Toderick & Lunsford, 2009	√	√		
Stewart, Humphries & Andel, 2009	√			
Li & Toderick, 2010	√			
Wannous & Nakano, 2010	√	√	√	
Wang, Hembroff & Yedica, 2010	√			
Yan, 2011	√	√		
Chan & Martin, 2012	√			
Dinita et. al., 2012	√	√		
Willems & Meinel, 2008, 2011, 2012	√			
Ruiz-Martinez et. al., 2013	√	√	√	
Hwang, Kongcharoen & Ghinea, 2014				√
Konak et al., 2014				√
Xu, Huang and Tsai, 2014	√	√	√	
Salah, Hammoud & Zeadally, 2015	√	√		

Study	*Level 1 – Technical Design &/or Evaluation*			*Level 2 – Technology, Pedagogy & Evaluation*
	TD	**TD & TE**	**TD, TE & LI**	**TP & E**
Zhu, 2015	√	√		
Caminero et al., 2016	√	√		
Gercek, Saleem and Steel, 2016	√			
Konak et al., 2016	√			√
Perez et al., 2016	√	√		
Soceanu et al., 2017	√			
Kongcharoen et al., 2017				√

TD – Technical Design, TE – Technical Evaluation, LI – Learning Impact, TP&E – Technology, Pedagogy & Evaluation

It can be observed from the above literature review that, in comparison to Level I (24 studies), only a few (4) studies take a Level II approach (i.e., using PLTs in the design of virtual laboratories). The hypothesis in section 2.2.2 states that the design of technology-enhanced lab environments based on sound PLTs have a higher potential for effective learning. This thesis aims to fill this research gap.

This research project presents a Level II approach by designing a technology-enhanced pedagogical framework incorporating a virtual lab for a systems and networking course. The course is designed to take into consideration PLTs, providing a sound theoretical foundation. Technology artefacts such as virtual labs, automated feedback tools, discussion boards and dashboards are integrated to create a rich learning environment. The proposed framework is presented in Chapter 3.

2.4 Summary

In this chapter, a literature review was conducted on research into technology-enhanced labs in different disciplines with a view to answer the broad research question presented in Chapter 1 - *How do we design a lab environment to take advantage of technology for effective learning?* The literature review resulted in a number of observations, findings and insights. One particular insight was that rather than considering the lab by itself, it is crucial to consider a holistic view of the learning context, curriculum, support tools, materials and resources, and to follow sound pedagogical theories and principles in the design of technology-enhanced lab environments for effective learning. This led to postulating the hypothesis in Chapter 2 to answer the broad research question posed in Chapter 1 as follows: *Design of technology-enhanced lab environments taking a holistic view of learning incorporating the learning context, curriculum design, lab activities, assessments, resources and technology artefacts based on sound pedagogical and learning principles and theories have a higher potential for effective learning*.

In order to validate the hypothesis, this research project aims to design and evaluate a technology-enhanced lab environment incorporating *curriculum design, lab activities, assessments, resources and technology artefacts based* on sound pedagogical and learning theories and principles (PLTs) for a particular learning context – this is termed a Technology-enhanced Pedagogical Framework (TePF) for a lab environment.

The first step in developing a TePF for a lab environment is to decide a particular learning context. This research project takes a technology-enhanced lab environment in system level courses in computing as the learning context.

In the recent past, with the maturing and expanding use of virtualization technologies, the development of virtual labs for system level courses in computing overcome many limitations of existing physical labs. In the literature, a number of implementations of such virtual labs can be found. In this chapter, a comprehensive literature review of virtual labs based on virtualization technologies was undertaken. The review showed us that the majority of studies focus on technical aspects of developing virtual labs to overcome limitations of existing environments taking advantage of new opportunities for learning. Very few studies consider PLTs in the design of these technology-enhanced labs. This gap provided us with an opportunity to focus on developing and evaluating a TePF for a lab environment in system level computing education. The proposed TePF is presented in the next chapter.

Chapter III

3. Proposed Framework

This chapter details the proposed pedagogical framework – TePF (Athauda et al., 2018). Firstly, in section 3.1, the theoretical model that forms the basis for the proposed framework is discussed. Next, section 3.2 outlines a number of pedagogical and learning theories/principles (PLTs) that are used by the framework. Section 3.3 describes the application of PLTs to develop the framework. The technology artefacts of the framework are presented in section 3.4. Finally, section 3.5 concludes the chapter.

3.1 **TPACK Framework**

The Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006; Koehler & Mishra, 2009) provides a theoretical reference model for the proposed framework. Mishra and Koehler (2006) extend Shulman's (1986) model that describes teacher knowledge domains with the incorporation of the technological knowledge domain (T) to present the TPACK model – see Figure 3.1.

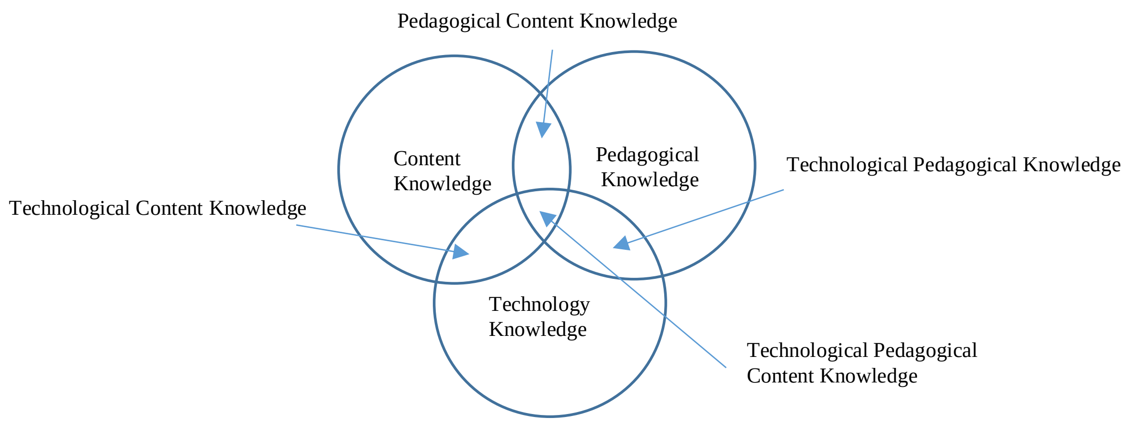


Figure 3. 1 TPACK Framework (Mishra & Koehler, 2006)

The different knowledge domains in TPACK are described below:

- Content Knowledge (CK): Knowledge pertaining to a particular subject matter (e.g. Mathematics, History, etc.).

- Pedagogical Knowledge (PK): Knowledge about teaching and learning approaches, processes, methods and also of overall education purposes, values and aims (e.g. classroom management, lesson plan development, etc.).

- Pedagogical Content Knowledge (PCK): Knowledge of which teaching/learning approaches are appropriate to a particular subject or content (e.g. laboratories for sciences, etc.). "*PCK is concerned with the representation and formulation of concepts, pedagogical techniques, knowledge of what makes concepts difficult or easy to learn, knowledge of students' prior knowledge, and theories of epistemology*" (Mishra & Koelher, 2006).

- Technology Knowledge (TK): Knowledge about standard technologies (e.g. use of word processors, browsers, etc.).

- Technological Pedagogical Knowledge (TPK): Knowledge of existing technologies and their capabilities for use in teaching and learning contexts (e.g. Learning Management Systems (LMSs), discussion boards, etc.)

- Technological Pedagogical Content Knowledge (TPCK): "*TPCK is an emergent form of knowledge that goes beyond all three components (content, pedagogy, and technology). This knowledge is different from knowledge of a disciplinary or technology expert and also from general pedagogical knowledge shared by teachers across disciplines. TPCK is the basis of good teaching with technology and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones.*" (Mishra & Koelher, 2006).

TPCK requires knowledge of all three domains, content, pedagogy and technology, to develop and deliver successful teaching. The proposed framework has utilised TPCK knowledge in its design to develop an effective learning environment.

A number of points in Mishra et al. (2006) have resonated and provided further evidence in support of the proposed approach:

- Mishra et al. (2006) state that "… *our model of technology integration in teaching and learning argues that developing good content requires thoughtful interweaving of all three key sources of knowledge: technology, pedagogy, and content*". This was supported by the findings and the hypothesis in Chapter 2 for a holistic approach to virtual lab design considering all three domains of content, pedagogy and technology.
- "*The core of our argument is that there is no single technological solution that applies for every teacher, every course, or every view of teaching*". This was also supported by our observation and findings in the literature review which outlined that different types of labs and technologies need to be developed for different contexts.
- "*Productive technology integration in teaching needs to consider all three issues not in isolation, but rather within complex relationships in the system defined by the three key elements"*. The holistic view of considering pedagogy along with technology design for a particular learning context – such as virtual labs in system level courses in computing – takes all three perspectives of content, pedagogy and technology into the design of the proposed framework.

The next section outlines the PLTs considered in the design of the proposed learning environment.

3.2 Pedagogy and Learning Theories/Principles (PLTs)

This section outlines a number of PLTs that have been used to design the proposed framework.

3.2.1 Constructive Alignment

"*Constructive alignment (CA) is a design for teaching in which what it is intended students should learn, and how they should express their learning, is clearly stated before teaching takes place. Teaching is then designed to engage students in learning activities that optimise their chances of achieving those outcomes, and assessment tasks are designed to enable clear judgments as to how well those outcomes have been attained*" (Biggs, 2014). Thus, in Constructive Alignment, the intended learning outcomes, teaching and learning activities, and assessments are aligned as shown in Figure 3.2. Constructive Alignment has provided a guide for curriculum design and practice in the proposed framework.

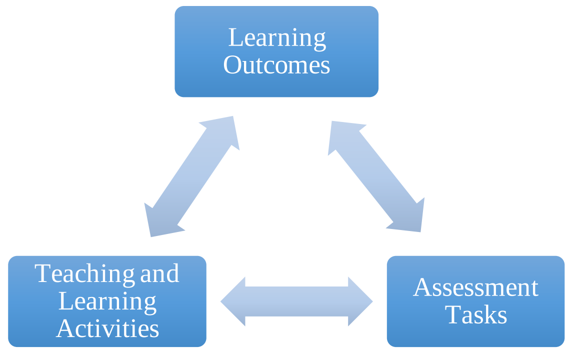


Figure 3. 2 Biggs's Theory of Constructive Alignment (Biggs, 2003)

3.2.2 **Kolb's Experiential Learning Cycle**

According to Kolb, "*Learning is the process whereby knowledge is created through the transformation of experience*" (Kolb, 1984, p. 38). In Kolb's Experiential Learning Cycle (ELC) (Kolb, 1984), learning takes place in four stages (see Figure 3.3). *Concrete experience* means direct experience by performing a task. *Reflective observation* means observation and reflection on the experience. *Abstract conceptualisation* means formation of new concepts and learning from the experience. *Active experimentation* means applying what is learnt. Kolb argues that for a complete learning experience, a learner must engage in all four stages of the cycle.

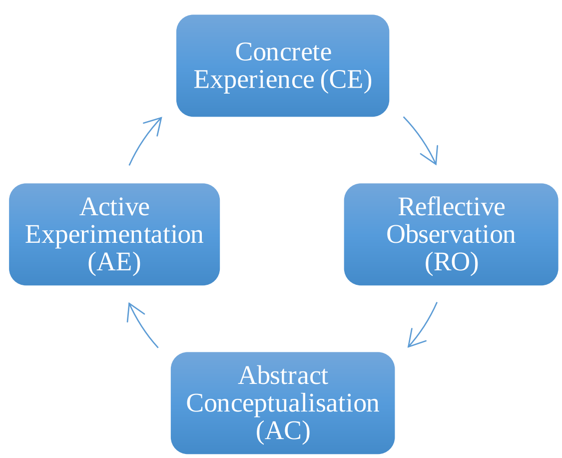


Figure 3. 3 Kolb's Experiential Learning Cycle (Kolb, 1984)

In the literature, Abdulwahed and Nagy (2009) and Konak et al. (2014) applied Kolb's ELC to successfully develop engaging laboratory activities to achieve higher learning outcomes.

3.2.3 Bloom and SOLO Taxonomies

The Taxonomy of Educational Objectives (frequently referred to as Bloom's Taxonomy) was originally proposed by Bloom et al. (1956) and revised in 2001 by Anderson et al. (2001). The revised Bloom's Taxonomy (Anderson & Krathwohl, 2001) provides a classification of six cognitive levels of complexity (Figure 3.4). Table 3.1 provides the definitions for the levels arranged from simple to complex (Anderson & Krathwohl, 2001). The taxonomy is hierarchical in that each higher level subsumes the lower level. For instance, a learner at the "Applying" level has mastered the "Understanding" and "Remembering" levels. The taxonomy can guide curriculum designers in developing learning activities and assessments.

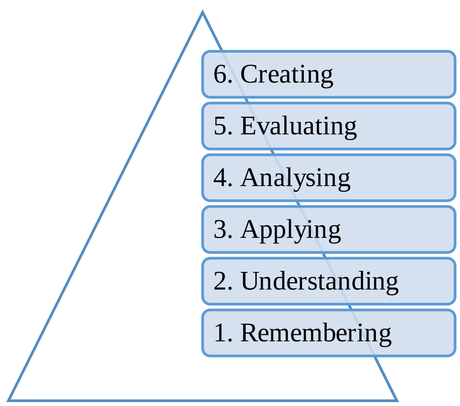


Figure 3. 4 Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001)

Table 3. 1: Revised Bloom's Taxonomy Levels (Anderson & Krathwohl, 2001)

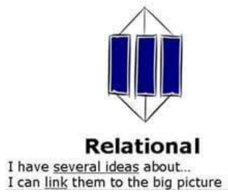
Bloom's Cognitive Level	Learning Activity
Remembering	Retrieving, recognising and recalling relevant knowledge from long-term memory.
Understanding	Constructing meaning from oral, written and graphic messages through interpreting, exemplifying, classifying, summarising, inferring, comparing and explaining.
Applying	Carrying out or using a procedure through executing or implementing.

Analysing	Breaking material into constituent parts, determining how the parts relate to one another and to an overall structure or purpose through differentiating, organising and attributing.
Evaluating	Making judgments based on criteria and standards through checking and critiquing.
Creating	Putting elements together to form a coherent or functional whole; reorganising elements into a new pattern or structure through generating, planning or producing.

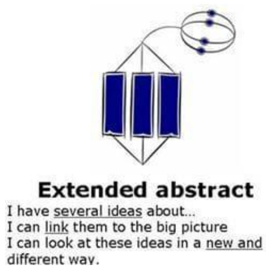
Biggs and Collis (1982) proposed the Structure of Observed Learning Outcomes (SOLO) defined as *"a simple and robust way of describing how learning outcomes grow in complexity from surface to deep understanding"* (Biggs & Collis, 1982). It is a systematic way to describe how learner performance evolves from simple to complex and is a learning model that helps teachers and students develop and understand the learning process. Thus, SOLO provides a structured framework for students to use to progress their thinking and learning. Table 3.2 below describes the SOLO levels of understanding.

Table 3. 2: Cognitive Processes in SOLO levels (Biggs & Collis, 1982; Biggs, 2003, p. 34-53)

Stage- level of understanding	SOLO Taxonomy Category Definitions / Example lab 2*
	*SOLO 1: The Pre-Structural Level* - This is the first stage where students don't really have any knowledge or understanding. In the lab 2 example of the Peer to Peer (P2P) network, a student who is pre-structural will usually respond with 'I don't understand what P2P network is'
	*SOLO 2: The Unistructural Level* - Here the student picks up or understands one single aspect, and there is no relationship of facts or ideas. At this level, in the lab 2 example, students have limited knowledge of networking concepts such as NIC or IP – they remember concepts, or they may just use instructions to change a static IP. So, a student's response will be 'I have some understanding of IPs'.
	*SOLO 3: The Multistructural Level* - At this level, the student can deal with two or more aspects of a task or understand serially but cannot interrelate the ideas. For example, the understanding from unistructural to multistructural means that the student may be able to distinguish IP parts (host/network parts), configure a static IP and find out system information– but is unable to design or connect them in a P2P network. So, their response might be 'I know a few things about IPs'.



SOLO 4: The Relational Level - At this level, the student may understand relations between several aspects and can integrate them so that the whole has a coherent structure and meaning. At the relational level, higher level thinking is used – in the lab 2 example, students are able to design and connect two VMs and explain several ideas related to the P2P network. The student response might be 'I can configure the IPs and network between two VMs and share resources'.



SOLO 5: The Extended Abstract Level - The final and most complex level is extended abstract. At this level, in the lab 2 example, students are not only able to network two VMs to share resources, but they can also link these to other bigger ideas and concepts such as explaining why and when should different networks models (P2P, client-server) needs to be used. Also, I can troubleshoot and resolve network issues.

* lab 2 – INFT 2031(IP - Internet Protocol, NIC - Network Interface Card) see Table 3.4

Each SOLO level provides a metric of the complexity of understanding of the material by the student. The levels at the relational and extended abstract levels are considered deeper levels of learning while the others are considered as surface-level learning.

3.2.4 **Collaborative Learning**

Collaborative Learning (CL) can be defined as students at various performance levels working together toward a common goal using well-structured assignments that help guide a group of students toward a learning outcome (Gokhale, 1995; Smith et al., 2005). Collaborative learning can refer to several educational approaches and environments in which students work together in small groups to solve a problem, complete a task, or create a product (Laal & Godsi, 2012).

Several researchers have found that groups performed better than individuals on computer-based laboratory activities (Hwang et al. 2014; Konak et al., 2016; Kongchareoen et al., 2017). Gokhale (1995), found out that collaborative learning fosters the development of critical thinking and problem solving through discussion, clarification of ideas and evaluation of others' ideas. This fact led us to consider integration of collaborative activities.

3.2.5 Formative Assessments and Feedback

Formative and summative assessments are the two most widely known assessment types. The formative assessment's primary purpose is to provide feedback to learners, also called *assessment for learning*, while the summative assessment's primary purpose is to evaluate learning, also called *assessment of learning* (Bennet, 2011). Formative assessment, a primary category of feedback in educational research, is a process that involves assessing the learning outcomes of a learner, formally or informally, and feeding back to him/her the assessed outcome. In the literature, formative assessment and feedback are significant factors that can improve learning: "*There is a body of firm evidence that formative assessment is an essential component of classroom work and that its development can raise standards of achievement. We know of no other way of raising standards for which such a strong prima facie case can be made*" (Black & William, 2010). Formative assessment can provide feedback at multiple levels: feedback to the learner about his/her learning and what the next steps in learning should be and also feedback to the teacher about current levels of student understanding (Heritage, 2007). Feedback has been emphasised as an important factor for effective instruction (Collis et al., 2001; Dick et al., 2001; Race, 2005). Incorporating feedback into teaching and learning has been frequently reported to enhance the learning process in comparison with cases where no feedback has been provided (Hanna, 1976; Krause et al., 2009). Formative assessment may involve activities such as classroom questioning, peer- and self-assessment and the formative use of summative tests (Black et al., 2003; Wiliam, 2000). Formative assessments and feedback help students to take control of their own learning (Nicol & Macfarlane-Dick, 2006) and achieve self-regulated learning (Sadler, 1998) where feedback on student performance is given to accelerate the student's own learning.

While formative assessment provides regular feedback on the student learning process, summative assessment's purpose is to evaluate student learning. Summative assessment is normally conducted in the middle or end of a course, such as midterm or final exams, final projects, etc. and it is normally used to measure a level of success or proficiency in comparison against some standard or benchmark. It is imperative to see both formative and summative assessments working hand in hand and complementing each other.

3.3 Applying PLTs in the Proposed Framework

This section discusses the application of the PLTs discussed above in the proposed framework. The first step in planning a pedagogical framework is to identify the context of the learning environment and develop a teaching and learning plan. In this thesis, an introductory systems and network administration course in the undergraduate computing program at the University of Newcastle (UoN) was selected. The course is structured as a 12-week semester with 2 hours of lecture and 2 hours of lab contact weekly within the term.

3.3.1 Curriculum Design

Constructive Alignment (Biggs, 2011) provides an overarching framework for curriculum design and practice (see Figure 3.3). In Constructive Alignment, the intended learning outcomes (ILOs), teaching and learning activities (TLAs) and assessment tasks (ATs) are aligned.

In designing the curriculum for the course, CA was applied. Firstly, the ILOs were outlined (see Table 3.3). Next, the TLAs and ATs were designed to align to the ILOs. The TLAs aim to engage students to acquire the knowledge and skills to achieve the ILOs. The ATs (i.e. summative assessments) were used to demonstrate the achievement of the ILOs by students. Table 3.4 provides the teaching and learning plan for the course.

Table 3. 3: Alignment of Learning Outcomes, Teaching and Learning Activities and Assessment Tasks

Intended Learning Outcome (ILOs)	Teaching and Learning Activities (TLAs)	Assessment Tasks (ATs)
ILO 1: Understand the fundamental principles of networks and network communication (hardware, models, protocols and security).	L1 – L5, L9 – L11, review exercises T1-T5 & T9-T11	A1, PT1, PT2, Formal Exam
ILO 2: Understand the role of PC-based and Network Operating Systems (NOS) in organisations	L1 – L2, L6 – L8, T1 – T3, T6 – T9	PT1, PT2, A2
ILO 3: Demonstrate the ability to design network and Active Directory (AD) solutions for organisation scenarios	L7, L11	A1, A2, Formal Exam

ILO 4: Demonstrate ability to install, configure and troubleshoot PC, NOS and network services	Practical activities in T1 – T3, T6 - T9	PT1 and PT2

Table 3. 4: Teaching and Learning Plan for Systems and Network Administration Course

Week	Lecture Topics	Lab Activities	Summative Assessments
1	L1: Introduction to course, Introduction to hardware, OS, network and virtualization basics		
2	L2: ISO/OSI Model, TCP/IP Protocol Suite and OSI Model, network models, Windows Shared Folder and NTFS Permissions	T1: VMs, Win10 installation, review exercises	
3	L3: Network Layer – Logical addressing with IPv4	T2: P2P, shares, review exercises	
4	L4: IPv4 address allocation, Internet protocol, routing	T3: Share + NTFS permissions, review exercises	
5	L5: Topologies, network hardware, ethernet, wireless LAN	T4: Formative Assessment - Practice Test 1, review exercises	
6	L6: Network Operating System (NOS)	T5: Practical Test 1 (PT1), review exercises	PT1: Summative Assessment
7	L7: DNS Class exercise: Network diagrams	T6: NOS, PowerShell, review exercises	
8	L8: Active Directory (AD)	T7: DHCP, review exercises	A1: Assignment 1 – Network Design (Summative Assessment)
9	L9: Process-to-Process Delivery: TCP and UDP	T8: Active Directory, review exercises	
10	L10: Network security part 1 – Cryptography, message confidentiality, integrity, authentication and non-repudiation, key management	T9: Group policy, review exercises	
11	L11: Network security part 2 – IPSec, VPN, SSL, firewalls, proxies, VLANs Class Exercise: AD network diagrams	T10: Formative Assessment - Practice Test 2, review exercises	
12	L12: Review, Q&A	T11: Practical Test 2 (PT2), review exercises	A2: Assignment 2 – AD Design (Summative Assessment), PT2: Summative Assessment
Exam Period			Formal Exam

Lx - Lecture x, Tx – Tutorial/Lab x, Ax – Assignment x, PTx – Practical Test x

ILO1 and ILO2 developed the fundamental knowledge and understanding of concepts and ILO3 and ILO4 aimed to demonstrate the application of this knowledge and these skills to solve real-world scenarios/problems. ILO3 and ILO4 were designed to encourage higher levels of learning (i.e. relational and extended abstract levels of the SOLO Taxonomy or “applying” to “creating” levels of Bloom’s Taxonomy). By applying CA, TLAs aimed to develop the knowledge and skills of students to meet the ILOs while the assessment tasks aimed to demonstrate students’ achievement of the ILOs.

The next sections discuss the design of the TLAs and the ATs.

3.3.2 **Design of Teaching and Learning Activities**

In the learning context, the course had 2 hours of lecture contact and 2 hours of laboratory contact timetabled. The lectures required the instructor to deliver content through presentations and interactive activities such as discussions and class exercises. The lectures were recorded to be available to students through the Learning Management System (LMS). The laboratory activities provided students with hands-on activities, review questions, quizzes, group-work, discussions and interactions with the tutor to gain knowledge and skills.

This research project applied a number of PLTs in order to redesign the lab activities. Kolb’s ELC, Bloom’s Taxonomy and Collaborative Learning were applied in the redesign of the lab activities. According to Kolb, “Learning is the process whereby knowledge is created through the transformation of experience” (Kolb, 1984). In Kolb’s ELC, learning takes place in four stages: *Concrete Experience (CE)*; *Reflective Observation (RO)*; *Abstract Conceptualisation (AC)*; and *Active Experimentation (AE)*. Kolb argues that for a complete learning experience, a learner must engage in all four stages of the cycle. Abdulwahed and Nagy (2009) and Konak et al. (2014) applied Kolb’s ELC to successfully develop engaging laboratory activities. In this current research project, all lab sessions were redesigned to use all four stages of Kolb’s ELC. For illustration purposes, the schematic flow of the redesigned Lab 1 activities incorporating Kolb’s ELC, Bloom’s taxonomy and Collaborative Learning are presented (see Figure 3.5).

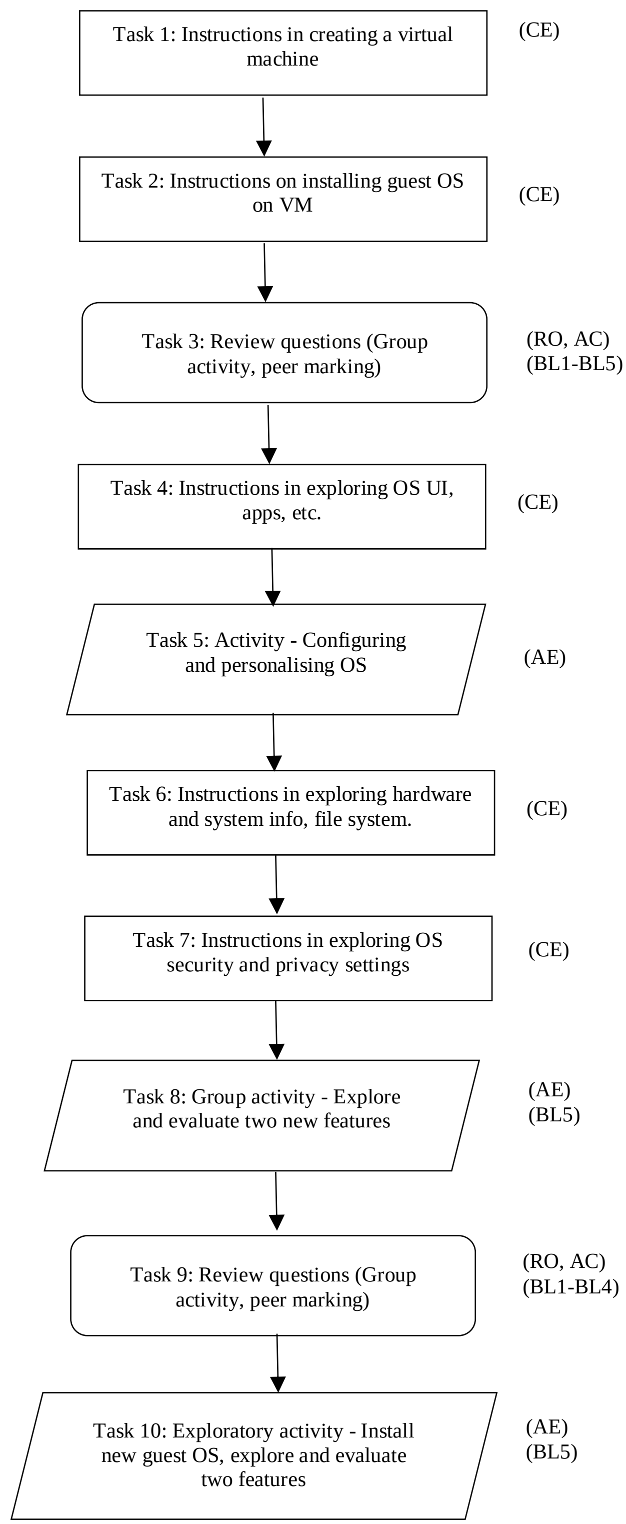


Figure 3. 5 Lab 1 Activities Design based on Kolb's ELC and Bloom's Levels (1-6)

The lab activities were designed to cover all stages of ELC. In Lab 1, Task 1 provided explanation and step-by-step instruction to create a virtual machine using a selected hypervisor. In Task 2, explanation and instruction to install a guest OS on the configured VM was provided. In Tasks 1 and 2, learners learn through direct experience which maps to the CE stage of Kolb's ELC. In Task 3, a set of review questions was provided. The review questions spanned from Bloom's Level 1 (BL1) *Remembering* (For example, "what is a hypervisor?") to BL4 – *Analysing* level questions (e.g. "Describe a situation where using a VM is not appropriate"). This activity also mapped to the RO and AC stages in the ELC. Each student in the laboratory class had to partner with another class member to discuss and answer the review questions. The group interaction aimed to provide interaction, increase engagement and develop critical thinking. Next, the group posted their answers on the LMS's Discussion Board and shared them with the class. Also, each group reviewed the other groups' answers and commented on them. This peer-review process led learners to an activity at Bloom Level 5 – *Evaluating*. Task 4 provided explanations and step-by-step instructions to navigate and explore applications and guest OS's user interfaces which maps to the CE stage of the ELC. In the Task 5 activity, learners were asked to customise the OS settings and configurations to personalise their preferences. The learners explored and configured OS features, which maps to the AE stage of Kolb's ELC. Tasks 5 and 6 explored and explained OS hardware and device configurations, the file system and security and privacy settings which also maps to the CE stage of the ELC. In Task 8, students explored new features of OS versions. Also, students partnered with another class member and discussed each others' features. The group posted two features on the LMS's Discussion Board to share with the class. Also, the group evaluated and commented on at least one other group's posts. This activity maps to the AE stage of the ELC and to Bloom's Level 5 – *Evaluating*. The Task 9 review questions covered review exercises from the content covered in the lecture. This activity maps to the RO and AC stages in the ELC. Task 10 was an exploratory activity demonstrating their understanding and skill in the entire lab. Learners created a VM and installed a guest OS (a different OS from Task 2), explored and posted discussion on features and evaluated other groups' features. This activity was completed by learners without explicit step-by-step instructions. This activity maps to the AE stage of the ELC and to Bloom's Level 5 – *Evaluating*. The development of lab activities based on Kolb's ELC, catering to higher levels of Bloom's taxonomy and integrating collaborative work have resulted in the design of an interactive and engaging lab experience with the aim of achievement of higher levels of learning. The redesigned labs for the entire course are presented in Appendix E.

This approach of applying Kolb's ELC, collaborative activities and using exercises catering to the higher levels of Bloom's taxonomy aimed to produce interactive lab activities that were engaging and encouraged deeper levels of learning. This research project evaluated these redesigned labs in the following chapters. The application of Kolb's ELC and collaborative activities to redesign lab activities has been applied in the literature with successful outcomes. In Konak et al. (2014) and Abdulwahed et al. (2009), the authors applied Kolb's ELC to redesign lab activities with successful outcomes avoiding "cook-book" style approaches to labs in information security and chemical engineering. Konak et al. (2016), Hwang et al. (2014) and Kongcharoen et al. (2017) all used collaborative activities in labs to improve learning outcomes.

The next section discusses the design of the assessment tasks.

3.3.3 Design of Assessment Tasks

This section discusses the design of assessment tasks. The curriculum design incorporated summative assessments as well as formative assessments. The formative assessment aim was to provide feedback to improve learning while the summative assessment aimed to provide feedback and also to assess student achievements with respect to the ILOs.

With the application of Constructive Alignment, the summative assessment tasks directly aimed to assess student achievements with respect to the ILOs:

- *Assignment 1 (A1)*: was an exercise aimed at designing a network (devices + addressing scheme) for a particular organisation. This assessment aligned with ILO 1 and partly with ILO 3.
- *Assignment 2 (A2)*: was an exercise aimed at designing an AD hierarchy for a particular organisation. This assessment aligned with ILO 2 and partly with ILO 3.

- *Practical Tests 1 and 2 (PT1 & PT2)*: included practical assessments aimed at meeting ILO 4.
- *Formal Exam*: was an assessment that covered ILO 1-3 in an exam setting.

In addition to these summative assessments, formative assessments and feedback were incorporated. Previously, research has shown that formative assessments and feedback are considered an essential component of assessment work and their development can raise standards of achievement (Black & Wiliam, 2010). Thus, formative assessments were incorporated in the TLAs throughout the course in addition to the summative assessments. A number of mechanisms and tools such as review questions, a discussion board, a feedback tool and online quizzes were designed into the lab activities to provide formative feedback.

The next section discusses the lab's feedback tool in detail. In addition, the lectures and labs incorporated a number of class discussion exercises and practice tests which provided formative assessments aligned to summative assessments: A1, A2, PT1 and PT2. The reasons for this approach were twofold. Firstly, this approach aimed to provide students with an opportunity to attempt to a similar problem to the summative assessment while having the ability to get formative feedback without grade penalty. This built up understanding and confidence before students attempted the summative assessment which was more detailed and extended than the formative assessment. The formative assessment and feedback provided students with a clear understanding of the learning goals expected by the assessment. This fact is supported by Black, Harrison, Lee, Marshall and Wiliam (2004): "*Students can achieve a learning goal only if they understand that goal and can assess what they need to do to reach it*". Secondly, the formative assessment aimed to engage students in the assessment as the formative assessment provided an opportunity to learn and then demonstrate understanding with the summative assessment, thus increasing the achievement of learning outcomes.

The next section discusses the technology architecture and artefacts of the proposed framework.

3.4 **Design of Technology Architecture and Artefacts**

This section discusses the design of the technology architecture and artefacts of the technology-enhanced pedagogical framework. The system architecture of the framework is shown in Figure 3.6. The technology artefacts consist of the: Virtual IT Infrastructure Lab; Student Interface; Feedback Tool; Student and Teacher dashboards; and LMS. The inspiration for the immediate feedback (i.e., Feedback Tool) and dashboards was inspired by Khan TED presentation (https://www.ted.com/talks/salman_khan_let_s_use_video_to_reinvent_education?language=en).

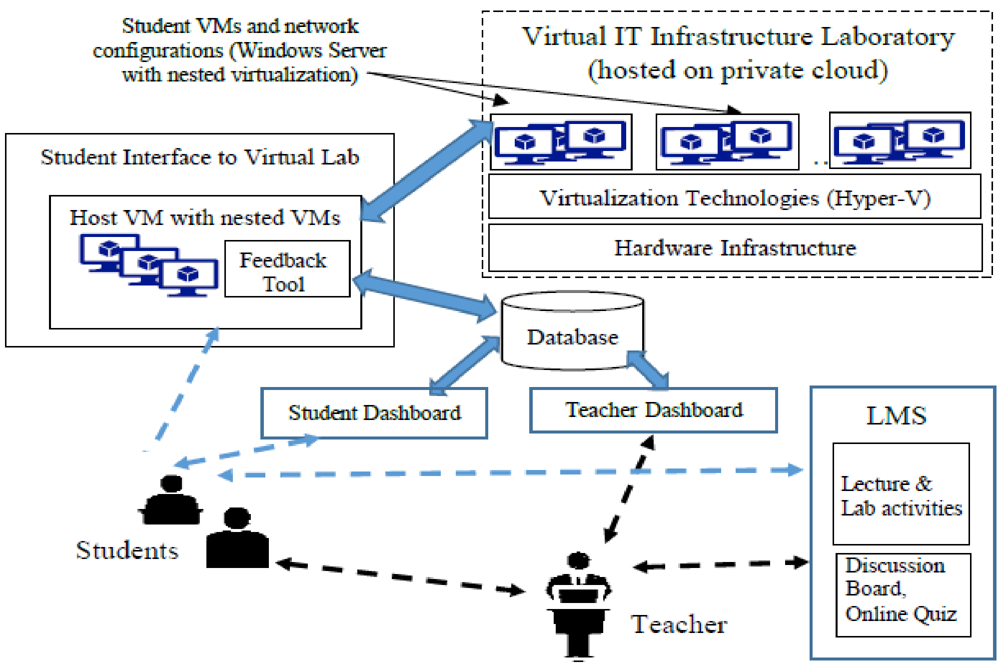


Figure 3. 6 Architectural Design of the TePF

LMS: The LMS provided an online portal for learners in the course. Blackboard[1] was the adopted LMS at the university and was used as the online course portal. The LMS hosted all content including lecture presentations, lecture recordings, laboratory sheets, assessments and submissions, discussion boards, progressive marks, announcements,

[1] Blackboard ™, http://www.blackboard.com/index.html.

online quizzes and links to the student lab portal and dashboards. All lectures delivered were video captured and hosted on the LMS. The LMS was the most used technology artefact by learners.

Virtual Laboratory and Student Interface: The virtual laboratory was hosted on a private cloud at UoN Callaghan Campus. Hyper-V (Microsoft, 2016 a) was used as the virtualization platform. The private cloud hosted virtual machines (VMs) for each student. Each student was provided a host VM which had Windows Server 2016 with nested virtualization (Microsoft, 2016 b) enabled (see Figure 3.7). This host VM provided each student with a sandboxed environment to create and configure guest VMs and networks to conduct different laboratory activities without impacting any campus networks. vWorkspace software suite (https://support.quest.com/vworkspace/8.6.3.) was utilised to manage the private cloud environment and also provided access to the host VMs via the browser or a client application – *Student Interface to Virtual Lab* (see Figure 3.8).

The virtual lab architecture had a number of advantages over physical labs including accessibility – 24/7 remote access, flexibility to learn at the student's own pace and other advantages as outlined in Chapter 2. To the best of our knowledge, in the literature, this research project was the first implementation using Microsoft Hyper-V with nested virtualization to provide virtual labs for system level courses in computing.

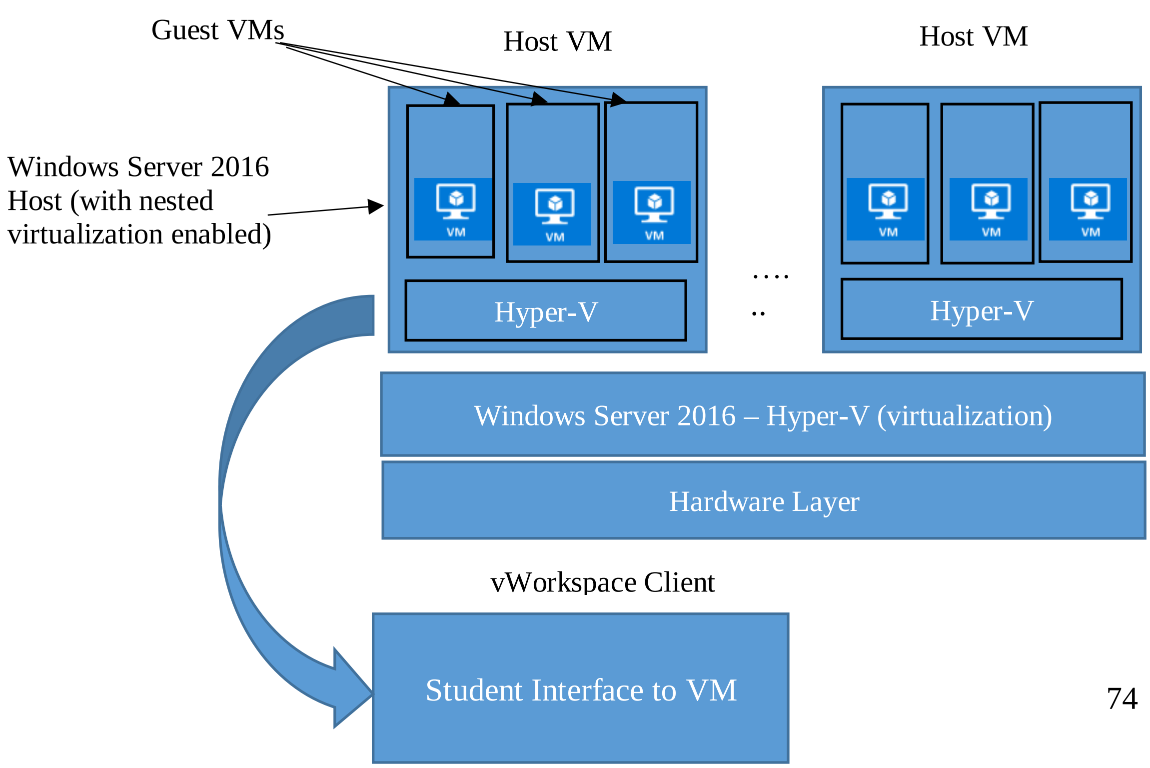


Figure 3. 7 Architecture of the Virtual Lab

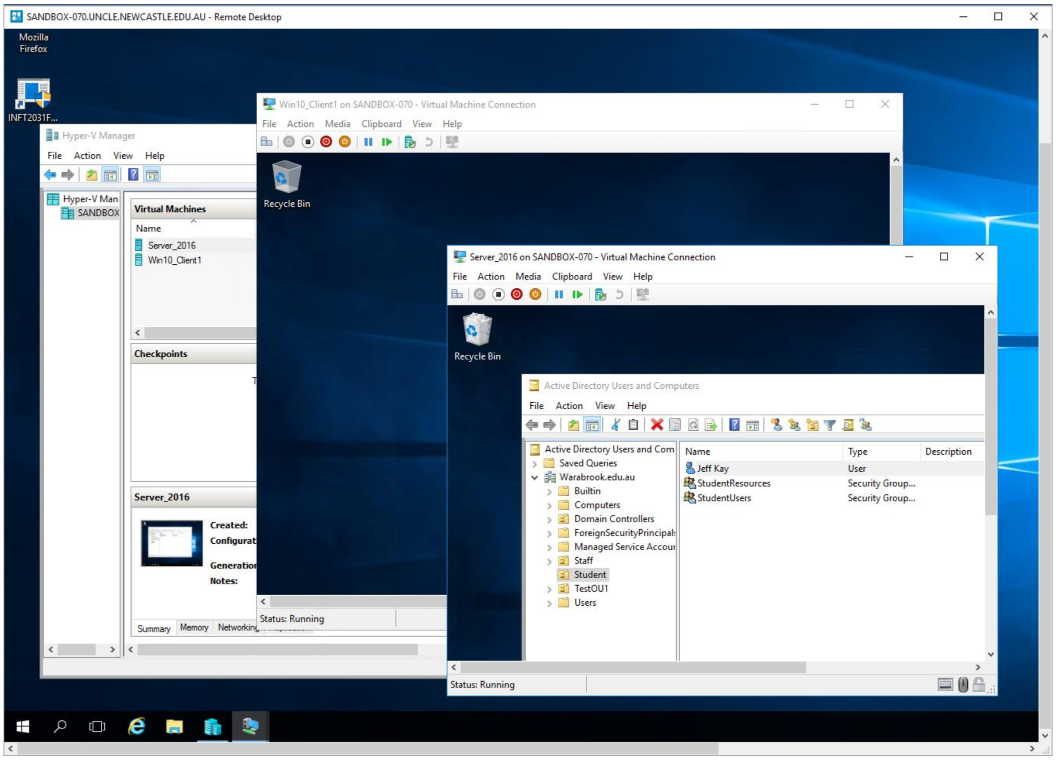


Figure 3. 8 Student Interface to the Virtual Lab

Feedback Tool and Dashboards: Feedback is critical for learning (Black & Wiliam, 1998; Hattie & Timperley, 2007). As discussed earlier, formative assessments and feedback were integrated to TLAs in the proposed framework. Lectures included class exercises as formative assessments, practice tests in the labs and lab activities which included feedback from online quizzes (self-assessment), discussion board posts (peer-assessment) and tutor interaction both during class and through discussion board posts.

It was not practical for tutors to manually check and provide feedback for each hands-on lab activity task. Thus, a feedback tool was developed that verified each student's lab configuration and generated a report. Students ran the feedback tool and selected a particular lab to verify. The feedback tool ran a Microsoft PowerShell script https://docs.microsoft.com/en-us/powershell/) which checked the student's lab configurations and generated a lab report specifying correct and incorrect configurations for the lab. The tool was designed so that the tutor could update the configurations to verify by updating the XML configuration files. The PowerShell scripts and configuration files were stored on a file server and managed centrally. The feedback tool ran the PowerShell script which verified the configurations in the guest VMs and created output of a report showing correct and incorrect configurations. The architecture for the feedback tool is presented in Figure 3.9. A sample report generated by the feedback tool is provided in Figure 3.10. Note that in the report a green tick signifies a correct configuration while a red cross is an incorrect configuration.

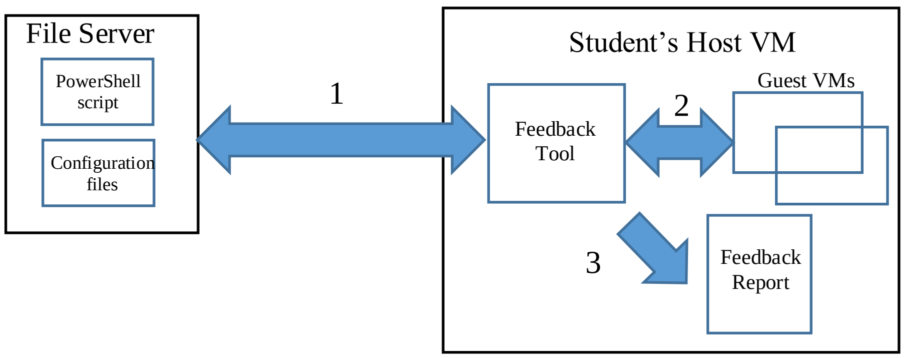


Figure 3. 9 Architecture of the Feedback Tool

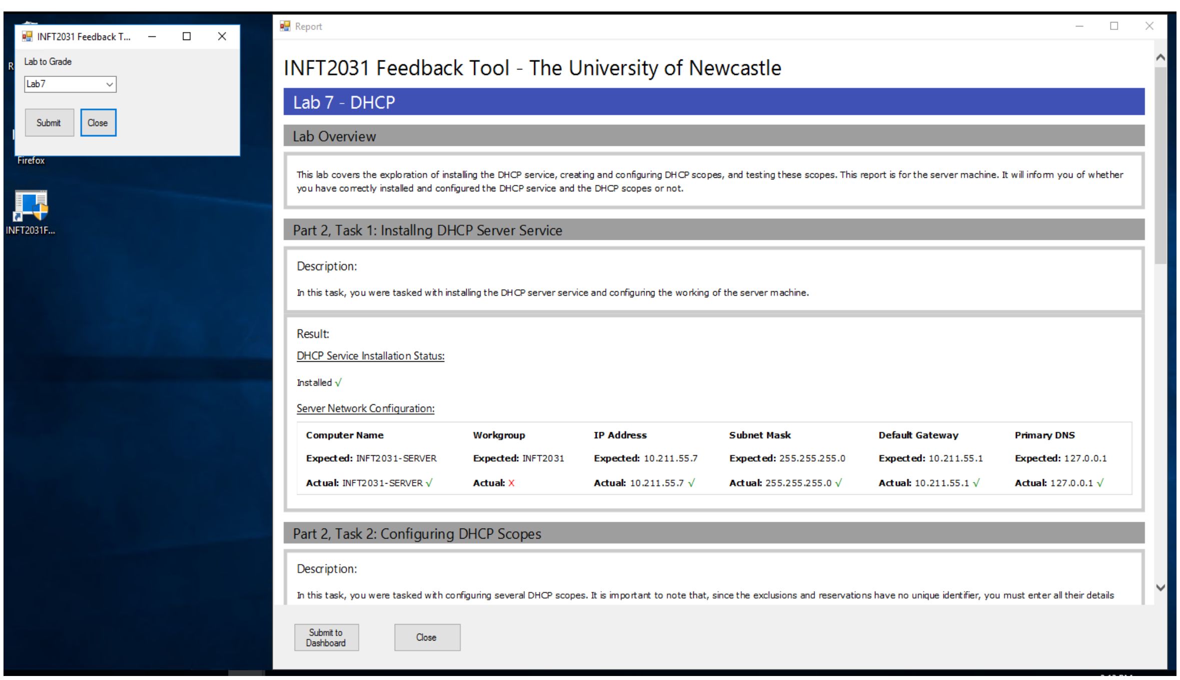


Figure 3. 10 A Sample Report from the Feedback Tool

Formative assessment can provide feedback at multiple levels: feedback to the learner and also to the teacher (Heritage, 2007). Thus, in the feedback report, an option was provided for students to submit their formative feedback reports to a centralised database. The database was accessed from the student and teacher dashboards. The student's dashboard provided a view of the student's individual progress through the labs. This helped the students to obtain an overall view of their progress. The teacher's dashboard provided a collated view of student progress. The aim of this was to assist the tutor to assess the students' progress in lab work, identify areas where groups of students may have been struggling and intervene where necessary.

3.5 **Summary**

Technology provides capabilities to develop learning environments that are engaging while also providing new possibilities for learning. This chapter presented the proposed framework for a lab environment. The proposed framework took into consideration a number of PLTs in its design. Constructive Alignment (Biggs, 1992) was used for curriculum design. The ILOs were outlined. The TLAs were organised and aligned to the ILOs and the ATs were aligned to the ILOs and aimed to evaluate student achievement of ILOs. The TLAs for labs were redesigned based on Kolb's ELC and catered to all stages of the ELC. Engaging collaborative activities were incorporated into lab activities. Formative assessments and feedback were incorporated throughout with frequent formative feedback/assessments and intermediate summative assessments. During lab activities, feedback was provided through self-, peer- and tutor assessments. Students had online quizzes, the discussion board (where peers commented and evaluated student work) and tutor interactions. A feedback tool was designed to provide feedback for hands-on lab configurations. To improve the transparency of learning, teacher and student dashboards were designed. The student dashboard provided a view of the student's progress in labs. The teacher dashboard provided a collated view of student progress. This allowed the teacher with a transparent view of students' progress enabling to intervene where necessary. The virtual labs were incorporated to the framework, providing a number of advantages such as 24/7 remote access to labs, flexibility, ability to reset and retrial experiments, etc. Overall technology artefacts used in the framework included: the Virtual

Lab, the Feedback Tool, the LMS and the Teacher and Student Dashboards. The proposed framework integrated technology, pedagogy and content and so falls into the TPCK dimension of the TPACK framework. Also, the proposed framework is a Level II – TPD&E stage intervention (as discussed in Chapter 2).

The proposed framework had a number of significant characteristics that are worth noting when compared to a physical lab environment:

- The incorporation of the virtual lab provided 24/7 remote access to labs for students. Other advantages include flexibility, ability to reset and retrial, etc.
- The use of Constructive Alignment resulted in alignment of ILOs, TLAs and ATs.
- The use of Kolb's ELC and Collaborative Learning to redesign labs created interactive, engaging lab activities avoiding "cookbook" style instruction.
- Formative assessments and feedback, including for hands-on lab activities, provided an environment that encouraged learning.
- Teacher and student dashboards provided transparency and learning progress.

Overall, by incorporating PLTs for a particular learning context and developing technology tools/artefacts to facilitate learning to take advantage of technological advances has resulted in a technology-enhanced pedagogical framework (TePF) for a lab environment fulfilling the hypothesis presented in Chapter 2. The following chapters will iteratively implement and evaluate the proposed framework presented in this chapter.

The next chapter will discuss the research methodology used for implementing and evaluating the framework.

Chapter IV

4. Research Methodology

This chapter discusses the methodological approach, research methods and iterations taken in the research project to design and evaluate the proposed framework, and the reasons for choosing them. Design-Based Research (DBR) was adopted as the methodological approach, discussed in section 4.1. Section 4.2 discusses the research methods used in data collection and evaluation of the proposed framework. Two iterations used to develop, implement and evaluate the proposed framework is discussed in section 4.3. Section 4.4 concludes the chapter.

4.1. **Design-Based Research (DBR)**

Design-Based Research (DBR) (DBR Collective, 2003) was selected as the methodological approach for this project. In literature, this approach is also referred to as development research (van den Akker, 1999), design experiments (Brown, 1992; Collins, 1992), and formative research (Newman, 1990 and with slightly different focus Wang & Hannafin, 2005). A number of characteristics of DBR makes it the appropriate approach for this research project. DBR acknowledges the complexity of educational technology interventions and allows context-specific interventions in authentic settings (Barab & Squire, 2004). In DBR, development and research happen through iterative cycles of design, development, enactment, evaluation and re-design (see Figure 4.1) (Plomp, 2013). Researchers and practitioners work in collaboration (not in isolation) (Reeves, 2006). DBR aims to bring theory and practice closer together by developing practical applicable theories and design principles.

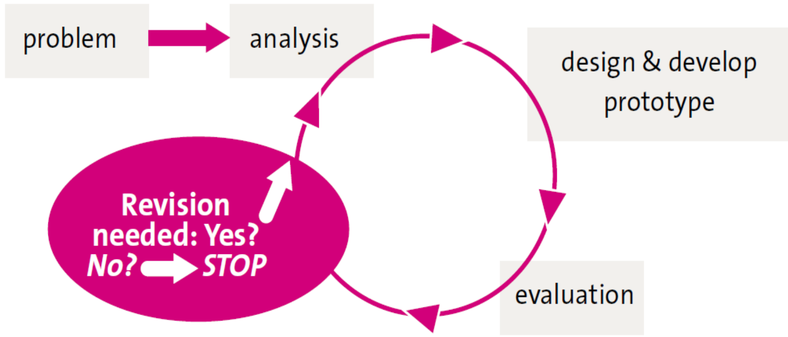


Figure 4. 1 DBR – Iterations of Systematic Design Cycles (Plomp, 2013, p. 17)

Wang and Hannafin (2005) define DBR as "*a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories*". Wang and Hannafin (2005) describe five basic characteristics of DBR: (i) pragmatic; (ii) grounded; (iii) interactive, iterative and flexible; (iv) integrative; and (v) contextual. *Pragmatic* because its goals are solving current real-world problems by designing and enacting interventions as well as extending theories and refining design principles. *Grounded* in both theory and the real-world context. I*nteractive, iterative and flexible* because DBR requires interactive collaboration between researchers and practitioners. Without such collaboration, interventions are unlikely to effect changes in a real world context. DBR interventions tend to be continuously improved and refined through an iterative design process from analysis to design to evaluation and redesign. This continuous recursive view of the design process also allows greater flexibility than traditional experimental approaches. *Integrative* because researchers need to integrate a variety of research methods and approaches from both qualitative and quantitative research paradigms, depending on the needs of the research. *Contextual* because the research process, the research findings and changes from the initial research plan are documented and thus interested researchers or designers can trace the emergence of an innovation or combinations of innovations according to their interests by examining closely contextual factors or conditions that led to particular effects (Wang & Hannafin, 2005).

Mishra et al., (2006) summarise design experiments as follows: "*Design experiments, as a research methodology, emphasize the detailed implementation and study of interventions with evolving pedagogical goals in rich authentic settings. It acknowledges the complexities of classroom teaching and enlightens both practitioners and researchers by leading to the development of theoretical ideas grounded in contexts of practice; design experiments narrow the gap between research and practice, between theory and application*.". Barab and Squire (2004) also describe DBR: "*Design-based research is not so much an approach as it is a series of approaches, with the intent of producing new theories, artifacts, and practices that account for and potentially impact learning and teaching in naturalistic settings*".

Reeves (2006) depicts DBR as follows (Figure 4.2):

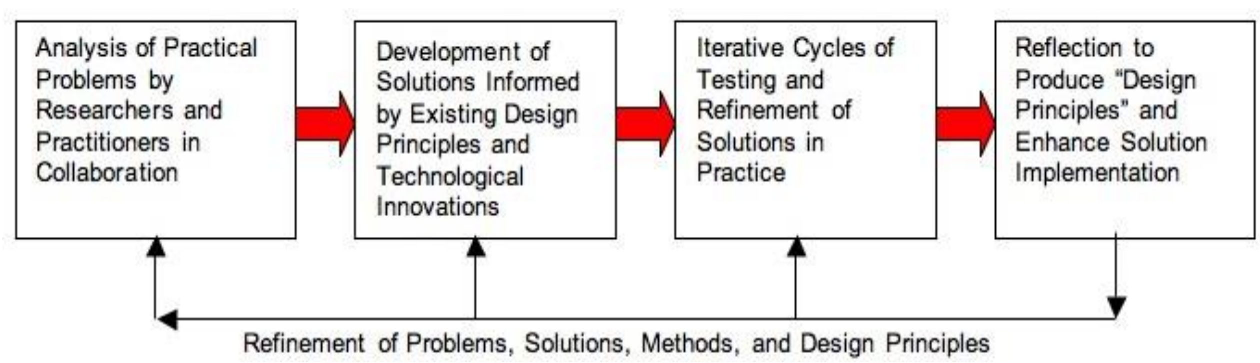


Figure 4. 2 DBR Approach (adapted from Reeves, 2006, p. 59)

In this thesis, the first two steps of Figure 4.2 were completed and outlined in Chapters 1-3. The thesis has analysed the problem of technology-enhanced lab environments, specifically in the context of system-level courses in computing in the literature review chapter (Chapter 2). The author has had extensive discussions with practitioners. It is important to note that the principal supervisor of the author for this thesis is the practitioner and was the lecturer responsible for the selected system-level course for which the proposed pedagogical framework was implemented. Therefore, close collaboration and discussion between practitioner and researcher was involved in the design and implementation of the intervention. Next step was the development of a solution which is the proposed framework which considered a number of pedagogy and learning theories and principles in its design (see Chapter 3). The following chapters (Chapters 5 and 6) discuss the iterative cycles of design, development and evaluation of the proposed framework. Finally, discussions, reflections and generation of design principles are discussed in Chapter 7. Figure 4.3 illustrates the proposed framework within the context of the DBR methodology. Note that the context for the intervention in this research project (i.e., a system-level course in computing) does not entirely subsume phase 1 (Problem Analysis) and phase 4 (Design Principles) as the problem analysis considered related work in other contexts so that the intervention and design principles discovered will be applicable in other contexts as well.

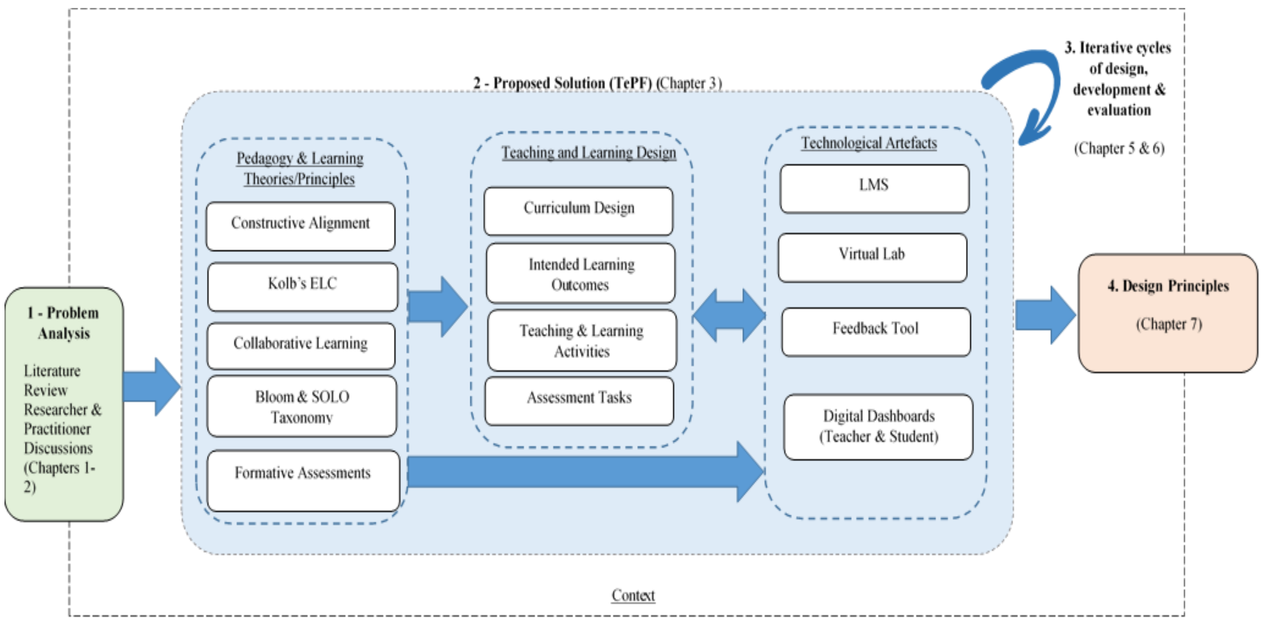


Figure 4. 3 Application of the DBR Methodology in the Research Project

For evaluation, DBR typically triangulates multiple sources and types of data to connect intended and unintended outcomes to processes of enactment (DBR Collective, 2003). Such analysis typically requires a combination of quantitative and qualitative methods to analyse how designs work in practice and to gain an understanding of how students learn in learning contexts. The following sections describe the quantitative and qualitative research methods.

4.2. **Research Methods**

Research methods refer to the tools and techniques for conducting a research project (Mackenzie & Knipe, 2006). The research methods used in a study are dependent on: what the study entails; the specific context of the study; and other components of the research design (Maxwell, 2005). Research method designs can be summarised into two basic approaches: quantitative and qualitative (Creswell, 2013). The next section discusses these research methods.

4.2.1. **Quantitative Research**

Quantitative research methods are designed to collect data (numeric or otherwise) that can be translated into numbers and can be numerically or statistically evaluated. Quantitative data allows direct comparison and analysis of large datasets through mathematical and statistical techniques. Numerical data can be collected through different instruments, such as Likert scale surveys. In general, the quantitative approach has several advantages. Quantitative approaches allow for accurate and systematic recording of data which permits the management and analysis of large amounts of information. There are a number of statistical and mathematical techniques available for the analysis of numerical data. Some basic methods include visualisation and descriptive analysis through tables, charts and graphs to see patterns or detect trends in data. More advanced statistical techniques are also available to analyse large datasets. Oates (2005) states that statistical techniques "*offer more universal means and criteria for evaluating key points and making generalized conclusions based on evidence*". They also provide statistical measures: mean, median, mode, range, fractiles, standard deviation, correlation coefficients, chi-square tests, t-tests and others.

A major limitation of quantitative research is that it does not consider qualitative data in its analysis. Thus, quantitative analysis does not provide deeper meanings that can result from the analysis of qualitative data. Qualitative data analysis considers these types of data and is discussed in the next section.

4.2.2. **Qualitative Research**

The qualitative research method deals with the gathering and analysis of qualitative data – text, images, etc. Interpretation of qualitative data requires subjective human interpretive analysis to obtain meaning from the data. Typically, qualitative analysis is performed to obtain opinions, reasoning for opinions and deeper meaning. Flick et al. (2014) describe qualitative research as "*interested in analysing subjective meaning or the social production of issues, events, or practices by collecting non-standardised data and analysing texts and images rather than numbers and statistics*". The data gathered from a qualitative approach is more descriptive than numerical data and requires human interpretation for analysis and to derive meaning. Such data can be collected through qualitative research methods such as interviews and questionnaires with open questions. This approach allows participants to provide detailed responses on an issue, providing context and details (unlike numerical data). The analysis of qualitative data can lead to a deeper holistic understanding of context, reasoning and exploratory analysis. There are a number of qualitative analysis methods including thematic analysis (Braun & Clark, 2006), grounded theory (Strauss & Corbin, 1998) and others.

There are a number of limitations to qualitative data as well. Qualitative data requires careful analysis by a human to interpret and provide results, whereas a number of standard statistical tests are available for analysis of quantitative data. Quantitative data analysis methods scale to large datasets. However, qualitative data analysis requires human interpretation and does not scale to large datasets. The results of qualitative data analysis also depend on the ability and skill of the researcher to draw valuable conclusions whereas quantitative data analysis has a number of statistical techniques/tests readily available.

The next section discusses mixed methods that utilise both quantitative and qualitative data analysis.

4.2.3. **Mixed Methods**

Mixed methods combine both qualitative and quantitative research methods. In the mixed methods approach, the researcher aims to achieve greater validity through studying corroboration between quantitative and qualitative data (Creswell & Clark, 2007; Creswell, 2009; Doyle, Brady & Byrne, 2009). In mixed methods research, incorporating qualitative data analysis with numerical data analysis enhances findings and, through convergence and corroboration, provides stronger evidence for a conclusion than when a single method is used (Johnson & Onwuegbuzie, 2004). In addition, this approach enables researchers to utilise all the different types of data available to answer research questions by providing multiple perspectives. The most common and well-known mixed methods design is triangulation design, which is also known as 'concurrent triangulation design' (Creswell, 2003). In concurrent triangulation design, researchers implement quantitative and qualitative methods during the same timeframe and with equal weight. The purpose is to obtain different but complementary data on the same topic. The intent is to bring together the differing strengths of quantitative methods (large sample size, trends and generalisation) with those of qualitative methods (small sample, details and in-depth perspectives). This design is used when a researcher wants to directly compare and contrast quantitative statistical results with qualitative findings or to validate or expand quantitative results with qualitative data. The traditional model of triangulation mixed methods design is the convergence model where integration occurs during the interpretation phase (Doyle et al., 2009) (see Figure 4.4).

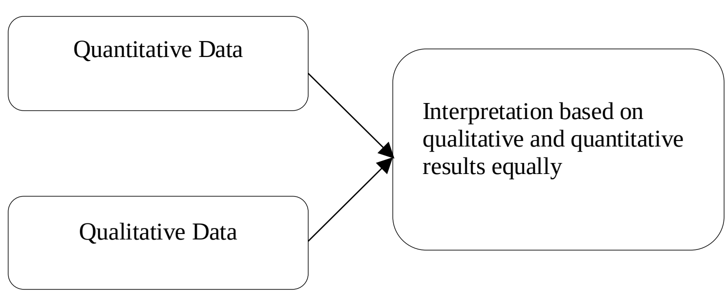


Figure 4. 4 Mixed Methods Triangulation Design

Since this research project aims to determine the impact on learning of the proposed intervention, mixed methods triangulation was employed. To identify the impact on learning, quantitative data such as student scores were used in the data analysis. Also, data collection from student surveys (using Likert scales) provided quantitative data for analysis of students' general attitudes and satisfaction. To delve deeper into the reasoning behind students' opinions on, and attitudes to, the proposed framework and exploratory analysis, qualitative data was collected and analysed through open-ended survey questions, focus group discussions, etc.

The Technology Acceptance Model (TAM) (Davies, 1989) was utilized to measure students' experience and acceptance of the different types of virtual laboratories (VMware lab, Azure lab, and server-based lab environment). To verify the validity of the survey instruments, Confirmatory Factor Analysis (CFA) was performed using the IBM-SPSS AMOS[2] environment.

A summary of the overall model fit measures is given in Appendix F. These models were found to be valid, as evidenced by the competence indices such as chi-square statistic (χ^2). The chi-square statistic is an intuitive index for measurement goodness of fit between data and model. In chi-squared test of model fit, values closer to zero indicate a better fit (Gatignon, 2010). Also, as recommended by Hair, Anderson, Tatham & Black (2003), several other fit indices such as the root mean squared residual (RMR), the root mean squared error of approximation (RMSEA), and the goodness-of-fit index (GFI) are examined. According to Hair et al., (2003), GFI and CFI are best if above 0.90 and demonstrate marginal acceptance if above 0.80, and RMR below 0.05. These fit indices indicate that the measurement model showed a good fit for the data collected.

The next section discusses the iterative phases of design, development and evaluation of the proposed framework in real classroom environments.

[2] https://www.ibm.com/us-en/marketplace/structural-equation-modeling-sem?mhq=AMOS&mhsrc=ibmsearch_a

4.3. **Iterations - Development of Prototypes**

The framework proposed in Chapter 3 was designed, implemented and evaluated iteratively in stages. This section discusses the iterative phases taken.

4.3.1. **Iteration 1**

In iteration 1, the technology artefacts - virtual lab and the feedback tool are implemented in a real-class environment and evaluated. There are two possible implementation architectures for the virtual lab – centralised vs. de-centralised. In the selected learning context, a decentralised virtual lab was currently in use. Therefore, a parallel implementation of a centralised lab was undertaken and evaluated towards the end of the term to find out users' perceptions with regard to the different virtual lab architectures. To evaluate users' perceptions, the Technology Acceptance Model (TAM) (Davies, 1989) was used. A survey was developed based on TAM model (see Appendix A). The survey questions consisted of 10 questions out of which 9 were categorised based on the definition of TAM scales. These survey questions are grouped into three dimensions (three questions measured "*Perceived Usefulness*", four questions measured "*Perceived Ease of Use*" and two questions measured "*Attitude towards using*"). Students were asked to provide their responses through a 5-point Likert scale ranging from "1 - Strongly Disagree" to "5 - Strongly Agree". In addition, the surveys had open-ended questions so as to collect qualitative data regarding the use of virtual labs (see discussions in the following sections). Last question (question 10) asked students to rate the lab overall. Likert scale 1-5 (1- Very Poor to 5 - Excellent) was used. Confirmatory Factor Analysis (CFA) was performed to verify model fitness to the data. Table 4.1 presents the factor loadings of the TAM questionnaire. Missing data is handled by listwise deletion (all cases with missing observations on any indicator are removed).

Table 4. 1: Factor Loading of CFA to verify the construct validity of items in the instrument

Survey Questions	Factor Loadings (Decentralised labs, n=83/ Centralised labs, n=64)		
	Perceived usefulness	Perceived ease of use	Attitude towards using
1. The lab environment helped me to learn in INFT2031	.876/.738		
2. The lab environment improved my performance	.776/.831		
3. The lab environment helped me to achieve learning outcomes	.835/.824		
4. The lab environment provided easy access to the lab (24x7)		. 679/.671	
5. Having access to the lab from any device/location is helpful to me		.470/.555	
6. I find it easy to use the lab environment		.781/.876	
7. I find the lab setting flexible to conduct my lab work		.815/.834	
8. I am satisfied with using the lab environment for my practical work in INFT2031			.924/.769
9. I would like to use the lab environment in future networking and systems administration courses			.724/.725
10. Overall, how would you rate the lab environment	Overall question		

Decentralised labs (using an external drive), Centralised labs (uses Azure cloud)

The TAM model achieved good fit statistics χ^2 (28) = 35.058, *p*= .003. The RMSEA (0.079) value ranges from 0 to 1, with smaller values indicating better model fit. CFI (.964) and TLI (.908) values meet the criteria (0.90 or larger) for acceptable model fit (Hair et al., 2003). Given the small sample in our study we decided using alternative absolute fit indices such as chi-squared and GFI as these have been found to be more sensitive to sample size than RMSEA (Gatignon, 2010). Thus, we conclude a good fit model (Table 4.2).

Table 4. 2: Model Fit Summary for the TAM model (n= 147)

Fit measures	**Values**	**Recommended value**
Chi squared	χ^2 (28) = 53.058, *p*=.003	p>.05
CFI	.964	>.90
TLI	.908	>.90
RMSEA	.079	<.08

Note that the model fit is for the total model and within this single model we are comparing multiple groups (Sample size is 147). VMware lab =83, and Azure lab = 64.

A reliability analysis was carried out using Cronbach's Alpha to examine its internal consistency (Nunnally, 1978). The instrument has a high degree of reliability if the value of Cronbach's Alpha is obtained as follows:

- If Cronbach's Alpha> 0.90 = Very high reliability
- If Cronbach's Alpha 0.70 to 0.90 = High reliability
- If Cronbach's Alpha 0.50 to 0.70 = Reliability is quite high
- If Cronbach's Alpha <0.50 = Low reliability

The overall Cronbach's alpha values for all dimensions were above 0.70, which is considered of high reliability (Creswell, 2013). This indicates that both surveys have a high internal consistency level and are therefore statistically reliable (see Table 4.3).

Table 4. 3: Cronbach alpha Reliability Coefficient (Reliability Analysis)

Scale	N of items	Cronbach's Alpha	
		De-centraliased labs	Centralized labs
Perceived usefulness	3	.868	.824
Perceived ease of use	4	.751	.816
Attitude towards using	2	.810	.734

Cronbach's α= (.870/.903, N of items = 9)

The descriptive statistics (i.e., Mean (M), Standard Deviation (SD) and Median) for each question and grouping these statistics according to the categories were then analysed. A summary of the descriptive analysis results of all measurement items related to this dimension can be found in Appendix G. The interpretation used for the mean of grouped data is given in Table 4.4.

Table 4. 4: Scale for Mean

Rating Scale	Interpretation	Range
SD =1	Strongly Disagree – Almost none of the indictors are satisfied	1.00 – 1.80
D = 2	Disagree – 25% of the indicators are satisfied	1.81 - 2.60
N = 3	Neither satisfied or dissatisfied – 50%	2.61 – 3.40
A = 4	Agree – 75% of the indicators are satisfied	3.41- 4.20
SA = 5	Strongly Agree – Almost all indicators are satisfied	4.21 -5.00

A paired t-test is used to compare the means of two populations when samples from the populations are available, in which each individual in one sample is paired with the himself/herself in the other sample. In our example, students who used both types of virtual labs (i.e., centralized (n= 90) and decentralized (n=69)) are compared to evaluate any general changes in perceptions between the two types of labs.

In addition, four open-ended questions were included in the survey to provide qualitative data for analysis. The following questions were added to the survey:

- Did you use the Azure (i.e., centralised lab) cloud lab? If no, please explain why?
- If given the choice to use external drive (i.e., decentralised lab) vs Azure cloud lab (i.e., centralised lab) in conducting INFT2031 labs, which do you prefer? Why?
- Any disadvantages of using External Drive (i.e., decentralised lab)/Azure cloud lab

(i.e., decentralised lab)

- Please provide any suggestions that you would like to see implemented in the cloud lab (i.e., centralised lab) in future?

Thematic analysis (Braun & Clarke, 2013) was performed on the qualitative data.

To evaluate the Feedback Tool, a Likert-scale questionnaire (0 – *Not at all likely* to 10 – *Extremely likely*) was used based on the TAM model. Also, a general overall satisfaction question. In addition, the following open-ended questions were included to gather qualitative data to analyse:

- Did you use the PowerShell feedback scripts? If no, please explain why?
- What is the primary reason for your rating in the Feedback tool?
- Are there any suggestions for ow the feedback script could be improved?

Finally, in iteration 1, to find out if there was any observable impact on learning outcomes, an independent t-test is conducted on practical test scores.

The evaluation in Iteration 1 provides feedback and confidence to implement the proposed framework in the next iteration of the study. Chapter 5 presents Iteration 1 in detail.

4.3.2. **Iteration 2**

The iteration 2 evaluated the proposed framework - TePF. In this second iteration, the TePF was applied with the aim to evaluate of the impact on students learning. A quasi-experimental design with a control group not subjected to TePF and an experimental group subjected to the TePF was carried out. The learning outcomes of the two cohorts provides evidence on the impact of the TePF. Next, the different components of the TePF is rated and evaluated both quantitatively and qualitatively to provide students' perceptions of the TePF. An overall rating of all components of the TePF is conducted. Lab activities in TePF were designed based on a number of PLTs – such as Kolb's ELC. To evaluate lab activities, the survey used a number of survey instruments published in literature. Konak & Bartolacci (2016) evaluated students' perceptions based on a number of dimensions - Usefulness, Interaction, Competency, Interest, Reflection and Challenge for an intervention in a virtual lab environment. This survey instrument was used to evaluate lab activities. To evaluate the use of different stages of Kolb's ELC in the TePF lab activities, we used the survey instrument in (Kolb, 1981). Student approaches to learning were measured using the Revised Two Factor Study Process Questionnaire (R-SPQ-2F) (Biggs et al., 2001). Finally, the technology artefacts: virtual lab, the Feedback Tool and dashboards, was evaluated using a 5-point Likert scale questionnaire based on the TAM dimensions (Davis, 1989). Also, qualitative data was collected and evaluated using open-ended questions and focus group discussions. The complete survey and focus group discussion questions are provided in Appendices B and C respectively.

Table 4.5 demonstrates the fit statistics for the TAM survey questions, latent variables, and the reliability measures. This is followed by assessing the model fit using various fit indices and evaluating the research model. The results of confirmatory factor analysis indicated that the scales were reliable.

Table 4. 5: Results of Confirmatory Factor Analysis (CFA)

Survey Questions	**Factor Loadings (n=70)** TAM Dimensions		
	Perceived Usefulness	Perceived Ease of use	Attitude towards using
Cronbach's α	.822	.740	.834
1. The lab environment helped me to learn in INFT2031	.734		
2. The lab environment improved my performance	.785		
3. The lab environment helped me to achieve learning outcomes	.864		
4. The lab environment provided easy access to the lab (24x7)		.648	
5. Having access to the lab from any device/location is helpful to me		.519	
6. I find it easy to use the lab environment		.649	
7. I find the lab setting flexible to conduct my lab work		.751	
8. I am satisfied with using the lab environment for my practical work in INFT2031			.817
9. I would like to use the lab environment in future networking and systems administration courses			.878
10. Overall, how would you rate the lab environment	Overall question		

Cronbach's α= (.853, N of items = 9)

Evaluation of student approaches to learning can be a useful way of measuring the impact of educational interventions and provide information about how best to engage students during their learning. The Study Process Questionnaire (SPQ) has been widely used to evaluate student learning strategies. 74 Participants (2017 cohort) completed the revised Study Process Questionnaire (R-SPQ-2F) (Biggs et al., 2001), which consists of 20 items spread across 2 first-order factors (deep, surface) and 4 second-order factors (deep motive, deep strategy, surface motive, surface strategy). Each item is rated on a five-point Likert scale. Total scores were calculated for each first-order factor. We reported confirmatory factor analysis (CFA) statistics supporting the factor structure of the R-SPQ-2F. The internal consistency statistics (Cronbach's alpha) for all is above 0.70. We demonstrated higher alpha scores (>0.80) for the deep and surface factors. CFA statistics for the R-SPQ-2F are presented in Appendix F. Confirmatory factor analysis was used to determine the fit of the data to the 2-factor structure of the R-SPQ-2F. Satisfactory fit was achieved through the internal consistency was acceptable.

The IBM-SPSS AMOS[3] was used to perform the CFA. Robust weighted least squares was used as the estimation method as the data were ordinal. The chi-square statistic is used to report the fit of the data to the model, however there is no agreement as to the other fit statistics that should be presented. Hair et al. (2003) suggest that the comparative fit index (CFI), Goodness-of-Fit Index (GFI), Tucker-Lewis index (TLI), and the root mean square error of approximation (RMSEA) be used. The fit statistics calculated in this iteration and the cut scores for each statistic are presented in Table 4.6.

Table 4. 6: Summary of Confirmatory Factor Analysis (CFA) in Iteration 2

Statistics	**The six-factor model** (Konak & Bartolacci, 2016)	**R-SPQ-2F** (Biggs et al., 2001)	**Recommended value**
χ^2	233.131	195.660	NA
χ^2 p-value	.000	.010	p>.05
df	162	152	NA
CFI	.925	.937	>.90
GFI	.794	.788	> .90
TLI	.903	.922	>.90
RMSEA	.079	.065	<.08

Our results show that 3 fit statistics (CFI, TLI and RMSEA) indicate acceptable fit. GFI does not meet the criteria (0.90 or larger) for acceptable model fit. This could be because fit statistics does not work equally well with various types of fit indices, sample sizes, estimators, or distributions (Hu, & Bentler, 1999). Appendix F presents the summary of

[3] https://www.ibm.com/us-en/marketplace/structural-equation-modeling-sem?mhq=AMOS&mhsrc=ibmsearch_a

the models and their goodness of fit statistics, as well as the fitted unstandardized regression weights and Pearson coefficient correlations matrix.

4.4. **Summary**

This chapter presented the DBR as a suitable research methodology to develop and evaluate the TePF. The proposed framework was developed in close collaboration with practitioners and evaluated in a real-world classroom environment. An iterative process was used to develop and evaluate the TePF providing feedback and confidence to both researcher and practitioner on the approach is taken. A mixed methods approach was taken to evaluate the framework by providing data collection, determining reliability and validity of the instruments, and analyzing data for statistical significance. CFA was performed on the survey instruments which indicated a good fit model for the data. Also, a brief description of the experimental treatment and procedures is discussed. The detailed results and analysis of theses DBR’s iterations can be found in Chapter 5 and Chapter 6.

Chapter V

5. Iteration 1 – Centralised Lab and Feedback Tool

This chapter presents the design and evaluation of the first iteration of the DBR process. In this iteration, two technology artefacts were developed, implemented and evaluated in a pilot study. Firstly, the context of the proposed study is discussed. Next, the research questions answered by the iteration and the research design are presented. The data collection procedure is discussed in section 5.3. Section 5.4 provides the results and discussion. Finally, section 5.5 concludes the chapter.

5.1 **Context**

As discussed earlier, DBR is applied in authentic settings. In this research project, the first iteration of the design and evaluation of TePF for the lab environment, as presented in Chapter 3, was applied in an introductory system and networking course (INFT2031) at the University of Newcastle, Australia.

Prior to the intervention (pre-2016), the course was structured as follows: INFT2031 – Systems and Network Administration Course was offered in a 12 week semester (12 weeks) with 2 hours of lecture contact and 2 hours of lab contact per week. The labs commenced in week 2 of the semester and spanned through to week 12. Table 5.1 below illustrates the course plan for INFT2031.

Table 5. 1: Course Plan for INFT2031

Week	Topic	Learning Activity	Assessment Due
1	Introduction to Course Introduction to Hardware, OS, Network and Virtualization basics	Lectures	
2	ISO/OSI Model, TCP/IP Protocol Suite and OSI Model, Network Models, Windows Shared Folder and NTFS Permissions	Lectures & Labs	
3	Network Layer – Logical Addressing with IPv4	Lectures & Labs	
4	IPv4 Address Allocation, Internet Protocol, Routing	Lectures & Labs	
5	Topologies, Network Hardware, Ethernet, Wireless LAN, Network Diagrams	Lectures & Labs	
6	Network Operating System	Lectures & Labs	Practical Test 1
7	DNS	Lectures & Labs	
8	Active Directory	Lectures & Labs	Assignment 1
9	Process-to-process Delivery: TCP and UDP	Lectures & Labs	
10	Network Security Part 1 – Cryptography, Message Confidentiality, Integrity, Authentication and Non-repudiation, Key Management	Lectures & Labs	
11	AD Network Diagrams, Network Security Part 2 – IPSec, VPN, SSL, Firewalls, Proxies, VLANs	Lectures & Labs	
12	Review, Q&A	Lectures & Labs	Assignment 2, Practical Test 2

The lab environment was a decentralised lab environment. The course could not interfere with the existing campus network. Students were asked to purchase an external drive to host all their lab machines and networks for INFT2031. In 2015 and 2016, INFT2031 was offered at two campuses – Callaghan and Ourimbah. The Callaghan Campus labs were scheduled in a computer lab which contained Apple Mac computers while the Ourimbah labs were timetabled a lab using in a Windows environment. The lab computers were installed with VMware Fusion and VMware Workstation virtualization platforms at the Callaghan and Ourimbah campuses respectively. This allowed students to create VMs and networks among them. These VMs and networks were stored on their external drives which students brought to the lab class every week. The external hard drive had a partition created to store all VMs. This approach meant that students had their own lab work stored on the external drive without any impact to existing campus networks. Also, students could use this environment outside the campus on their personal computers as long as the students had the appropriate VMware platform installed. All students in the course had access to VMware's Academic Program so they could download and install the required VMware platform on their personal computers, if they wished, for educational purposes.

In terms of assessments of practical work, there were two practical tests in weeks 6 and 12 of the semester respectively. Each practical test was graded (summative) out of 20 and contributed 20% to the final grade. Out of the total 20 marks for each practical test, 15 marks were scored based on practical skills demonstrated by the accompanying system and network configuration tasks and 5 marks were scored based on an IPv6 quiz which was done by students after completion of an online learning module. Practical test 1 focused on configuring and sharing resources in a P2P environment and practical test 2 focused on configuring a client-server network environment and related network services. Prior to each practical test, a formative test was conducted for students in preparation for the practical tests.

To complete the practical work for the practical test, each student logged into a VM hosted on central servers owned by the department. The servers were Microsoft Windows based servers with Hyper-V used as the virtualization platform. In 2016, the version of Windows Server installed was Windows Server 2012. This virtual desktop environment (VDI) was managed by vWorkspace[4] platform. The configurations on each student's VM were marked by the tutors after the practical tests to provide a grade for the student's work.

5.2 **Research Design**

The TePF presented in Chapter 3 had a number of technology artefacts as well as a re-design of lab activities based on PLTs. In the first iteration, the implementation and evaluation of two technology artefacts were undertaken. The technology artefacts evaluated in this iteration were the virtual lab and the feedback tool.

Virtual Lab: The existing architecture of the virtual lab had a number of disadvantages pointed out by the practitioner from previous experience. Firstly, the decentralised architecture required students to purchase an external drive (if they didn't have one) which was an additional cost for students. Next, if the student's personal computer had a different architecture to the lab computers (e.g. Mac machines in the lab and Windows on the

[4] https://www.dell.com/community/vWorkspace/bd-p/workspace

personal machines), then students had to install additional software to read the external drive. Also, students needed to install VMware software on their personal machines if they needed to access the lab work using their personal machines. Thus, the ability to provide seamless access to a virtual lab 24/7 without the need for configuration was desirable. A centralised virtual lab platform that was remotely accessible would provide such a facility.

The department's existing virtual lab environment (based on Windows Server 2012, Hyper-V virtualization platform and vWorkspace) could provide a single VM accessible remotely by students. However, system-level computing courses, such as network and system administration, require students to configure multiple VMs and network resources without disrupting existing campus networks which needs a sandboxed environment. This was not supported by the existing architecture of the virtual lab implementation. New features in Windows Server 2016 with nested virtualization would have enabled deployment of sandboxed environments, as presented in Chapter 3 – TePF. However, at the time of iteration 1 (in 2016), this version of the Windows Server was not yet released and was therefore unavailable. Thus, it was decided to look at other alternatives to provide a centralised sandboxed lab environment.

Microsoft's Azure platform[5] provided the ability to deploy virtual resources through its public cloud offerings. Upon investigation, Microsoft's Azure Dev/Test Labs were considered as a suitable test environment to trial a centralised lab environment for INFT2031. Students had access to Microsoft's Imagine[6] subscription which provided them with $100 of Azure credit. This credit was deemed sufficient to conduct a number of labs. In this study, we used the popular Microsoft Azure (DevTest) cloud; however, the use cases and approaches laid out in this study are also applicable to other cloud providers such as Amazon Web Services (AWS).

Li and Jones (2011) evaluated both de-centralised and centralised labs in different system-level courses at East Carolina University. Their findings included the result that the use of centralised and decentralised labs are preferred over physical labs by students. Also,

[5] https://azure.microsoft.com
[6] https://imagine.microsoft.com

students preferred the labs (that is, centralised vs decentralised) they were most familiar with and used in their courses. For courses that required resource-intensive labs (such as multiple VMs and network components), the centralised approach was deemed preferable as student machines had limited resources to host these environments. The authors deemed that instructors needed to have the flexibility to select the approach required for the course. In the first iteration, students would be provided with the option to use centralised labs using Azure Dev/Test Labs as well as the option of using the decentralised labs as in previous years. The students' feedback was elicited and analysed.

Feedback Tool: The feedback tool was another artefact evaluated in this iteration. The first prototype of the feedback tool was developed, implemented and evaluated. As a first version of the prototype, a number of PowerShell scripts were developed for different labs to verify the students' lab configurations and provide a report. Students downloaded and ran the PowerShell script on their lab VM which generated a report showing correct and incorrect student configurations. An example report is provided in Figure 5.1.

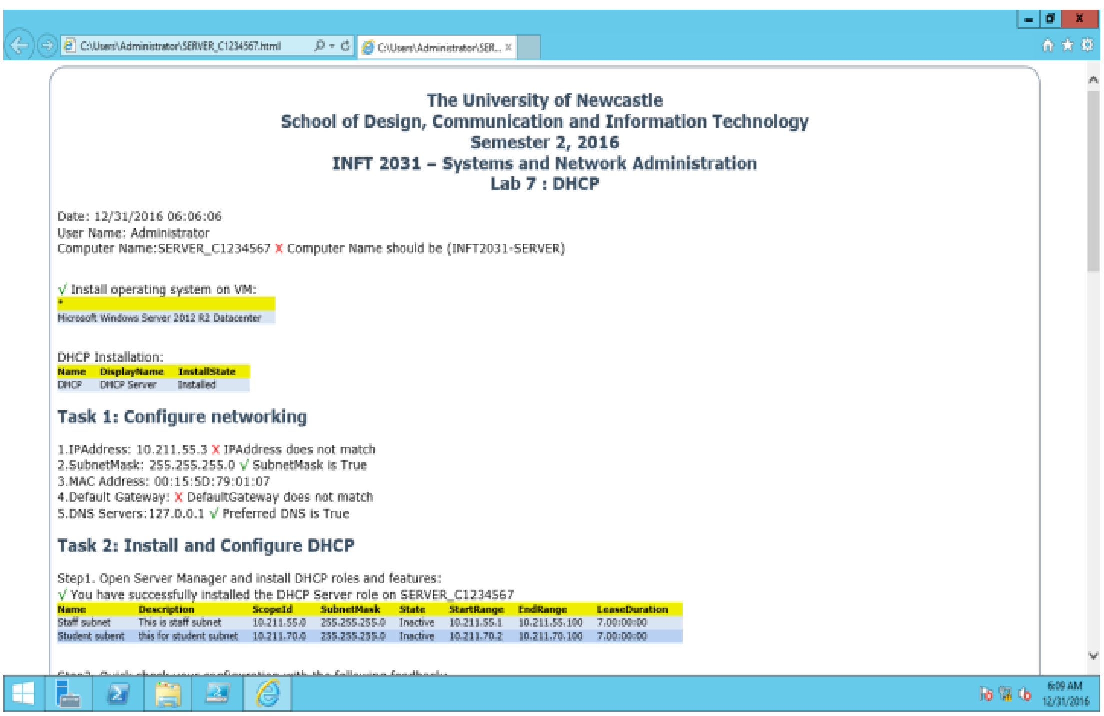


Figure 5. 1 Screenshot of Feedback Scripts Providing Automatic Feedback for a Lab Tutorial

There were a number of research questions that were addressed by this iteration, which are outlined below:

- RQ1 – What are students' perceptions of centralised and decentralised virtual labs?
- RQ2 – What are students' perceptions of the proposed feedback tool?
- RQ3 – Is there a measurable impact on learning outcomes based on the above intervention (i.e. centralised virtual labs and feedback tool)?

To answer research questions RQ1 and RQ2, the following research design was developed (see Table 5.2).

Table 5. 2: Types of Virtual Labs and Feedback Tool used in INFT 2031 for the Experiment

Lab (Topic)	Decentralised Lab	Centralised Lab	Feedback Tool
Labs 1 – 3 (P2P, NTFS and Shared Permissions)	√		
Lab 4 – Practice Test (Formative assessment)			
Practical Test 1			
Labs 6 - 9 (NOS, AD, DHCP, GPO)	√	√	√
Lab 10 – Practice Test (Formative assessment)			
Practical Test 2 + Survey			

The technology artefacts – the centralised virtual lab (based on Azure Dev/Test Lab) and the feedback tool – were deployed in the latter part of the semester. Students had the option of using either the centralised or the decentralised lab to complete Labs 7 – 9. Also, the feedback scripts were available for students to download on their lab VMs to be run to generate a report. Given that the students experienced the labs with and without centralised labs as well as with and without the feedback tool, the students were able to compare and provide feedback for evaluation. At the end of the semester, a survey was used to gather both quantitative and qualitative data to answer RQ1 and RQ2.

The survey consisted of 3 sections. Section 1 evaluated centralised and de-centralised labs. The quantitative survey questions were based on the Technology Acceptance Model (TAM) (Davis et al., 1989). In the literature, the TAM is used widely as a standard instrument to evaluate the acceptance of technology by users. Section 2 asked qualitative questions to elaborate on the answers in Section 1 as well as asking exploratory questions, such as "suggestions to improve". Section 3 of the survey collected data from students on the feedback tool. Quantitative data was collected using a 5-point Likert scale ranging from 1 - Strongly Disagree to 5 - Strongly Agree. Open-ended questions were used to gather the qualitative data.

To evaluate students' perceptions of the virtual labs and feedback tool, analysis of both the quantitative and qualitative data was performed. A number of statistical techniques, such as descriptive analysis, means, standard deviations, paired t-test and independent t-test, and a thematic analysis of the qualitative data were used. Triangulation was performed to provide a deeper understanding of student perceptions and to identify the reasons for them.

To address RQ3 - impact on learning outcomes based on the intervention - the impact on marks for the practical tests was observed. This is because the lab activities and lab environment aim to achieve intended learning outcome ILO4 - *Demonstrate ability to install, configure and troubleshoot PC, NOS and network services* - which were evaluated by practical tests 1 and 2. To identify the impact on learning outcomes of the intervention, a quasi-experiment (Creswell, 2015) with a control and experimental group was performed with an independent t-test based on marks for the practical tests. The experiment design was as follows:

- The 2015 cohort who completed INFT2031 course was the control group. The 2016 cohort that completed INFT2031 where the intervention occurred was the experimental group.
- Both control and experimental groups had the same teaching environment. That is, both groups were taught with the same course materials (i.e. content and labs) by the same lecturers in 2015 and 2016.
- Both control and experimental groups sat for the same practical tests.
- The intervention occurred in Labs 7-9 for the experimental group only.

Firstly, the marks for practical test 1 (pre-test) between the control (2015) and experimental (2016) groups were compared using independent t-tests to see if there was any statistically significant difference between the groups. If there was no statistically significant difference, then we could conclude that the experiment and control groups were similar (condition 1). Next, the marks for practical test 2 (post-test) between the control and experimental groups were compared using independent t-tests. If there was a statistically significant difference between the groups while condition 1 was also met, then it could be concluded that the intervention had an impact on the learning outcomes, answering RQ3. This experiment's design is presented in Table 5.3.

Table 5. 3: Quasi-experimental Design to Answer RQ3

Lab	2015 Cohort (Control Group)	2016 Cohort (Experimental Group)
Labs 1 - 3	No intervention	No intervention
Pre-Test	Practical test 1	Practical test 1
Lab 6	No intervention	No intervention
Lab 7	No intervention	*Intervention – feedback tool*
Labs 8 - 9	No intervention	*Intervention – Azure lab + feedback tool*
Post-Test	Practical test 2	Practical test 2

5.3 **Data Collection**

The pilot study to evaluate the above technology artefacts was conducted in semester 2, 2016 of the INFT2031 course. The course was offered on both the Callaghan and Ourimbah campuses. Students were invited to participate in a survey at the end of the course. Prior to the collection of any data, the researcher and supervisors had applied and obtained approval from the Human Ethics Research Committee of the university (Ethics Application: H-2016-0205). In 2016, a total of 103 students (85 - Callaghan, 18 - Ourimbah) completed the course and 94 students (76 - Callaghan and 18 - Ourimbah) participated in the research project and filled in the survey. Out of the 94 survey responses, 69 of them (73%) had used both types of virtual labs (centralised and decentralised) while 25 of them (21%) had used only the decentralised lab (i.e., external drive). For the evaluation of the feedback PowerShell scripts, 51 students answered that they had used the feedback scripts, 35 students answered they did not use them, and 8 students did not answer.

For the quasi-experiment, marks for the practical tests for the 2015 and 2016 cohorts were collected. In 2015, 87 students completed INFT2031 at Callaghan. Out of 87 students, 86 students completed practical test 1 and 82 students completed practical test 2. In 2015, at Ourimbah, 20 students completed the INFT2031 course. All 20 students completed both practical tests. In 2016, 94 students participated in the research project (76 from Callaghan campus and 18 from Ourimbah campus) and they all completed Practical Tests 1 and 2. These student marks were taken into consideration in the quasi-experiment.

5.4 **Results and Discussion**

This section presents the results of the experiment aiming to answer RQ1 – RQ3. Firstly, perceptions and acceptance of decentralised and centralised labs are presented addressing RQ1. Next, perceptions of the feedback tool are presented addressing RQ2. RQ3 is then addressed in section 5.4.3.

5.4.1 RQ1: Perceptions of Centralised and Decentralised Labs

All students who participated in the research project used the decentralised labs and filled in the survey. Table 5.4 presents all responses from the research participants who used the decentralised lab.

Table 5. 4: Descriptive Statistics of Student Responses about the Decentralised Virtual Lab Environment

Item - VMware Fusion labs (n=83)	Descriptive Statistics		
	M	**SD**	**Median**
1. The lab environment helped me to learn in INFT2031	4.33	.769	4.50
2. The lab environment improved my performance	4.25	.729	4.00
3. The lab environment helped me to achieve learning outcomes	4.24	.725	4.00
4. The lab environment provided easy access to the lab (24x7)	3.21	1.379	3.00
5. Having access to the lab from any device/location is helpful to me	3.86	1.227	4.00
6. I find it easy to use the lab environment	4.12	.817	4.00
7. I find the lab setting flexible to conduct my lab work	3.79	.959	4.00
8. I am satisfied with using the lab environment for my practical work in INFT2031	4.09	.878	4.00
9. I would like to use the lab environment in future networking and systems administration courses	3.80	1.087	4.00
10. Overall, how would you rate the lab environment	4.03	.798	4.00

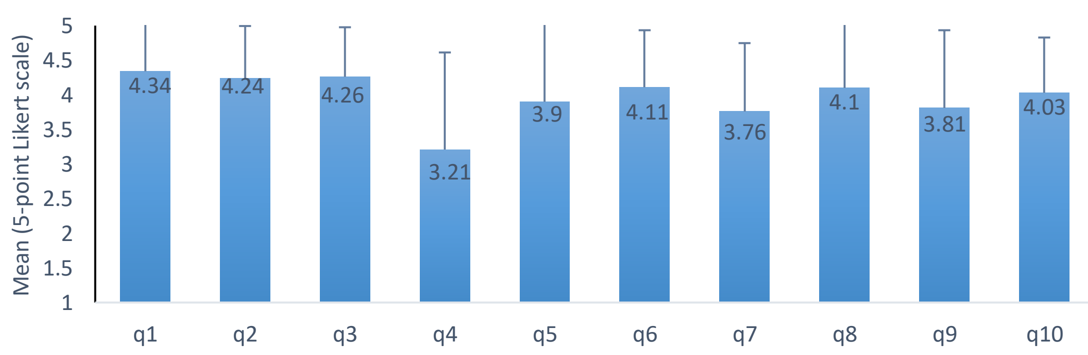


Figure 5. 2 Students’ Responses about using the Decentralised Virtual Lab Environment

Figure 5.2 shows the percentage of participants' answers against the total number of participants for each question item. Table 5.5 presents the descriptive statistics, i.e. Mean (M) and Standard Deviation (SD), for each question and groups these statistics according to the categories of TAM. This finding is similar to that found in previous studies by (Sarkar & Petrova, 2011; Caminero et al., 2016).

Table 5. 5: Descriptive Analysis for Decentralised Labs (n=83)

Category	Items	Mean	SD	Interpretation	Median
Perceived usefulness	1. The lab environment helped me to learn in INFT2031 2. The lab environment improved my performance 3. The lab environment helped me to achieve learning outcomes	4.28	.663	Strongly Agree	4.33
Perceived ease of use	4. The lab environment provided easy access to the lab (24x7) 5. Having access to the lab from any device/location is helpful to me 6. I find it easy to use the lab environment 7. I find the lab setting flexible to conduct my lab work	3.74	.834	Agree	3.75
Attitude towards using	8. I am satisfied with using the lab environment for my practical work in INFT2031 9. I would like to use the lab environment in future networking and systems administration courses	4.00	.798	Agree	4.00
Overall	10. Overall, how would you rate the lab environment	4.03	.718	Agree	4.00
SAT		3.82	.718	Agree	4.40

It can be observed that the decentralised labs were rated highly for usefulness in achieving learning outcomes and improving students' performance in the course. Many students considered it a valuable tool for learning and supporting course material. This can be seen from the number of 'Strongly Agree' and 'Agree' responses for questions Q1-Q3. Q4 – easy access (24x7) scored the lowest in the survey (M = 3.21). This was expected given that the decentralised lab environment did not provide seamless access. Also, Q5 – access from any device scored low (M = 3.90) in comparison. This lab environment did not provide access from all platforms easily as the format of the external partition was architecture specific. Q6 – ease of use – scored highly (M = 4.11) for the decentralised lab environment. VMware platform is an intuitive tool to use for the labs and students found it easy to use. Q7 – flexibility – did not comparatively score high (M = 3.76). The decentralised lab environment was not flexible to use across different OS platforms. Students were overall satisfied and scored highly for Q8 (satisfaction) and Q10 (overall rating) with mean scores of 4.10 and 4.03 respectively. However, interestingly, students only gave a mean score of 3.81 when asked whether they would like to use the environment again. This may be due to a preference for the centralised. This will be considered later in the discussion.

Next, we examine the descriptive statistics for the centralised labs. Table 5.6 presents all the responses for the centralised lab environment. Note that only 69 students (n = 69) responded that they did use the centralised lab environment.

Table 5. 6: Descriptive Statistics of Student Responses to the Centralised Virtual Lab Environment

Item –DevTest Azure Cloud labs (n=64)	Descriptive Statistics		
	M	**SD**	**Median**
1. The lab environment helped me to learn in INFT2031	4.27	.730	4.00
2. The lab environment improved my performance	4.25	.859	4.00
3. The lab environment helped me to achieve learning outcomes	4.23	.719	4.00
4. The lab environment provided easy access to the lab (24x7)	4.28	.944	5.00
5. Having access to the lab from any device/location is helpful to me	4.62	.574	5.00
6. I find it easy to use the lab environment	4.17	.796	4.00
7. I find the lab setting flexible to conduct my lab work	4.25	.804	4.00
8. I am satisfied with using the lab environment for my practical work in INFT2031	4.40	.698	5.00
9. I would like to use the lab environment in future networking and systems administration courses	4.55	.706	5.00
10. Overall, how would you rate the lab environment	4.32	.754	4.00

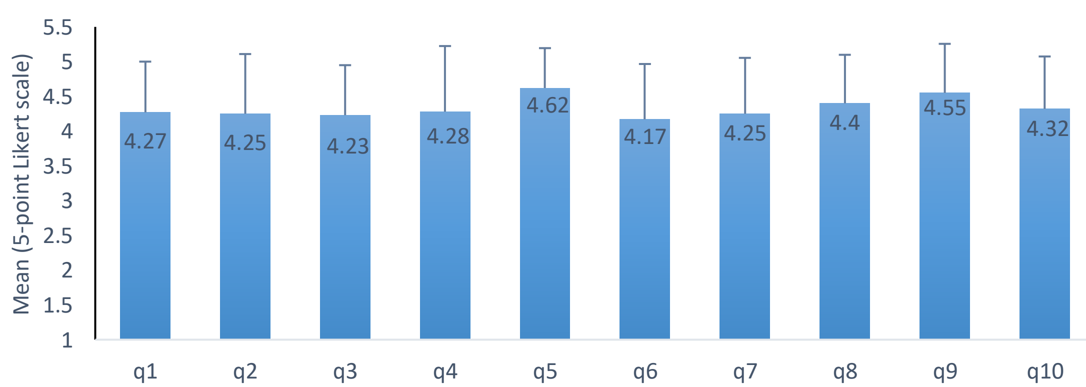


Figure 5. 3 Students' Responses to the Centralised Virtual Lab Environment

Figure 5.3 shows the mean scores for each survey question. Table 5.7 shows the summary statistics, i.e., mean (M), standard deviation (SD) and median, for each question and groups these statistics according to the categories described in (Table 5.6 above).

Table 5. 7: Descriptive Analysis on Centralised Lab Environment Responses (N=69)

Category	item	Mean	SD	Interpretation	Median
Perceived usefulness	1. The lab environment helped me to learn in INFT2031 2. The lab environment improved my performance 3. The lab environment helped me to achieve learning outcomes	4.24	.663	Strongly Agree	4.33
Perceived ease of use	4. The lab environment provided easy access to the lab (24x7) 5. Having access to the lab from any device/location is helpful to me 6. I find it easy to use the lab environment 7. I find the lab setting flexible to conduct my lab work	4.34	.632	Strongly Agree	4.50
Attitude towards using	8. I am satisfied with using the lab environment for my practical work in INFT2031 9. I would like to use the lab environment in future networking and systems administration courses	4.48	.624	Strongly Agree	4.50
Overall	10. Overall, how would you rate the lab environment	4.32	.753	Strongly Agree	4.00
	SAT	4.37	.571	Strongly Agree	4.50

From the descriptive analysis, all questions have a mean of over 4.0. This is a strong indication of student support for the use of the centralised lab environment. The respondents found that the Azure cloud virtual labs helped in improving their performance and achieving the learning outcomes as seen in the 4.25 mean score for the usefulness category. They also found that this kind of lab easier to use than the decentralised lab environment with a higher mean score at 4.33. Furthermore, the students were satisfied with the centralised lab environment and wished to use this type of lab again in the future (4.48 mean score).

It is evident that although both lab environments are useful and rated highly, the centralised lab environment was preferred and rated higher in ease of use, attitude and overall dimensions compared to the decentralised lab. Table 5.8 and Figure 5.4 illustrate means for each category for centralised and decentralised labs.

Table 5. 8: The Relationships between the Factors that Affect Student Satisfaction

Category	Decentralised lab environment			Centralised lab environment		
	M (SD)	**Interpretation**	**Median**	**M (SD)**	**Interpretation**	**Median**
Usefulness (1,2,3)	4.13 (.697)	Strongly Agree	4.00	4.24 (.669)	Strongly Agree	4.33
Ease of use (4,5,6,7)	3.54 (.830)	Agree	3.50	4.34 (.632)	Strongly Agree	4.50
Attitude (8,9)	3.84 (.924)	Agree	4.00	4.41 (.627)	Strongly Agree	4.50
Overall (10)	3.90 (.848)	Agree	4.00	4.33 (.774)	Strongly Agree	4.00

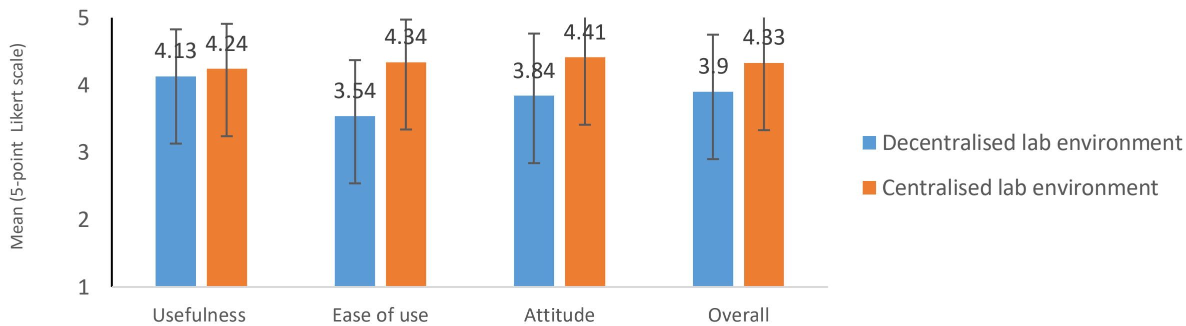


Figure 5. 4 Students' Perception of Centralised and Decentralised Lab Environments

An important point to note is that there were 94 participants in total who used decentralised lab environment which included 69 participants who used both labs and 25 participants who used the decentralised lab only. It is useful to examine the perceptions of each group of respondents. So, next, the descriptive statistics for each group are presented. The responses to the surveys are grouped as follows:

- SAT1 – The survey responses about the decentralised lab environment from participants who only used the decentralised lab environment (n = 25)
- SAT2a – The survey responses about the decentralised lab environment from participants who used both the centralised and decentralised lab environments (n = 69)
- SAT2b – The survey responses about the centralised lab environment from participants who used both the centralised and decentralised lab environments (n = 69).

The responses for SAT1, SAT2a and SAT2b are shown in Figure 5.5.

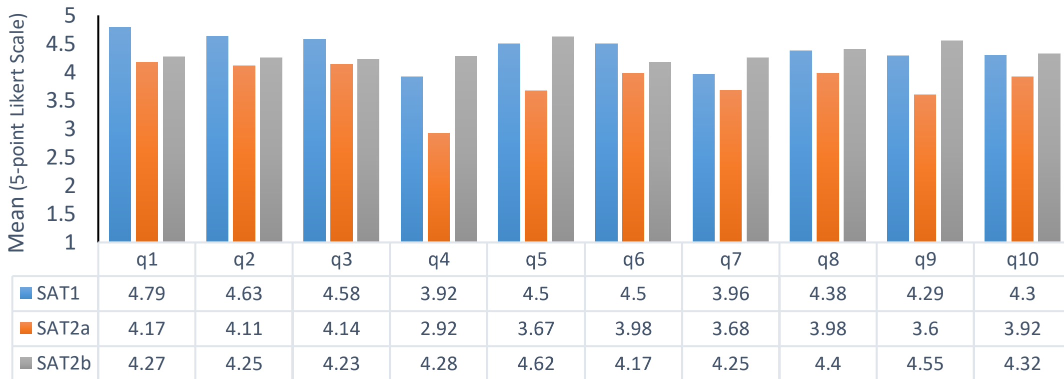


Figure 5. 5 Students' Perception categorised by Virtual Lab Environments.

- SAT1 – mean response about the decentralised lab environment from those who only used the decentralised lab environment.
- SAT2a – mean response about the decentralised lab environment from those who used both the centralised and decentralised lab environments.
- SAT 2b – mean response about the centralised lab environment from those who used both the centralised and decentralised lab environments.

From the above graph, it can be seen that students who used both lab environments rated centralised lab environments higher in all survey questions. To verify whether the result was significant, a paired t-test was performed. The results are presented in Table 5.9.

Table 5. 9: Paired t-test for the Two Virtual Labs in INFT2031

Category		**SAT 2a**		**SAT 2b**		**t-test**		
	n	M	SD	M	SD	df	*t*	*p*-value
Perceived usefulness	63	4.13	.697	4.24	.669	62	-1.029	.307
Perceived ease of use	64	3.54	.830	4.34	.632	63	-6.365	.000
Attitude towards using	63	3.84	.924	4.41	.627	62	-3.999	.000
Overall	49	3.90	.848	4.33	.774	48	-2.384	.021
SAT	64	3.80	.710	4.36	.577	63	-3.417	.000

The previous table shows that, except for the perceived usefulness dimension (which only has a 0.1 difference in mean), all other dimensions have a statistically significant difference in perception. From the above, it can be concluded that where the students experienced both lab environments, most students preferred to use the centralised lab environment over the decentralised lab environment. Analysis of the qualitative data provided further insights about the reasons for this difference. Also, it was interesting to find out why certain students chose to only use decentralised labs given the option of centralised labs was available in the latter part of the semester. Analysis of the qualitative data provided further answers to these questions, as discussed next.

The qualitative analysis provided a number of insights. For qualitative data, responses from all respondents who submitted qualitative data were collected and analysed.
Firstly, for the question Q1 in the survey (see Appendix A) - "*Did you use the Azure cloud lab? If no, explain why*", there were 25 responses. The analysis of the responses are given below:

- Of the 24 responses, 13 felt that they did not need to use the cloud lab as they were already familiar with the external drive which was easy to keep using and they did not see the need to change over (e.g. "*Already had my external drive and was happy using it for the course*").
- Five respondents had not attended the lab, did not know about it, and did not have time to try out a new environment or felt it was introduced too late.
- Two respondents felt that the cloud lab was slow, and the external drive was more reliable.
- Two respondents had technical issues with the use of cloud labs.
- Two respondents had other reasons (wanted to keep all lab work in one location, heard about issues in cloud labs from other students) to keep on using external drives for the labs.

The responses and analysis are provided in Table 5.10.

From the above analysis, it is clear that over 18 out of 25 (72%) of the respondents did not attempt to use the centralised lab environment because they either did not know/have time or did not see a need to change to cloud labs given that they were already familiar with and using the external drive. Out of the 25 respondents, it is clear that only 4 used the cloud lab and then decided to stay with the decentralised lab. These respondents did so because of technical, reliability and speed issues. Others did not attempt it as they did not see a reason to do so or were already familiar with decentralised labs or for other reasons. The technical, speed and reliability issues will be considered in the design of the centralised virtual lab in the second iteration. These aspects are discussed later in the chapter.

Table 5. 10: Qualitative Analysis of Q1 in the Survey

Theme (Frequency)	Response
Already Familiar/ Didn't see the need to change (13)	• *Use to using my VM and was easiest for me* • *I found it easier to use my own HD* • *Already had external HDD so I just kept using that* • *Already had my external drive and was happy using it for the course* • *I didn't need it* • *I had already started using the external drive* • *I had gotten used to using the VM stored on my external drive* • *I was satisfied with the external drive* • *It didn't seem necessary to change how I had already been learning the course for 8 weeks* • *Used the external drive as that was what I was used to and it required no further configuring* • *I was in the labs all the time* • *It is easier to use the hard drive and have no lag and across to windows key shortcuts. Flexibility to use Azure at home is great however* • *I tried it on Azure from home, but I found it easier on an external VM. It was my first time using Azure*
Did not know/ Didn't have time /Introduced too late (5)	• *Away for tutor* • *Did not attend labs, would have liked to try* • *Didn't have the time to test that* • *It looks so interesting. I wish I do it, but I'm doing INFT3970, I didn't have much time to do it* • *I found it implemented too late and preferred using the previous Mac and HDD method*
Speed/Reliability (2)	• *Don't like the delay when using keyboard and mouse* • *USB external was more reliable*
Technical Issues (2)	• *Ran out of availability* • *Used once, but soon ran into issues, then made progress with VM*
Other (2)	• *I heard other students complaining that it was not as efficient as the VMs on the ext. hard drives* • *I preferred having all of my work in one location*

When considering the qualitative data for question Q12 of the survey - *If given the choice to use external drive vs Azure cloud lab in conducting INFT2031 labs, which do you prefer? Why?* – 55 responses chose the Azure cloud lab (centralised lab environment) while 31 responses chose the external drive (decentralised lab environment). The thematic analysis of the 31 responses are given in Table 5.11.

Overwhelmingly (55 out of 94 responses), students preferred the centralised (Azure) lab due to its accessibility (from any device, remotely, 24/7 access), portability (across multiple platforms) and the convenience of not having to purchase, format and carry an external drive as with the decentralised lab environment. Seven responses also mentioned the cost effectiveness of the cloud solution as students did not need to purchase an external drive to complete the labs. Three responses mentioned the efficiency of using cloud-based solutions. One response considered the external drive solution to be unreliable. Three responses were categorised as "Other" which included comments such as "good to experiment" and "not having to use lab time to format configure drives". Seven students who had answered previously to Q1 - "*Did you use the Azure cloud lab? If no, explain why*" answered that they would prefer to use the Azure cloud lab if given the choice in Q12. Table 5.11 provides the thematic analysis of the participant comments.

Table 5. 11: Thematic Analysis for Q12 – Preference for Centralised Lab

Theme (Frequency)	Response
Accessibility/ Portability/ Ease of use/ Do not need to carry external drive/ Flexibility and convenience to work from anywhere anytime (44)	• *As it was able to be used anywhere and didn't need to remember the external drive* • *Azure - easier to use and more accessible* • *Azure allows access anywhere without need of an external HDD. Which is beneficial in both functionality and financial reasons* • *Azure as it is really accessible* • *Azure since I can easily access from home and no need to waste time setting up VMs. Had issue where Azure did not work at home but if that is fixed (might just have been me) it would be easier* • *Because you can access Azure using an internet connection and an updated browser* • *Can use on any platform. Especially useful for practice at home* • *Ease of accessibility* • *Easier access and less equipment required. No need to remember external drive* • *Easier to access and does not rely on me having the external drive on me at all times, plus I do not use a mac at home* • *Easier to access from home* • *Easier to access on multiple OS as you need a partitioned HDD with 2 ISO's to use the HDD anywhere* • *Easier to use* • *Easy access without the hassle of hardware* • *Easy to logon at home* • *I don't have a mac PC at home and sometimes I forget my external drive at home when I come to class* • *It is much easier to set up and use on the go. I can use it anywhere* • *Modern choice, flexible, 24/7 access*

	• *Much easier to use cloud lab anytime/anywhere. External drives aren't always reliable, they can break, cost to repair, etc. Gives exposure to using Azure* • *Much more convenient to be able to use anywhere on any device with no need of an external drive* • *The machine I use at home is a windows machine, thus I have no access to VMware Fusion* • *Because it is convenient* • *Convenience. Sadly I wasn't able to use it* • *Easier and simpler* • *Easier to use at home, from only computer (I didn't have a Mac at home)* • *Flexibility, no cost* • *For the convenience of not have to install a VM onto an external and then have to bring it every week* • *I enjoyed doing the labs in my own time. It was easier to catch up if you missed a lab* • *I kept forgetting to bring my drive* • *I prefer Azure as I do not need to carry an external drive and am able to go over lab content at home* • *It does not require a portable hard drive to be kept with you at every class as forgetting it was easy. Once I am used to Azure it should be a lot easier* • *It is so much easier to use and setup* • *It's a lot easier and removes the hassle that is involved with using the external hard drive. Direct access rather than downloading 10 different things* • *It’s easier to use and setup* • *Less chance of file compatibility access. Found Azure easier to use and check* • *No need for hard drive, meaning cheaper and easy* • *Portability, don't have to have HDD with you* • *Portable, cheaper, impossible to forget, work at home* • *So I don't have to format hard drives to Mac OS* • *Azure is way more efficient and closer to the real world programs we will use* • *Azure gives a view into cloud-based server operation whilst being less of a hassle than using VMware particularly across multiple machines* • *Doesn't require a device to be carried* • *Faster, and do not have to carry hard drive or sacrifice hard drive space* • *I would prefer Azure or another cloud-based system solution, so I could access the labs from home. Alternatively, I would be happy to continue using an external drive but use free, platform-independent VM software which I could install on my home machine. I think getting a hard drive wasn't the problem for me, being able to access the VM's on it without a Mac and its software was the problem*
Cost-effectiveness (7)	• *Azure allows access anywhere without need of an external HDD. Which is beneficial in both functionality and financial reasons.* • *No need for hard drive, meaning cheaper and easy* • *Portable, cheaper, impossible to forget, work at home*

	• *Flexibility, no cost* • *Azure. External drives can be expensive for a student.* • *Don't have to purchase or format external hard drive* • *VMware features a trial or license for $90. I would have used Azure if it was available from Lab 1*
Unreliable (1)	• *Much easier to use cloud lab anytime/anywhere. External drives aren't always reliable, they can break, cost to repair, etc. Gives exposure to using Azure.*
Other (3)	• *Good to experiment with* • *Had to buy an external drive, would be easiest to begin with Azure, but since I had bought the external drive and was used to it, I stuck with it.* • *Letting off setting up drives takes up a week that could be used to get a better start on the work in the course*

For Q12 – "*If given the choice to use external drive vs Azure cloud lab in conducting INFT2031 labs, which do you prefer? Why?*", 31 respondents chose to use the external drive (decentralised lab environment). Out of the 31 respondents, 21 mentioned that using the decentralised lab environment was easier, faster, flexible, more familiar and more reliable than the Azure cloud lab. Five respondents stated that they had never tried the cloud lab, 3 indicated it was due to personal preference and 2 had other reasons. Table 5.12 provides the analysis of the qualitative data. Out of 31 responses, 15 responses were from respondents who had used the cloud lab.

Table 5. 12: Thematic Analysis for Q12 – Preference for Decentralised Lab

Theme (Frequency)	Response
Easier, quicker, familiar, flexible and reliable (21)	• *Azure cloud was slow to start and lagged when changing settings and uninstalling features*[*,P] • *Azure had more problems and was consuming much time*[*, P] • *External Drive-Easier to play with, all settings without a chance of losing access*[*, R] • *I felt it was a simpler way of doing the labs*[E] • *I found it quicker and easier. Azure seems a little slow and hard to configure to log on*[*, P, E, FLEX] • *Just because I prefer a fast responsive input when using a computer. Although not having to use an external hard drive is also a big benefit* • *Less complications with computer*[*, E] • *Much easier and works*[*, E] • *When I made a mistake assigning some IP I shouldn't have on Azure, I had to delete and recreate a VM which wasted a bunch of time. External drives are just simpler once set up I feel*[*, E] • *I am more familiar with this method*[*, F] • *If Azure was implemented earlier perhaps, but due to already becoming comfortable using an external drive, I found it easier and more physical*

	• *One I mainly used* • *External drive is more reliable/personal*[*, R] • *I would use my HDD as it is more reliable. Azure frequently crashed or my Virtual Machine broke. I believe Azure is fantastic but it needs more work to iron out the bugs*[*, R] • *Seems more reliable* • *External drive because I think it's less likely to experience errors*[*, R] • *It has less chance of disconnecting on me*[*, R] • *Using the external drive allows the user to fix a mistake. When configuring the IP/DNS addresses on Azure, I was forced to delete the VM and start over*[*, FLEX] • *Maybe it was just me, but it performed far better*[*, P] • *Sometimes Azure is unresponsive and/or the RDP connection fails*[*, R] • *At the moment it seems like the most suitable and most efficient option*
Never tried (5)	• *I never tried the cloud as it seemed to require a lot of setting up* • *Didn't get a good opportunity to use Azure* • *I never used Azure so I stuck with what I knew* • *I would use the drive as I have not had the chance to use the Azure cloud, therefore I don't know how well it works* • *If Azure was implemented earlier perhaps, but due to already becoming comfortable using an external drive, I found it easier and more physical*
Personal preference (3)	• *Personal preference* • *The only issue I had with the external drive is having to purchase one, however I prefer it* • *This is mixed for me but would prefer the HDD because it's plug & play. I also used the HD from home. I would use Azure if there was no choice*
Other (2)	• *Because I can do it any time* • *More helpful to go to class and have lecturer to help if you get stuck*

* Had used the centralised lab (14), [R] – Reliability (6), [P] – Performance (5), [E] – Ease of use (4), [FLEX] – Flexibility (2), [F] – Familiarity (1).

For Q13 – "*Any disadvantages of using external drive/Azure cloud labs?*", there were 75 responses out of which 64 responses were taken into consideration for the analysis. Eleven responses were discarded as their meaning/intention was unclear. The thematic analysis for the responses is provided in Table 5.13. Six responses mentioned lag or delay as a disadvantage of using the Azure cloud lab, while 6 responses also mentioned the need to have a constant network connection, compared to the external drive, as a disadvantage. Lack of ease of use (1), lack of flexibility to manipulate configurations (2) and reliability issues (2) in the Azure cloud lab were mentioned as disadvantages. Three respondents were concerned with technical issues such as lack of sufficient IP addresses in the cloud lab, and lack of sufficient documentation and instructor help on the Azure cloud lab was mentioned in 2 responses. Reliability was mentioned as an issue in 2 responses. These concerns and how the study aimed to address these in the second iteration will be discussed later.

In terms of the decentralised labs, lack of accessibility and portability were the main disadvantages (20 responses), followed by the cost of external drives (13 responses). Overhead, hassle to purchase and the need to bring the external drives to the lab with the possibility of loss or being forgotten were also disadvantages (11 responses). The initial setup of the external drive also was considered a disadvantage by 6 respondents. Reliability of external drives when conducting labs was also a concern (5 responses). Other disadvantages included the external drive being an "old school" method, and the requirement for an appropriately resourced computer to complete lab work outside the allocated computer labs.

Table 5. 13 : Thematic Analysis for Q13 – Disadvantages for Azure Cloud and External Drive

Type	Theme (Frequency)	Response
Azure	Slow Performance (6)	• *Azure has some lag* • *Azure: small amount of lag (to be expected)* • *Azure at times didn't load fast* • *Slow, internet connection may drop out* • *Cloud labs were a bit slow to load* • *Azure can run a bit slow*
	Network connection (6)	• *Azure clouds require an internet connection* • *Constant network connection* • *Azure is reliant on a good connection* • *When the network is down, external drive is more convenient to use* • *Azure needs internet* • *Slow, internet connection may drop out*
	Ease of use, Flexibility, Reliability (5)	• *Azure - Difficult to repair after potential mistakes* • *Setting VM was harder in Azure* • *Azure disadvantages - cannot play with the IP address easily without connection loss* • *Azure played up on me and had to be stored* • *Azure Cloud: Sometimes it breaks*
	Technical issues (3)	• *Not enough IP addresses on cloud* • *Changing DNS and IP settings ruin Azure cloud* • *Azure cloud - didn't have enough slots for the public IP*
	Lack of documentation/ help (2)	• *No instructor to help - Azure* • *Azure needs more explanation on how it works and difficulty logging in from home*

	Other (2)	• *The Azure environment didn't work at first* • *For use in lab Azure had poor compatibility with Mac*
External Drive	Accessibility, Portability (20)	• *External drive requires a MAC for use outside of the labs* • *External drive would not be used to practice in my own time from home and was only usable on a Mac* • *Students without access to a MAC must wait for available library machines* • *Disadvantage of external - I don't have a Mac* • *External drive - No access at home due to Mac partition* • *You cannot use the Windows version* • *External: Have to have it on me, cannot use on windows* • *External drive less accessible* • *Azure could use anywhere. Fusion caused pain with corruptions* • *Disadvantage of using HDD - if no mac at home, won't work on windows PC* • *External is portable but since we use mac, it can't be used at home* • *Using an external drive requires being on site, in the lab, at a Mac* • *External drives can suffer from compatibility issues* • *Ability to use drives outside lab environments difficult due to platform choice Mac* • *External drive is Mac partition* • *External Drive disadvantages - using a Mac partition made it very difficult to continue working at home* • *The external drive was restricted to Mac computers which had VM Fusion software. Which means only my lab computers had the software and it made it hard for me to practice using the Windows Lab work* • *External Drive disadvantage: harder to use at home, can't use virtual machines on a PC* • *Had to use External Drive on Macs* • *Drive must be formatted restricting user on other systems*
	Cost (13)	• *The external drive is cumbersome and expensive, if you don't already have one. Azure is very easy* • *External drive - Disadvantages = have to buy drive* • *Price of drive* • *External is additional cost and hassle however does all understanding of central install and setup* • *External: having to purchase/carry an external drive* • *External drive had the disadvantages of costs if you didn't own one before using this course* • *The external makes it so students buy $100 hard drive and spend 2 weeks setting it up* • *Having to buy external drive if you don't own one* • *Yes, for some people I can see the price of an ED hard*

		• *Cost of external* • *The price of external* • *Hard drive is expensive* • *Externals are expensive*
	Overhead to buy/bring, can be lost/left behind (11)	• *Sometimes I forgot to take the HD to the lab. Then I can't do anything without it* • *External drives can be lost/left behind* • *The external drive is cumbersome and expensive, if you don't already have one* • *External is additional cost and hassle however does all understanding of central install and setup* • *External: having to purchase/carry an external drive* • *Better not forget/lose external drive* • *External drives, unnecessary burden, easy to forget and takes much longer to install software* • *External: Have to have it on me* • *Portable hard drives can get lost or forgotten very easily* • *Ext. drives can easily forget* • *Having to format or buy another external hard drive*
	Overhead to setup external drive (6)	• *The fact that I had to reformat and commit 200 GB of HDD memory was a huge negative for HDD* • *External drive needed to be formatted for my home PC as its specs were different* • *Having to format or buy another external hard drive* • *External drive setup felt too hard for beginners* • *Having to wipe your HDD. That was super annoying* • *The external makes it so students buy $100 hard drive and spend 2 weeks setting it up*
	Reliability (5)	• *External hard drive: takes too long to download everything* • *ED has issues starting up* • *Fusion caused pain with corruptions* • *Had some drive issues in earlier labs* • *Harder to lose info with Azure*
	Other (4)	• *Drive - Old school, when we need to be utilising tools that will be used in the industry (Azure, Cisco Meraki)* • *External drive needs VMware (and a powerful PC)* • *External drive is slow. Easy to make mistakes and corrupt VM need to start over* • *External drives, unnecessary burden, easy to forget and takes much longer to install software*

For Q14 – "*Please provide any suggestions that you would like to see implemented in the cloud lab in future*", there were 31 responses. The results of the thematic analysis are given in Table 5.14. Eleven respondents wanted to improve the labs with tutorial videos, clearer explanations and details, walkthroughs, etc. Five respondents requested an improved and more user-friendly interface. Five respondents wanted better performance (faster loading, restarts, etc.) from the cloud lab. Four respondents stated that it would be better to have cloud labs introduced earlier on. Three respondents wanted resolution of technical issues and improved reliability.

Table 5. 14: Thematic Analysis of Q14 – Suggestions for Cloud Lab

Theme (Frequency)	Response
Improve on help, documentation, lab sheets, presentation (11)	• *Great detail on use and up to date notes* • *Tutorial Videos* • *Maybe an explanation tute of Azure* • *Cleaner tutorials* • *Clearer pictures and walkthroughs* • *A better tutorial* • *More how-to presentation style learning on a projector* • *More support for servers* • *More explanation on how to use* • *Azure standard profile then add project for each new week* • *Having a simpler server to practice with*
Improve interface (8)	• *More user friendly* • *Easier to use interface* • *Easier UI to navigate* • *Too many links on the main page so I got confused. Maybe more simple. Groups of VMs* • *Resizable window. Had to scroll horizontally* • *Make it easier to connect from home* • *HTML5 RDP for Azure (instead of having to download an RDP app)* • *Simpler resume function in event of disconnect*
Improve performance (5)	• *It was a bit slow at times* • *The cloud lab was slow in terms of performance. I understand this is perhaps not easily solvable and the ability to complete labs from home compensates for this. Just thinking out loud* • *Faster loading, easier setting up* • *Faster access* • *Faster restart times*
Use cloud lab early on (4)	• *Use cloud labs for all lab work* • *More Azure based labs* • *Earlier implementation. Learning it late in the semester when everything gets hectic might leave people reluctant to try it* • *Expanded use of Azure*
Resolve technical issues, improve reliability (3)	• *Make sure there's enough IP addresses :)* • *A less buggy version. My VMs would crash frequently* • *Ensure it works*

The above results and analysis answered RQ1 comprehensively. From the above analysis, we can conclude that the majority of respondents preferred to use the centralised lab environment. Many students who used only the decentralised labs did so because they were familiar with it and did not see the need or have time to change over to use the centralised labs. The centralised lab environment has a number of advantages that make it the preferred choice: 24x7; flexible; and seamless access from any device remotely without the need to purchase or configure and handle external drives. Also, the quantitative data illustrates that participants rated the centralised labs higher than decentralised labs in most survey questions and the centralised labs had similar or higher TAM results. Also, the paired t-test showed that students who used both labs rated the centralised lab higher in all dimensions with the exception of perceived usefulness (which was similar), at a statistically significant level. However, when evaluating the qualitative data, there were 15 student respondents who used both labs and preferred to use the decentralised labs. The main reasons for their choice was reliability without errors, performance lag with Azure, ease of use and flexibility to configure. The suggested improvements for the centralised lab (Q14) were: improve labs (with more how-to and documentation); provide easier to use interface and features; improve performance; introduce centralised labs early on in the semester; and resolve technical issues causing errors. The second iteration addressed these suggestions. As discussed in Chapter 3, all labs were revised by applying PLTs (such as Kolb's ELC), making them more interactive and engaging. The centralised virtual lab environment outlined in Chapter 3 provides an interface which is the same as a decentralised lab environment (a sandboxed Windows Server 2016 interface) which is easy, intuitive, flexible and resolves technical issues such as the limited number of addresses in the Azure environment. Also, given that the virtual lab was now hosted on a private cloud at the university with no restrictions on budget (such as Azure credit), the instructor has the flexibility to provide a higher resourced sandboxed environment for each student for lab work. As the private cloud is hosted on the campus network environment (similar to the lab network) with access using tools such as vWorkspace client, a more reliable, faster and responsive connection was expected as opposed to using the Azure Dev/Test environment. The centralised lab environment was made available from the first lab for students in the second iteration. This environment was implemented and evaluated in the second iteration.

The next section addresses RQ2 and evaluates the feedback tool.

5.4.2 RQ2: Perceptions on the Feedback Tool

This section addresses RQ2 – students' perception on the feedback tool. Question 15 of the survey (see Appendix A) was "*Did you use the PowerShell feedback scripts?*" Fifty-one students answered yes, 35 answered no and 8 did not answer. The thematic analysis of the second part of the question – "*If no, please explain why?*" is provided in Table 5.15. Fourteen responded that they did not have enough time or had not progressed far enough. Eight responses stated that they did not feel the need or forgot to use the feedback tool. There were six responses where the students were unsure how to use it (*had no idea*). Two others had difficulty downloading the scripts to the VM. From the above responses, it is clear that only 2 out of 30 (five who answered no did not provide qualitative feedback) actually had attempted to use the feedback tool and had technical difficulties (i.e. had issues downloading the scripts), while the others had not attempted to use the feedback tool at all.

Table 5. 15: Thematic Analysis of Q15 – Reasons for not using the Feedback Tool

Theme (Frequency)	Response
No time, did not progress far enough (14)	• *Ran out of time* • *Didn't get time to do them a lot* • *Limited time* • *Didn't have the time* • *Never got round to it* • *Did not get the chance before they were (workstations) taken down* • *Ran out of time catching up* • *Did not progress far enough* • *Didn't get around to wing it* • *I fell behind as a result of Mac partition limiting usability, so I didn't fully complete each lab so didn't test* • *Not enough time, would have otherwise* • *Didn't get around to using them - time restriction* • *Didn't get around to doing it* • *I didn't have enough time during the lab class to use the feedback*
Didn't feel the need, forgot (8)	• *I felt confident that I had done it well* • *Didn't see the need* • *Did not feel the need to* • *Configured in manager* • *Forgot to look at it* • *I forgot to use them* • *Preferred to do things manually*

	• *Easier alternatives*
Unsure how to use (6)	• *Unsure of how to utilise* • *It was hard to understand* • *I had no idea* • *Didn't know what they were* • *Missed tute* • *Tutor didn't explain how to use it*
Technical difficulties (2)	• *Couldn't really log into Blackboard to download them onto VM* • *I wasn't able to download them from my external drive VM*

Of the 51 students who used the feedback tool, the quantitative data for the survey questions are given below (see Table 5.16 and Figure 5.6). The section three survey questions Q1 to Q5 have means over 7.5 (out of 10). All responses were above 5 (out of 10) except for 1 response of 4 (out of 10) in Q2 (fast to load) and Q3 (encourages me to do work). Q4 – "*I prefer to have this feedback script with the labs*" and Q5 – "*Based on this script feedback, how likely are you to recommend it to students in next semester?*" scored means of 8.35 and 8.41 respectively. Also, overall (94.1%) of students were satisfied (70.6%) or highly satisfied (23.5%). No student responded as dissatisfied or extremely dissatisfied. This is a highly positive result and shows acceptance of the feedback tool by the students. To find out the reason for such ratings, a thematic analysis of Q17 of the survey – "*What is the primary reason for your rating?*" was performed. The qualitative analysis is provided in Table 5.16.

Table 5. 16: Item Descriptive Analysis Results of the Feedback Scripts Tool (n=51)

Dimension	Survey Question	10-point Likert scale		
		Mean	SD	Median
Perceived ease of use	Q1. The feedback offering descriptions were easy to understand	7.86	1.497	8.00
	Q2. The feedback page on your VM was fast to load	8.06	1.475	8.00
Perceived usefulness	Q3. This feedback script encourages me to do my lab work	7.72	1.715	9.00
Attitude towards using	Q4. I prefer to have this feedback script with the labs	8.35	1.610	8.00
	Q5. Based on this script feedback, how likely are you to recommend it to students next semester?	8.41	1.472	8.00
		5-point Likert scale		
Overall	Q6 - How satisfied are you with feedback generated from the script?	4.18	.518	4.00

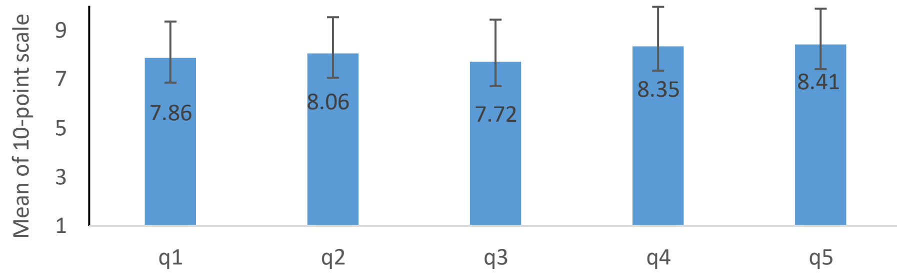


Figure 5. 6 Feedback Tool Mean Survey Question Results (based 10-point scale)

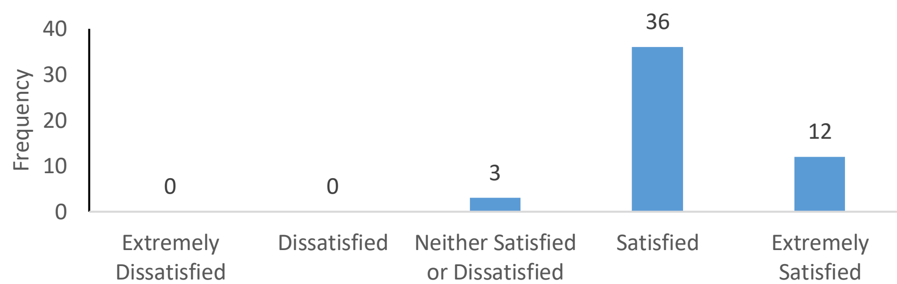


Figure 5. 7 Overall Rating of Feedback Tool

Table 5. 17: Thematic Analysis of Q17 – Reason for Rating of Feedback Tool

Theme (Frequency)	Response
Detailed, clear, useful, intuitive feedback that helps me and keeps me on the right track (36)	• *The scripts are very useful, a few value errors gave incorrect results at times* • *It tells me what needs to be done and what I have done correctly* • *simple to use, a lot of feedback* • *It showed where I went wrong with (almost) no ambiguity, test feedback is nice* • *Nice to be able to get instant feedback* • *It is very clear and informative* • *Helped me stay on the right track* • *Effective program that helped me to understand my mistakes made in the lab.* • *Easy to learn functionality* • *They told me whether I had done work correctly, which I would otherwise be unsure of* • *A large amount of feedback was provided but some of it was pretty vague with no real exploration* • *Helps to know if what you're doing is correct* • *Detailed explanation of what I did right and wrong* • *It was good to see what I achieved, but I found that it would sometimes display data incorrectly* • *Was useful however it was often buggy and incorrect* • *Made sense and was able to self-analyse my work* • *All feedback was comprehensive* • *Easy to read, understand, annoying to execute* • *Scripts made it easy to know where I went wrong so I could fix it* • *It worked well*

	• *Quick and easy response to work* • *Made classes easier* • *Often gave wrong output but still extremely useful nonetheless* • *They worked well but it was sometimes hard to read at all* • *Told me that I got right/wrong in my configuration instantly* • *Very accurate. That way I also know if I am doing something wrong and I can learn from mistakes* • *I found it useful* • *I knew what I was doing right and wrong* • *It provided a very nice summary of the work I had done for checking errors* • *Made checking easy* • *Reason: It was satisfying* • *PowerShell is good but not used by most* • *They were to the point in terms of feedback* • *It provided me with relevant feedback* • *It gives me an idea on how I go with the lab* • *It was well presented and more comprehensive than I expected*
Ease of use (5)	• *Simple to use, a lot of feedback* • *Easy to learn functionality* • *It seemed very intuitive* • *PowerShell is easy to use and there is lots of info online* • *Ease of use was a pro for me*
Instant feedback (5)	• *Nice to be able to get instant feedback* • *Instant feedback was great, there were some errors in it still but* • *Quick and easy response to work* • *It provided immediate feedback* • *Told me that I got right/wrong in my configuration instantly*
Error free * (8)	• *The scripts are very useful, a few value errors gave incorrect results at times* • *Instant feedback was great, there were some errors in it still but* • *Had a minor issue here and there. Overall good* • *It was good to see what I achieved, but I found that it would sometimes display data incorrectly* • *Was useful however it was often buggy and incorrect* • *Some code in PowerShell did not work* • *Often gave wrong output but still extremely useful nonetheless* • *There was a couple of questions where I did exactly as the tute notes said and it didn't see that I had done it*
Feedback could be more precise and more explanation* (2)	• *A large amount of feedback was provided but some of it was pretty vague with no real exploration* • *It will be good if there are more feedbacks*
Make it easier to execute * (1)	• *Easy to read, understand, annoying to execute*
Make the results easier to read * (1)	• *They worked well but it was sometimes hard to read at all*
Other (2)	• *I'd rate it just above average, not super intuitive*

* Suggestion for improvement

From the analysis, it is clear that the feedback tool performed as expected providing useful, detailed, clear, intuitive feedback as intended (35 responses). Students also liked the fact that the feedback tool was easy to use (5) and provided instant feedback (5). There were a number of comments that can be classified into feedback to be considered for improving the feedback tool: i) make the tool bug free (8); ii) make feedback more precise (2); iii) improve the display of the report making it easier to read (1); and iv) make it easier to execute the scripts (1).

In the survey, Q23 asks students on suggestions for improvement of the feedback tool. The thematic analysis of Q23 – "*Are there any suggestions for how the feedback script could be improved?*" is presented in Table 5.18. It is clear from the analysis that fixing bugs is the most frequently asked for improvement (7), followed by a more simple, precise, clear output (4); and also detailed output where needed (3). Downloading the scripts also was difficult (2) as stated by two respondents.

Table 5. 18: Thematic Analysis of Q23– Suggestions to Improve Feedback Tool

Theme (Frequency)	Response
Error fixes (7)	• *Less errors, a more user-friendly interface. The user is bombarded with information about the labs. A simple table would suffice* • *Some mistakes still because it's new* • *Minor bug fixing of issues that [arose] :-)* • *Fix any bugs/inconsistencies* • *Double check if PowerShell will work properly* • *Testing and revision so that the scripts are more accurate and don't give false feedback* • *Maybe better error association so you know how to fix errors*
Output is precise, clear, simple (4)	• *Less errors, a more user-friendly interface. The user is bombarded with information about the labs. A simple table would suffice* • *Provide a shorter summary that is quick to read* • *Just making sure each point of feedback is obvious, what it's [referring] to in the lab exercises* • *Simplified a little*
Output detailed where needed (3)	• *Evaluating the feedback given and see if any in-depth information or explanation could be given in some section.* • *Perhaps more descriptive. Like did not map drive properly, for instance :)* • *Perhaps more intricate explanations or guide links*
Avoid script downloading (2)	• *I don't know if it's possible but downloading it onto the Virtual PC was difficult* • *Have VM's able to connect to internet so can download them*

The above results and analysis comprehensively addressed RQ2 – students' perceptions of the feedback tool. It can be concluded that students were highly satisfied and found it useful and helpful in completing lab work. A number of improvements for the second iteration were noted including: improving the scripts to be bug-free; providing more user-friendly output with clear, precise information and detail where needed; downloading the scripts to the VM was considered a hassle which was also a technical difficulty stated by 2 respondents as a reason for not using the feedback tool (see Table 5.17 – Technical Difficulties). The next iteration uses an improved version of the feedback tool that addressed these issues. It is important to note that the feedback tool outlined in the Chapter 3 architecture did not require scripts to be downloaded and had an improved user-friendly interface. Also, the scripts were reviewed to fix bugs and provide concise, useful information presented in a user-friendly manner. The updated version of the feedback tool was implemented and evaluated in the second iteration (presented in Chapter 6).

The next section addresses RQ3 and presents the results of the quasi-experiment.

5.4.3 RQ3: Impact on Learning Outcomes

This section aims to address RQ3 – "*Is there a measurable impact on learning outcomes based on the above intervention?*". As discussed in the research design in section 5.2, a quasi-experiment was conducted to verify whether there was a measurable impact on learning outcomes based on the intervention. Marks for practical test 1 and practical test 2 for the control group (2015 cohort) and the experimental group (2016 cohort) were examined. The control group (2015 cohort) consisted of students enrolled in INFT2031 in semester 2, 2015 at the Callaghan and Ourimbah campuses. In the 2015 cohort, 106 students sat practical test 1 and were given marks and 102 students sat practical test 2 and were given marks. The experimental group (2016 cohort) consisted of students enrolled in INFT2031 in semester 2, 2016 at the Callaghan and Ourimbah campuses. From the 2016 cohort, 94 students participated in the research project and all of these students sat practical test 1 and practical test 2. These student marks were takin into consideration (see Table 5.19).

Table 5. 19: Number of students' marks used for the Quasi-experiment

	2015 Cohort (Control Group)	2016 Cohort (Experimental Group)
Practical Test 1	106	94
Practical Test 2	102	94

As discussed in the research design, a quasi-experiment was undertaken. The intervention occurred for the 2016 cohort in Labs 7-9 (i.e., the latter part of the semester) after practical test 1. To compare whether the control and experimental groups were similar, practical test 1 marks were compared (pre-test), which is prior to the intervention. The results of the independent t-test are below (see Figure 5.8).

Group	2015 Cohort – Practical Test 1	2016 Cohort – Practical Test 1
Mean	16.637	17.239
SD	2.317	2.740
SEM	0.225	0.283
N	106	94

P value and statistical significance:
- *The two-tailed P value equals 0.0936*
- *By conventional criteria, this difference is considered to be not quite statistically significant.*

Confidence interval:
- *The mean of* 2015 Cohort – Practical Test 1 *minus* 2016 Cohort – Practical Test 1 *equals -0.603*
- *95% confidence interval of this difference: From -1.308 to 0.103*

Intermediate values used in calculations:
- *t = 1.6846*
- *df = 198*
- *standard error of difference = 0.358*

Figure 5. 8 Results of Independent t-test for Practical Test 1 Marks between Control and Experimental Groups

From the above results, it can be concluded that there was no significant difference in the scores for the 2015 cohort's practical test 1 (M = 16.637, SD = 2.317) and the 2016 cohort's practical test 1 (M = 17.239, SD = 2.740) conditions; t (198) =1.6846, p = 0.0936. This meets condition 1 of the research design (see section 5.2) and we can conclude that the cohorts were similar (i.e., not statistically different) based on their practical test 1 scores.

Next, the intervention (i.e., using the Azure cloud lab and the feedback tool) occurred for the 2016 cohort (experimental group) only. To determine whether a measurable impact on learning outcomes had occurred with respect to the experimental group, an independent *t*-test was conducted on the practical test 2 marks for both the control and experimental groups.

Group	2015 Cohort – Practical Test 2	2016 Cohort – Practical Test 2
Mean	15.549	16.303
SD	3.372	2.735
SEM	0.334	0.282
N	102	94

P value and statistical significance:
- *The two-tailed P value equals 0.0887*
- *By conventional criteria, this difference is considered to be not quite statistically significant.*

Confidence interval:
- *The mean of* 2015 Cohort – Practical Test 2 *minus* 2016 Cohort – Practical Test 2 *equals -0.754*
- *95% confidence interval of this difference: From -1.624 to 0.115*

Intermediate values used in calculations:
- *t = 1.7110*
- *df = 194*
- *standard error of difference = 0.441*

Figure 5. 9 Results of Independent t-test for Practical Test 2 Marks between Control and Experimental Groups

The results of the independent *t*-test for practical test 2 for the 2015 cohort and the 2016 cohort are shown in Figure 5.9. From these results, it can be concluded that there was no significant difference between the scores for the 2015 cohort's practical test 2 (M=15.549, SD=3.372) and the 2016 cohort's practical test 2 (M=16.303, SD=2.735) (conditions: t (194) = 1.7110, p = 0.0887). Thus, it can be concluded that there was no measurable impact on learning outcomes (based on practical test scores) due to the intervention. There may be a number of reasons for not observing a significant impact on the learning outcomes. The intervention was only conducted for a short period (the last 3 labs out of 10 labs) and also not all of the 2016 cohort used the centralised lab environment (77%) or the feedback tool (59%). It is quite possible that the intervention period was too short, and the participant population was insufficient to show a measurable impact on the learning outcomes. In the next iteration (detailed in Chapter 6), a complete implementation of TePF will be run for the entire semester and then evaluated.

5.5 **Summary**

In this chapter, the first iteration of the DBR process was presented. Two technology artefacts of the TePF were evaluated: i) the virtual lab; and ii) the feedback tool. Two architectures for the virtual lab were evaluated – a centralised lab and a decentralised lab. A comprehensive analysis of both quantitative and qualitative data was conducted and evaluated. It is clear that the centralised virtual lab environment had a number of advantages such as 24/7 access, flexibility and seamless access from any device remotely. The qualitative analysis of the centralised and decentralised labs provided new insights and issues, limitations and disadvantages of each type of lab. It was evident that advantages of centralised labs far outnumber and outweigh those of the decentralised lab environment. In the next iteration, a new design and implementation of a centralised virtual lab, addressing many of the concerns revealed in this chapter is implemented and evaluated.

The first version of the feedback tool was implemented as a number of PowerShell scripts and evaluated. Students accepted and rated the feedback scripts highly. There were a number of suggestions for improvement including fixing bugs, a more user-friendly interface and avoiding the need to download scripts to the VM which will be implemented in the next version of the feedback tool (as outlined in Chapter 3) and evaluated in the second iteration in Chapter 6.

To determine whether we could detect a measurable impact on learning outcomes due to the intervention presented in this chapter, a quasi-experiment and independent t-test was conducted based on the scores of practical tests 1 and 2 for the 2015 and 2016 cohorts of students who completed INFT2031. There was no statistically significant observation revealed by the practical test scores. Limitations of this intervention were that it was implemented for a short period and that not all students participated in the intervention. In the next iteration (detailed in Chapter 6), the proposed TePF will be implemented for the entire semester and evaluated for any observable impact to learning outcomes in the lab environment.

Chapter VI

6. Iteration 2 – TePF Implementation & Evaluation

This chapter presents the second iteration of design, implementation and evaluation of the Technology-enhanced Pedagogical Framework (TePF) for the lab environment. The rest of this chapter is structured in the following manner. Section 6.1 provides the aim and explains the proposed extension of the TePF implementation. Next, the research design that was used to evaluate the proposed pedagogical framework is presented in Section 6.2. Finally, details of the evaluation study and the results are presented in Section 6.3.

6.1. **Aims**

This iteration aims to design, implement and evaluate the entire TePF for the lab environment presented in Chapter 3. In the previous iteration, an evaluation of two architectures – centralised and decentralised – was performed. The analysis provided a number of helpful insights and it was decided to use a centralised virtual lab environment moving forward in this iteration. In addition, the first version of the feedback tool had been developed as a set of PowerShell scripts. This was evaluated and the overwhelming positive response for this tool resulted in development of the next version of the feedback tool (as presented in Chapter 3). This was incorporated into the TePF in this iteration. The other technology artefacts developed and integrated in this iteration were the teacher and student dashboards. Another major change in the lab environment came from the implementation of lab activities incorporating a number of PLTs (as outlined in Chapter 3). The lab activities were also facilitated by LMS features such as discussion boards, online quizzes and other items. This chapter essentially implements the proposed TePF in its entirety (as outlined in Chapter 3) and evaluates it with the aim of verifying the hypothesis - *Design of technology-enhanced lab environments taking a holistic view of* *learning incorporating learning context, curriculum design, lab activities, assessments, resources and technology artefacts based on sound pedagogical and learning principles and theories have a higher potential for effective learning*. The next section presents the research design for the experiment conducted in this iteration.

6.2. **Research Design**

In this iteration, the proposed TePF for the lab environment was designed following a number of PLTs to design curriculum and lab activities, and also used technology capabilities to facilitate learning through the incorporation of technology artefacts such as virtual labs, feedback tools, dashboards, discussion boards, online quizzes, etc. To validate the hypothesis, this iteration evaluates whether there were any measurable impacts on learning by using the implemented TePF. A quasi-experiment was designed to evaluate the TePF's impact on learning as follows:

- Firstly, the TePF for the lab environment in INFT2031 should impact the ILOs of learning in the labs. The labs are geared towards developing knowledge and skills with hands-on practical work which is aligned to ILO4 - *Demonstrate ability to install, configure and troubleshoot PC, NOS and network services*. ILO4 was assessed by practical test 1 and practical test 2. Thus, the impact of learning in the labs could be observed by observing the students' results in practical test 1 and practical test 2.
- Next, the quasi-experiment design has a control group which did not have the TePF applied and an experimental group which had the TePF applied for the entire period. In this experiment, the 2015 cohort of students who completed INFT2031 formed the control group as these students did not have the TePF applied in their learning. In 2017, students enrolled in the INFT2031 class did have the TePF applied to their learning and they formed the experimental group.
- To keep all other variables as constant as practically possible, the course was taught by the same lecturers for both control and experimental groups and evaluated using the same practical tests.

If an impact on learning was observed in the practical test scores, we would have strong evidence to believe this was due to the use of the TePF. Table 6.1 outlines the quasi-experiment for iteration 2.

Table 6. 1: Quasi-Experiment Design for Iteration 2

2015 Cohort (No TePF) (Control Group)	2017 Cohort (TePF) (Experimental Group)
P2P lab activities	P2P lab activities
Practical test 1	Practical test 1
Server-based lab activities	Server-based lab activities
Practical test 2	Practical test 2

An independent t-test of the marks for practical test 1 and practical test 2 between cohorts was conducted to find whether any observable impact in the marks between the cohorts could be detected.

Using the practical tests and observing any measureable impact on scores is one way to determine the impact of learning based on the TePF. There are a number of survey instruments that can be used to measure approaches to student learning, levels of student learning, and attitudes and perceptions towards learning. Additionally, the TePF has components such as lab activities based on PLTs and technological artefacts such as virtual labs, the feedback tool and dashboards. It was considered valuable to discover students' perceptions and levels of learning when using the TePF and its different components.

A survey to elicit both quantitative and qualitative results was deployed at the end of the semester 2, 2017 (see Appendix B for the complete survey). The survey evaluated each technology artefact and the lab activities in the TePF. Each technology artefact: virtual lab; feedback tool; and dashboards, was evaluated using a 5-point Likert scale based on the TAM dimensions (Davis, 1989). Lab activities were designed based on a number of PLTs – such as Kolb's ELC, Collaborative Learning, Bloom and SOLO taxonomies. To evaluate lab activities, the survey used a number of survey instruments. An evaluation of lab activities based on Usefulness, Interaction, Competency, Interest, Reflection and Challenge dimensions (Konak & Bartolacci, 2016) was included. The use of different stages of Kolb's ELC was measured using 12 questionnaire survey instrument (Kolb, 1981). Student approaches to learning (deep or surface) (Biggs et al., 2001) were measured by the Revised Two Factor Study Process Questionnaire (R-SPQ-2F). Finally, an overall rating of all components of the TePF was conducted. Table 6.2 presents the survey structure. The complete survey is provided in Appendix B.

Table 6. 2: The Structure of the Survey used to evaluate the TePF

Areas	Sections	Types of survey questions
Technology artefacts (using TAM)	1) Virtual lab	10 quantitative items 2 open-ended items
	2) Feedback tool	6 quantitative items 2 open-ended items
	3) Dashboard tool	8 quantitative items 2 open-ended items
	4) Suggestions for improvement	4 open-ended items
Lab activities	5) Lab activities	21 quantitative items
	6) Experiential learning stages	12 quantitative items
	7) Students' learning approaches	20 quantitative items
Overall	8) Overall evaluation of the TePF components	9 quantitative items
Student info and expectations	9) General attendance, reasons and expectations	5 quantitative items

In addition to the open-ended questionnaire (which collected qualitative data), focus group discussions were conducted to evaluate students' learning outcomes and their satisfaction with the TePF. Appendix C provides the sample discussion questions used in the focus groups to elicit responses and collect data.

To evaluate students' perceptions of the TePF, analysis of both quantitative and qualitative data was performed. A number of statistical techniques, such as descriptive analysis, means and standard deviations, and thematic analysis of qualitative data were used in analysing the responses to the open-ended questions and the feedback from the focus groups (Boyatzis, 1998; Auerbach & Silverstein, 2003). Triangulation was performed to provide a deeper understanding of student perceptions and to identify the reasons for their responses.

The next section presents the results and analysis of the data collected.

6.3. **Results and Discussion**

This section discusses the results from the experiment in this iteration. Firstly, it examines the data collection process. Next, the results of the quasi-experiment are presented and discussed. Finally, the results of the survey and discussion forums are presented and analysed.

6.3.1. **Data Collection**

For the quasi-experiment, marks for the practical tests for the 2015 and 2017 cohorts were collected. In 2015, 87 students completed INFT2031 at Callaghan. Out of 87 students, 86 students completed practical test 1 while 82 students completed practical test 2. In 2015, at Ourimbah, 20 students completed the INFT2031 course. All 20 students completed both practical test 1 and practical test 2. In 2017, 70 students were enrolled at Callaghan campus and 14 students at Ourimbah campus. Out of the 70 students at Callaghan, 60 students participated in the research project and 12 students participated at Ourimbah campus. In 2017, all students who participated in the research project completed both practical test 1 and practical test 2. Table 6.3 presents the number of student scores used for the quasi-experiment.

Table 6. 3: Number of Students Participating in the Quasi-Experiment

	2015 Cohort	**2017 Cohort**
Practical Test 1	106	72
Practical Test 2	102	72

In 2017, 72 students completed the survey and 64 students participated in focus group discussions (6 groups with 13, 7, 11, 13, 8 and 12) with the discussion running for about 20-25 minutes; five were held at Callaghan (52 students) and one was held at Ourimbah (12 students).

The next section presents the results of the quasi-experiment.

6.3.2. **Evaluation of Learning Outcomes**

The results of the independent t-tests for practical test 1 are shown in Figure 6.1.

Group	2015 Cohort – Practical Test 1	2017 Cohort – Practical Test 1
Mean	16.637	17.556
SD	2.317	1.855
SEM	0.225	0.219
N	106	72

P value and statistical significance:
- The two-tailed P value equals 0.0056
- By conventional criteria, this difference is considered to be statistically very significant.

Confidence interval:
- The mean of 2015 Cohort – Practical Test 1 minus 2017 Cohort – Practical Test 1 equals -0.919
- 95% confidence interval of this difference: From -1.565 to -0.273

Intermediate values used in calculations:
- t = 2.8077
- df = 176
- standard error of difference = 0.327

Figure 6. 1 Results of Independent t-test for Practical Test 1 Marks between Control and Experimental Groups

From the above results, it can be concluded that there is a statistically significant difference in the scores for the 2015 cohort's practical test 1 scores (M=16.637, SD=2.317) and the 2017 cohort's practical test 1 scores (M=17.556, SD=1.855) with conditions: t (176) =2.8077, p = 0.0056. This result provide evidence to support that the TePF had an impact on the mean score of practical test 1 between the experimental and control groups with a small to medium effect size (Cohen's d = (17.556 - 16.637)/2.098751 = 0.44).

Next, an independent t-test for practical test 2 scores between the control and experimental groups was conducted. These results are shown in Figure 6.2.

Group	2015 Cohort – Practical Test 2	2017 Cohort – Practical Test 2
Mean	15.549	16.528
SD	3.372	2.438
SEM	0.334	0.287
N	102	72

P value and statistical significance:
- The two-tailed P value equals 0.0368

- By conventional criteria, this difference is considered to be statistically significant.

Confidence interval:

- The mean of 2015 Cohort – Practical Test 1 minus 2017 Cohort – Practical Test 1 equals -0.979
- 95% confidence interval of this difference: From -1.897 to -0.061

Intermediate values used in calculations:

- t = 2.1045
- df = 172
- standard error of difference = 0.465

Figure 6. 2 Results of Independent t-test for Practical Test 2 Marks between Control and Experimental Groups

From the above results, it can be concluded that there is a statistically significant difference in the mean scores for the 2015 cohort's practical test 2 scores (M=15.549, SD=3.372) and the 2017 cohort's practical test 2 scores (M=16.528, SD=2.438) with conditions: *t* (172) = 2.1045, p = 0.0368. This result provides further evidence to support the TePF having an impact on the mean scores of practical test 2 between the experimental and control groups with a small to medium effect size (Cohen's d = (16.528 - 15.549)/2.942297 = 0.33).

The mean practical test scores for the 2015 and 2017 cohorts are shown in Figure 6.3.

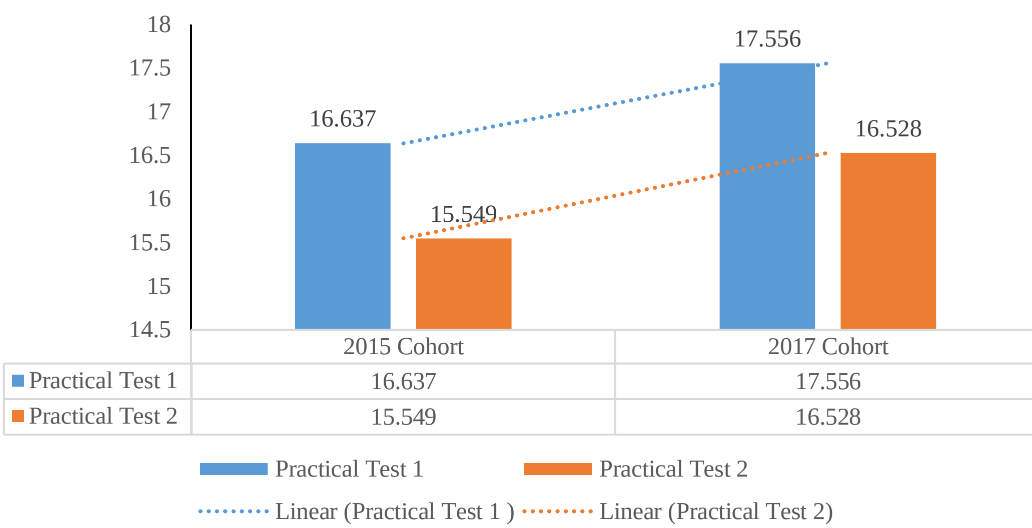


Figure 6. 3 Mean Practical Test 1 and Practical Test 2 Scores between the 2015 Cohort (Control) and the 2017 Cohort (Experimental)

Both independent t-test results provided strong support for a statically significant difference in the mean test scores for practical tests 1 and 2 between the control and experimental groups. In this experiment, variables such as lecturer and tests were kept constant for both groups. The fact that the TePF was applied for the experimental group but not to the control group provides evidence that the application of the TePF is the reason for the change in mean test scores. The mean practical test scores increased in the experimental group (2017 cohort) as compared to the control group (2015 cohort). These results provide evidence in support of the hypothesis.

Next, this thesis uses quantitative and qualitative data from surveys and focus groups to further evaluate the TePF and its components. Note that 2017 cohort is subjected to the entire TePF and its components. The quantitative and qualitative data is collected from 2017 cohort for evaluation in the following sections.

6.3.3. **Evaluation of TePF components**

There are many components that make up the TePF for the lab environment. Lab activities incorporated a number of PLTs and used technology artefacts such as virtual labs, a feedback tool and dashboards. Section 9 in the survey (see Appendix C) aims to identify the most significant components of the TePF that contributed to learning from the students' perspective and the rating for each component. The descriptive statistics are shown below (see Table 6.4).

Table 6. 4: Students' Responses to Survey Question "*Overall, what contributed most significantly to your learning in INFT2031? In other words, what are the important features to help in learning INFT2031? (Select all that apply)*"

Features	N	Likert Scale (%)					Descriptive Analysis		
		SD	D	N	A	SA	Mean	SD	Median
		1	2	3	4	5			
Lecture	74	0	4	22	24	24	3.94	0.918	4.0
Discussion board	73	11	19	32	6	4	2.59	1.077	3.0
Review Questions and Quizzes	73	2	8	22	21	20	3.63	1.168	4.0
Virtual labs	74	0	2	3	32	37	4.44	0.648	5.0
Lab Activities	74	0	1	3	23	47	4.57	0.646	5.0
Assignments	74	1	2	10	36	25	4.13	0.838	4.0
Feedback tool	70	4	10	19	15	22	3.40	1.469	4.0
Dashboard Tool	70	3	13	32	11	11	3.03	1.278	3.0
Group Work	72	20	23	15	12	2	2.28	1.201	2.0

Other	• *Practical tests* • *Practical test and practice runs Waraboork scenario* • *Practical tests* • *Third party videos exploration* • *I used Lynda.com. It is good for this type of thing*

The qualitative data from *Other* can be classified as practical tests (n=3), third party resources (n=2) and formative class discussions (n=1).

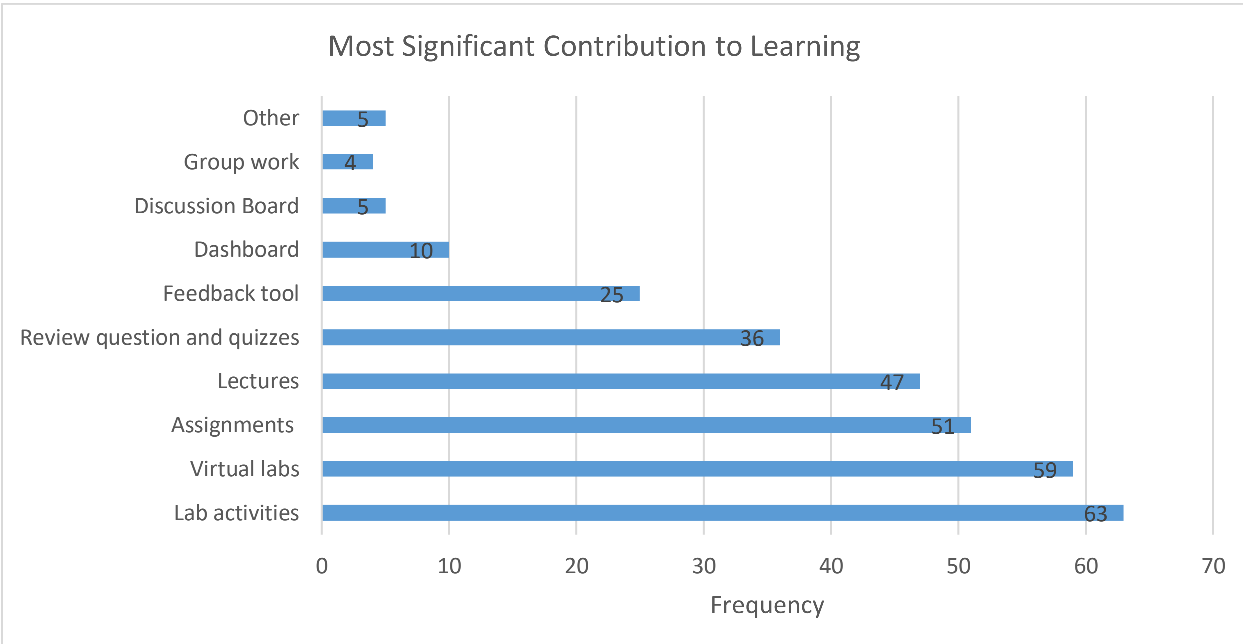


Figure 6. 4 Student responses to categories which contributed most to learning

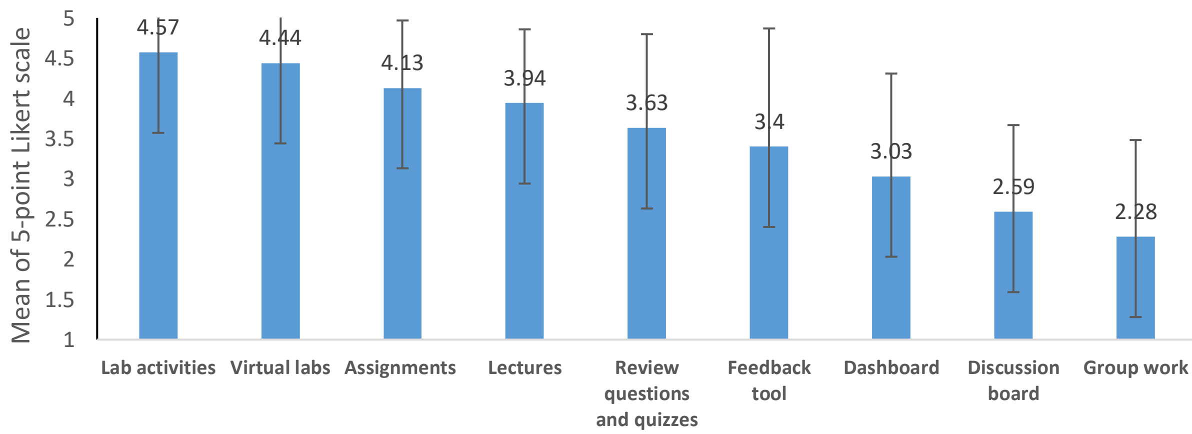


Figure 6. 5 Student Rating for each Category

Next, the thematic analysis of survey question 2 in section 4 – "*Which kind of activities helped you most in learning? (i.e., group work, review questions, online quizzes, reading activities, discussion boards). Explain your answer*", is presented in Table 6.5.

Table 6. 5: Thematic Analysis of Question 2 in Survey Section 4 – "*Which kind of activities helped you most in learning? (i.e., group work, review questions, online quizzes, reading activities, discussion boards). Explain your answer.*"

Theme (Frequency)	Response
Practical work/lab activities (28)	• *Practical work* • *Review and activities* • *Practical work* • *Going through configuration in the VMs. Theory best learnt on those* • *Labs, IPv6 learning module. Labs were good for some hands on experience* • *Individual lab work with easy pictures* • *Just the general work that the week's topic was about, labs the most important, virtual are very helpful* • *Definitely doing hands-on stuff e.g. setting AD, DHCP scopes etc. quizzes useful too to check your theory* • *Installing and working through the lab activities* • *The practical part, actually important the learning outcomes* • *The lab exercises as I found them the most helpful* • *Hands on configurations easiest way to learn is to do* • *Working though following the lab, easy to learn in how you do it* • *Lab walkthroughs* • *Practical work* • *Lab activities - doing the exercises that involved virtual labs* • *Step by step labs with screenshots* • *I think that lab activities themselves were most useful, followed by online quizzes* • *The step by step exercises were good for tests and developing skills, also online quizzes help* • *The labs that were straight to the point were best* • *All the practical labs* • *Hands-on practical work - helped apply my knowledge* • *Group work and anything practical helps to have something to actually see where my knowledge is going* • *The weekly tasks* • *Labs are best for this kind of work. I am course studying work for group* • *Doing the actual lab* • *Just the lab were on VMs, all the other stuff ignored* • *Virtual labs, I could grab the IP of the VM and use RDP from my laptop to connect to it. Group work - no; Discussion Board - no; online quizzes - yes; reading (IPv6) - yes*
Review questions (17)	• *Review questions were helpful with learning objectives* • *Review and activities*

	• *Review questions are helpful to prepare for exam* • *Review quiz examined … a lot about the tutorial* • *Review questions. The questions used were current and applies user knowledge with research to better understand concepts* • *Review questions, online quizzes* • *Review questions, great revision relating to the course that you may forgotten about* • *Mainly the review questions. Tests to see how much of the lecture you listened to* • *Discussion board, review questions and practical test* • *Review question - if I could answer it means I understood what was going on in the labs* • *Group work, review questions and IPv6, the online quizzes* • *Review questions and reading achieves help to revise content* • *The review question were a great [way] to revise each topic* • *Review question - help me go through the task* • *Review questions* • *Review questions* • *Review questions helped to reinforce theory*
Online quizzes (14)	• *Online quizzes for reviewing lectures. I like IPv6 module* • *Online quizzes* • *Quizzes so I can test myself. Discussion board to see how my peers tackle questions* • *Online quizzes getting a good score and sense of completion of the quizzes provide motivation. I got immediate feedback on where I went wrong. The activities (e.g. writing the IP address of the VM)* • *Online quiz – it's quick and easy to learn* • *Quizzes since I can redo … multiple times and can do if on my own time* • *Quizzes were nice* • *Online quizzes. Do the quizzes, know my mistake* • *Online quiz* • *Online quizzes* • *I think that lab activities themselves were most useful, followed by online quizzes* • *The step by step exercises were good for tests and developing skills, also online quizzes help* • *Online quizzes* • *Virtual labs, I could grab the IP of the VM and use RDP from my laptop to connect to it. Group work - no; discussion board - no; online quizzes - yes; reading (IPv6) - yes*
Group discussion/ group work/ discussion board (6)	• *Group discussion, as I could immediately see my problems* • *Group work, review questions and IPv6 the online quizzes* • *Group work and anything practical helps to have something to actually see where my knowledge is going* • *Group work activities helps me the most because I was able to learn a lot more* • *Discussion board* • *Discussion board, review questions and practical test*

Independent learning module (3)	• *Labs, IPv6 learning module. Labs were good for some hands-on experience. Learning module works well to reinforce the information with quizzes* • *Group work, review questions and IPv6, the online quizzes* • *Virtual labs, I could grab the IP of the VM and use RDP from my laptop to connect to it. Group work - no; discussion board - no; online quizzes - yes; reading (IPv6) - yes*
Tutor assistance (2)	• *Just asking my tutor for help benefitted me the most* • *Assistance from tutor*
Practical tests (2)	• *Practical tests* • *Discussion board; review questions and practical test*
Practice practical test (1)	• *Practice practical exam. Incredibly helpful to have someone work you through example*
Reading activities (1)	• *Reading activities forward it easy to read and understanding*
Other (3)	• *None really helped me, I mostly just worked with them* • *All* • *Not sure*

From the above results, it can be clearly seen that most students felt that lab activities contributed the most to their learning and these also were rated the highest. The lab activities included hands-on lab activities, review questions, quizzes, group activities, etc. and the design of the lab activities was influenced by a number of PLTs (such as Kolb's ELC). It was also interesting to note that students rated virtual labs as having the second biggest contribution to learning. This further provides support to the statement "…*virtual and remote labs and related technologies provide enormous opportunities to learning for both on-campus and distant learners. However, we need to be aware that these tools by themselves do not provide higher learning outcomes, rather, the combination of a good pedagogical framework, learner support, good content and tutor interaction, etc. are all essential to form a rich learning environment whereby learners can excel*" (Alkhaldi et al., 2016).

The next section evaluates the lab activities.

6.3.3.1. **Evaluation of Lab Activities**

From the above discussion, it is clear that students attributed the lab activities as contributing most to their learning. The questionnaire consisted of three survey instruments used to evaluate lab activities. Section 5 of the questionnaire was adopted from Konak et al. (2016) with 21 questions categorised to 6 dimensions: Usefulness, Interaction, Competency, Interest, Reflection and Challenge. The design of lab activities incorporated the use of Kolb's ELC and thus a survey instrument was adapted from Young et al. (2008) to measure the experiential learning stages of lab activities (12 survey questions in Section 6 of the survey). The students' approach to learning was evaluated using Biggs et al. (2001) survey instrument (Section 7 of the questionnaire). The survey results are presented below.

Table 6. 6: Survey Results for Evaluation of Lab Activities (n = 71)

Scale	item	M	SD	Median
Usefulness	1. The time I spent for the lab activity was worthwhile	4.55	0.555	5.00
	2. I find the lab activity useful to me	4.44	0.626	4.50
	3. I would like to do more of similar activities, even if it is time consuming	4.01	0.853	4.00
	4. The lab activity was very engaging	4.10	0.831	4.00
	5. The lab activity was pleasurable	3.90	0.831	4.00
Interaction	6. Interacting with other students helped me complete the lab activity	3.32	1.079	3.00
	7. I learned new concepts/skills by interacting with other students	3.11	1.178	3.00
	8. The lab activity encouraged me to ask questions to others	3.24	1.152	3.00
Competency	9. The lab activity helped me improved my problem solving skills	4.08	0.783	4.00
	10. The lab activity improved my technical skills and competency in the subject area	4.54	0.582	5.00
	11. I felt a sense of accomplishment after completing the lab activity	4.34	0.612	4.00
	12. I will be able to use what I learned in the lab activity in other courses or the future	4.26	0.775	4.00
Interest	13. The lab activity increased my curiosity and interest in this area	4.178	0.833	4.00
	14. The lab activity encouraged me to learn more about this topic	4.04	0.836	4.00
	15. I was very motivated for completing the lab activity	3.86	0.883	4.00
Reflection	16. The review questions were helpful to reinforce what was performed in the lab activity	3.86	0.961	4.00
	17. The lab activity provided opportunities to reflect back what was learned in the activity	4.01	0.819	4.00
	18. The lab activity promoted helpful discussions about what was performed in the activity	3.58	0.905	3.00
Challenge	19. The lab activity was challenging	3.61	1.121	4.00
	20. The activity review questions were difficult and time consuming	3.21	0.940	3.00
	21. The lab activity instructions were confusing	2.34	1.146	2.00

Cronbach's α= .893, N of items = 21

Table 6. 7: Descriptive Statistics for Evaluation of Lab Activities (n= 71)

Dimension	**N of items**	**Cronbach's α**	Descriptive Statistics		
			Mean	**SD**	**Median**
Usefulness	5	.867	4.21	0.617	4.20
Interaction	3	.940	3.25	1.063	3.00
Competency	4	.835	4.31	0.549	4.25
Interest	3	.844	4.01	0.766	4.00
Reflection	3	.779	3.82	0.751	3.67
Challenge	3	.693	3.07	0.809	3.00

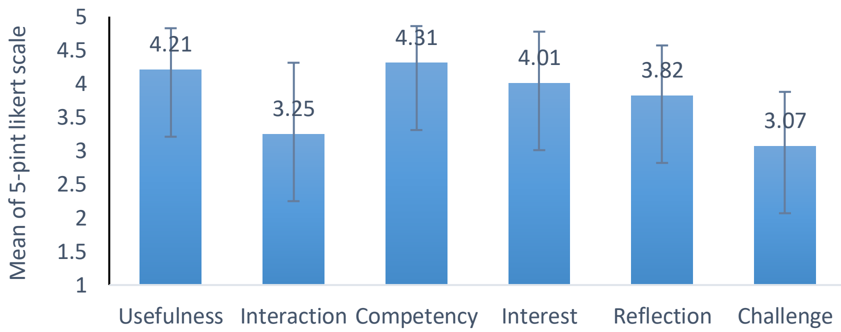


Figure 6. 6 Evaluation of Lab Activities

Tables 6.6 and 6.7 and Figure 6.6 provide the descriptive statistics for the evaluation of the lab activities (Section 5 of the survey). The results show that students rated highly the *Usefulness* and *Competency* dimensions. Also, the *Interest* and *Reflection* dimensions were rated above 3.5. Students were neutral about *Challenge* and *Interaction* dimensions. From the above, it can be concluded that students felt that the lab activities were very helpful for learning and developing the knowledge and skills required. Also, students agreed that the labs aroused their interest and allowed reflection on learning. However, in general, students did not find the lab activities to be challenging or interactive.

Next, the evaluation of Kolb's experiential learning stages of the lab activities is presented (Table 6.8, Table 6.9 and Figure 6.7). Given that Kolb's ELC was used in the design of the lab activities, it was expected that all stages of Kolb's ELC would be reflected in the survey results. The survey questionnaire to evaluate the experiential learning stages was adapted from Young et al. (2008).

Table 6. 8: Survey Results for Lab Activities Experiential Learning Stages (n= 72)

Sub Dimension	Item	Mean	SD	Median
Concrete Experience	1. The lab activities provided me with a direct practical experience to help understand the course concepts	4.46	0.555	4.0
	2. The lab activities gave me a concrete experience that helped me learn the class material	4.33	0.732	4.0
	3. The lab activities presented me with a “real world” experience related to this course	4.38	0.795	5.0
Reflective Observation	4. The lab activities assisted me in thinking about what the course material really means to me	3.96	0.801	4.0
	5. The lab activities helped me relate my personal experiences to the content of this course	3.76	0.801	4.0
	6. The lab activities aided me in connecting the course content with things I learned in the past	3.82	0.954	4.0
Abstract Conceptualisation	7. The lab activities required me to think how to correctly use the terms and concepts from this class	4.19	0.762	4.0
	8. The lab activities caused me to think how the class concepts were interrelated	4.07	0.861	4.0
	9. The lab activities made me organise the class concepts into a meaningful format	3.83	0.919	4.0
Active Experimentation	10. The lab activities made it possible for me to try things out for myself	4.39	0.761	5.0
	11. The lab activities permitted me to actively test my ideas of how the course material can be applied	3.94	0.977	4.0
	12. The lab activities allowed me to experiment with the course concepts in order to understand them	4.13	0.838	4.0

Cronbach's α= .916, N of items = 12

Table 6. 9: Descriptive Statistics for Experiential Learning Stages (n= 71)

Scale	N of items	Cronbach's α	Descriptive Statistics		
			Mean	SD	Median
Concrete Experience	3	.776	4.39	.700	4.5
Reflective Observation	3	.798	3.85	.856	4.0
Abstract Conceptualisation	3	.783	4.03	.859	4.0
Active Experimentation	3	.830	4.15	.879	4.0

Kolb’s ELC was used in the design of the lab activities. It is clear from the above evaluation that all stages of Kolb’s ELC were incorporated in the lab activities (with means of over 3.5 and medians greater or equal to 4.0). The thematic analysis of the open-ended question “*What kinds of activities helped you most in learning?*” (see Table 6.5), rated hands-on lab activities, review exercises, online quizzes and collaborative work positively for learning, all of which were designed to cater to the different dimensions of Kolb’s ELC.

Next, the student learning approaches were measured using the Revised Two-Factor Study Process Questionnaire (R-SPQ-2F) (Biggs et al., 2001) instrument. Tables 6.10 and 6.11

present the results of the R-SPQ-2F survey. In Young et al. (2008), the authors demonstrate how catering to all stages of experiential learning can lead to a deeper learning approach.

Table 6. 10: Descriptive statistics for the Student Approaches to Learning (R-SPQ-2F) (n =68)

Scale	Item	Mean	SD	Median
Deep Motivation	1. The lab activities gave me a feeling of deep personal satisfaction	3.69	0.833	4.0
	2. The lab activities helped me create questions that I wanted answered	3.69	0.815	4.0
	3. The lab activities made me work hard because I found the material interesting	3.94	0.879	4.0
	4. The lab activities were at times as exciting as a good novel or movie	2.87	1.118	3.0
	5. The lab activities were interesting once I got into it	4.03	0.880	4.0
Deep Strategies	6. The lab activities provided me with enough work on the topic so I could form my own conclusions	4.04	0.742	4.0
	7. The lab activities caused me to look at most of the suggested readings that pertained to the activity	3.06	1.170	3.0
	8. The lab activities caused me to spend time relating its topics to other topics, which have been discussed in different classes	3.38	1.098	3.0
	9. The lab activities allowed me to test myself on important topics until I understood them completely	3.92	0.917	4.0
	10. The lab activities' topics were interesting and I often spent extra time trying to obtain more information about them	3.31	1.083	3.0
Surface Motivation	11. For the lab activities, it was not helpful to study topics in depth because all you needed was a passing acquaintance with topics	2.97	1.063	3.0
	12. I was able to get by in the lab activities by memorising key sections rather than trying to understand them	3.01	1.133	3.0
	13. For the lab activities, there was no point in learning material, which was not likely to be on the exam	2.36	1.071	2.0
	14. I did not find the lab activities very interesting so I kept my work to a minimum	2.15	1.012	2.0
	15. My aim for the lab activities was to complete it while doing as little work as possible	2.31	1.091	2.0
Surface Strategies	16. The lab activities suggests the best way to pass exams is to try to remember answers to likely test questions	2.36	1.172	2.0
	17. I believe that the instructor should not expect me to spend significant amounts of time on the lab activities if it is not on an exam	2.24	1.111	2.0
	18. For these lab activities, I restricted my study to what was specifically required as it was unnecessary to do anything extra	2.51	1.215	2.0
	19. For the lab activities, I learned things by going over and over them until I knew them by heart even if I did not understand them	2.47	1.085	2.0
	20. For the lab activities, I only applied what was given in class or on the course outline	2.92	1.154	3.0

The study sought to provide evidence for the evaluation of lab activities derived from the R-SPQ-2F. Results suggested that data from this population fits the 2 factors (Deep and Surface). Fit statistics and the internal consistency statistics provide evidence for the data fitting the amended model, which is similar to that presented by (Biggs et al., 1987; Vaughan, 2016).

Table 6. 11: Descriptive Statistics for Student Approaches to Learning (n = 68)

Scale	N of items	Cronbach's α	Descriptive Statistics		
			Mean	**SD**	**Median**
Deep Motivation	5	.882	3.63	1.016	4.0
Deep Strategies	5	.822	3.54	1.086	4.0
Surface Motivation	5	.789	2.56	1.151	2.0
Surface Strategies	5	.844	2.50	1.187	2.0

Cronbach's α= .837, N of items = 20

It is clear from the above results that the lab activities did encourage a deeper approach to learning. Both deep motivation and deep strategies had means of over 3.5 and medians of 4.0 while surface motivation and surface strategies had means of around 2.5 with medians of 2.0.

In the literature, it is stated that it is important to evaluate not only the learning outcome but also the learning process (Young et al., 2008) "*…was high performance based on the use of surface learning strategies that may result in short-term performance but actually lacks long-term meaningful learning…".* The results so far have indicated the success of the approach taken (i.e., the incorporation of PLTs such as Kolb's ELC and others to design lab activities). The incorporation of all stages of Kolb's ELC has been successful (see Table 6.8). Also, the majority of students perceived lab activities to be the most significant contributor to learning as observed by the student responses to the survey instruments (see Tables 6.4 and 6.5). The students gained improved learning outcomes as evidenced by the higher scores in the practical tests (see quasi-experiment results above). This approach has not only led to students achieving better learning outcomes but also to them undertaking a deeper approach to learning (see Table 6.10).

Correlation analyses was used to examine the relationship between the three surveys instruments used to evaluate lab activities. The cross-analysis results are presented in Table 6.12.

Table 6. 12: Correlation Analysis for Evaluation of Lab Activities among Survey Instruments Scales (n= 74)

Dimension	**The six-factor model** (Konak & Bartolacci, 2016)						**Kolb's ELC**				**Biggs's R-SPQ-2F**			
	USE	ACT	COM	INT	REF	CHA	CE	RO	AC	AE	DM	DS	SM	SS
USE	1	.288*	.711*	.724*	.483*	-.096	.562*	.535*	.652*	.553*	.619*	.516*	.016	-.081
(p-value)		.013	.000	.000	.000	.414	.000	.000	.000	.000	.000	.000	.891	.495
ACT		1	.400*	.277*	.357*	.176	.275*	.487*	.371*	.151	.238*	.365*	.097	.103
(p-value)			.000	.017	.002	.133	.018	.000	.001	.200	.042	.001	.412	.383
COM			1	.710*	.485*	.072	.683*	.638*	**.717***	.650*	.659*	.550*	-.012	-.065
(p-value)				.000	.000	.543	.000	.000	.000	.000	.000	.000	.916	.585
INT				1	.617*	.038	.562*	.558*	**.703***	.644*	**.734***	**.696***	-.022	-.054
(p-value)					.000	.745	.000	.000	.000	.000	.000	.000	.850	.650
REF					1	.169	.403*	.527*	.506*	.441*	.574*	.645*	.070	.044
(p-value)						.151	.000	.000	.000	.000	.000	.000	.551	.710
CHA						1	.030	.228	.043	.000	.046	.157	.331*	.298*
(p-value)							.801	.051	.714	.999	.698	.180	.004	.010
CE							1	.573*	.705*	.569*	.494*	.488*	.003	-.108
(p-value)								.000	.000	.000	.000	.000	.980	.358
RO								1	.643*	.522*	.628*	.688*	.129	-.018
(p-value)									.000	.000	.000	.000	.274	.880
AC									1	.648*	.560*	.667*	.032	-.013
(p-value)										.000	.000	.000	.784	.915
AE										1	.530*	.549*	.018	-.031
(p-value)											.000	.000	.878	.792
DM											1	.692*	-.045	-.144
(p-value)												.000	.702	.220
DS												1	.073	.005
(p-value)													.538	.967
SM													1	.778*
(p-value)														.000
SS														1
(p-value)														

USE – Usefulness, ACT – Interaction, COM – Competency, INT – Interest, REF – Reflection, CHA – Challenge, CE - Concrete Experience, RO - Reflective Observation, AC - Abstract Conceptualisation, AE - Active Experimentation DM - Deep Motivation, DS - Deep Strategies, SM - Surface Motivation, SS - Surface Strategies

Correlation Matrix presented in Table 6.12 support assumed positive relationships among most variables with statistical significance ($p < .50$). In all instances, the scales were positively correlated with deep learning (DM and DS scales). In certain instances, a strong positive correlation was found (i.e., $r \geq 0.70$) between scales of different survey instruments. *Competency* and *Interest* scales were strongly correlated with *Abstract Conceptualisation* (AC) in Kolb's ELC stages, r (73) = .717, and .703 respectively ($p<.01$). *Interest* also has a strong positive correlation with the *Deep Motivation* (DM), (r = .734, p <.01) as well as *Deep Strategy* (DS), (r = .696, p <.01). This suggests increasing student interest (INT) can have a positive influence in enhancing a deep approach to learning.

Next, the other components of the TePF will be evaluated, starting with virtual labs.

6.3.3.2. Evaluation of Virtual Labs

The survey results for the evaluation of the virtual labs are shown in Table 6.13 below.

Table 6. 13: Survey Results for Evaluation of Virtual Lab (n= 70)

Scale	Items	Mean	SD	Median
Usefulness	1. Using virtual lab helped me to learn in INFT2031	4.59	0.577	5.0
	2. The virtual lab improved my lab performance	4.30	0.857	5.0
	3. The virtual lab helped me achieve learning outcomes	4.37	0.726	5.0
Ease of use	4. The virtual lab provided easy access to the lab at any time of the day (24x7)	4.06	1.020	4.0
	5. Having access to the virtual lab from any device/location (i.e. home etc.) is helpful to me	4.47	0.793	5.0
	6. I find it easy to use the virtual lab	4.11	0.910	4.0
	7. I find the virtual lab flexible to conduct my lab work	4.20	0.827	4.0
Attitude	8. I am satisfied with using the virtual lab for my practical work in INFT2031	4.20	0.861	4.0
	9. I would like to use Virtual labs in future networking and systems administration courses	4.21	0.915	4.0
Overall	10. Overall, how would you rate the INFT2031 virtual laboratories	4.32	0.731	4.0

Cronbach's α= .870, N of items = 9

The factors were analysed using Cronbach’s alpha which is the most frequently reported reliability statistic for multiple-item scales. All of the measures in this study verified excellent internal consistency, ranging from 0.724 to 0.847 (see Table 6.14), thereby exceeding the reliability estimates (<= 0.70) recommended by Nunnally (1967).

Table 6. 14: Evaluation of Scales for Virtual Labs (n = 70)

Scale	N of items	Cronbach's α	Mean	SD	Median
Perceived usefulness	3	.822	4.43	.718	5.0
Perceived ease of use	4	.740	4.23	.901	4.0
Attitude towards using	2	.834	4.21	.860	4.0
Overall rating			4.32	.731	4.0

It can be seen that from the results above (Tables 6.13 and 6.14) that students had a high acceptance of, and a positive outlook towards, the virtual lab (means are greater than 4.0 on all survey questions/scales and medians are 4.0 or above). This virtual lab implementation was different to the iteration 1 implementation of the virtual lab (using the cloud lab). A comparison of the results from 2016 is provided below (see Table 6.15). It can be seen that both types of centralised labs, the Azure cloud lab and the server-based cloud lab, were rated similarly and highly. The difference is that for the 2016 cohort, the cloud labs were used for only a few labs and decentralised labs were used for most lab work while the 2017 cohort used the server-based centralised labs for most of their lab work.

Table 6. 15: Cloud vs Server-Based Lab

Category	Cloud Lab 2016 Cohort (n=64)		Server-based Lab Environment 2017 Cohort (n=70)	
	Mean	**SD**	**Mean**	**SD**
Usefulness (1,2,3)	4.24	0.669	4.43	0.718
Ease of use (4,5,6,7)	4.34	0.632	4.23	0.901
Attitude (8,9)	4.41	0.624	4.21	0.860
Overall (10)	4.33	0.774	4.32	0.751

To obtain a further analysis of the perception of the virtual labs, the qualitative data was analysed. Table 6.16 provides the thematic analysis of the survey question "*What do you like most in the virtual IT infrastructure lab? Why? Explain your answer"*. Table 6.17 provides the thematic analysis of the survey question "*Any disadvantages of using virtual IT infrastructure lab?*". Next, Table 6.18 provides a thematic analysis of the focus group discussion - "*What is your opinion on the virtual labs used in labs in INFT2031? Did you find the virtual labs easy to use?*" The thematic analysis for the survey question "*What are the features that you would like to see implemented in future?*" is provided in Table 6.18.

Table 6. 16: Thematic Analysis for "*What do you like most in the virtual IT infrastructure lab? Why? Explain your answer*".

Theme (Frequency)	Response
Convenience, accessibility and 24x7 availability (30)	• *Can access anywhere to complete lab work* • *I like that it's complete from home. And that you can do any lab at any time* • *Feedback tool is good way to see due feedback. I like the lab [environment] so that we can access anytime* • *The virtual labs were great because it is easy to review at home* • *Flexible and easy access* • *Allows for access anywhere* • *It is accessible for any location. It [was] fairly stable and good to work with, really good practical experience* • *Accessibility* • *Liked it all. VL was a bit slow at times. Yet being able to login 24/7 is extremely appreciated. Feedback and dashboard tools were great to track how well everyone was doing*

	• *Being able to access from home, having actual server to work on* • *The virtual labs are accessible everywhere which is handy when I'm not able to come to lab or practice on my own* • *Virtual lab environment- it was easy to use and available to practice off campus* • *It all works well together and can be used on and off campus* • *Can be used anywhere and making a mistake doesn't matter* • *Ability to use anywhere i.e. at home. If I don't want or are not able to set up a test lab of home, I can still use the virtual lab* • *The ability to use anywhere at any time* • *Easily accessible* • *Virtual lab - I work full time so accessing it from home was important* • *Anywhere access and feedback help me correct errors* • *I like the 24x7 flexibility* • *Accessibility is good for working at home* • *Use it anywhere and anytime* • *The convenience of accessing the lab environment from any location* • *It was really convenient. It all worked well* • *Virtual lab environment - it is very convenient* • *Virtual lab environment is really convenient for me* • *The online system provides software that you may not have access to and is very useful to have* • *It was already set up and ready to go with the required software. The feedback tool was informative and there was no concern about where to save the VM* • *It is easier than having to always set up something or bring in something. You get valuable feedback so you can find out what you're doing wrong* • *Wide access to many different VMs. Wish I could download some to my local machine*
Virtual lab interesting and relevant to learning (24)	• *Virtual lab was the best, very information and relevant to learning* • *Virtual lab environment. Using VMs to [see] how networks communicate and work was interesting and making mistakes and learning helped* • *It was very interesting* • *It is accessible for any location. It [is] fairly stable and good to work with, really good practical experience* • *Virtual lab, feedback tool* • *It makes it easier to understand the concepts I learn in the lectures* • *Because it was actual metical, hands-on things that we could do which learning how to do things* • *Virtual lab environment/feedback* • *Virtual lab environment, mores labs more interactive and easies to learn* • *Liked it all. VL was a bit slow at times. Yet being able to login 24/7 is extremely appreciated. Feedback and dashboard tools were great to track how well everyone was doing* • *The virtual lab, as it showed the detailed working of the course's practical application* • *I liked the VMs* • *Very rewarding setting up servers from admin perspective*

	• *It all works well together and can be used on and off campus* • *Virtual lab mean I can return course information by applying it practically. Feedback tool and dashboard are good to understand my real of improvement* • *I understand that teaching network administration on an important network is difficult and I feel that virtual labs environment is great tool for solving some issues* • *Virtual lab - taught me how to use windows server* • *It feels pretty cool accessing a remote computer* • *Virtual labs environment. Because I have never used these technology before* • *Multipurpose system, loading different VMs* • *It was very interesting to use* • *Server virtualization. Closer to real world application* • *Virtual labs environment. I have been already interested in virtualization technology. Maybe some other students are also interested in* • *Being able to access from home, having actual server to work on*
Feedback Tool (13)	• *Feedback tool is good way to see due feedback. I like the lab [environment] so that we can access anytime* • *It was already set up and ready to go with the required software. The feedback tool was informative and there was no concern about where to save the VM* • *Feedback, it's easy to understand* • *It is easier than having to always set up something or bring in something. You get valuable feedback so you can find out what you're doing wrong* • *Virtual lab, feedback tool* • *Liked it all. VL was a bit slow at times. Yet being able to login 24/7 is extremely appreciated. Feedback and Dashboard tools were great to track how well everyone was doing* • *Lab environment easy to use/run; Feedback tool was quiet tool* • *Virtual lab environment/feedback* • *I can see my performance and if I make a mistake in the lab I can go back to it and redo the lab* • *The feedback tool was incredibly helpful for helping me complete my lab work. I wish every class had one* • *The feedback tool. Learn from mistake* • *Virtual lab means I can return course information by applying it practically. Feedback tool and dashboard are good to understand my real … improvement* • *Feedback tool - give the checklist*
Flexibility – can make mistakes without worry (6)	• *Errors made are not permanent. Allows to set up multiple machines at once* • *Flexible and easy access* • *Can be used anywhere and making a mistake doesn't matter* • *I can see my performance and if I make a mistake in the lab I can go back to it and redo the lab* • *I like the fact that you can test different configurations without risk* • *I liked being able to configure any settings in a risk free environment*

Ease of use (5)	• *Lab environment easy to use/run; Feedback tool was quiet tool* • *Virtual lab environment - it was easy to use and available to practice off campus* • *The virtual lab environment was great and having the app end not having to do it through a box was great* • *Easy to use* • *Virtual lab environment - easy to use and handy*
Dashboard (2)	• *Liked it all. VL was a bit slow at times. Yet being able to login 24/7 is extremely appreciated. Feedback and dashboard tools were great to track how well everyone was doing* • *Virtual lab means I can return course information by applying it practically. Feedback tool and dashboard are good to understand my real … improvement*
Reliable (1)	• *It is accessible for any location. It [is] fairly stable and good to work with, really good practical experience*
Suggestions for improvement (1)	• *If the speed can be enhanced*
Other (1)	• *VMware interesting, engaging and helpful*

It is clear from the above analysis, that convenience, the 24/7 accessibility remotely from any device, is the most liked feature of the virtual lab. The opportunities for learning created by the virtual lab also rated highly. There were 13 responses who mentioned the feedback provided by the feedback tool as the feature mostly liked. Flexibility (6), ease of use (5) and reliability (1) were also mentioned as most liked features. The dashboard was mentioned by two responses as a most liked feature. The feedback tool and the dashboard are analysed in later sections.

Table 6. 17: Thematic Analysis for "*Any disadvantages of using virtual IT infrastructure lab?*"

Theme (Frequency)	Response
Slow performance (38)	• *Sometimes was slow for unknown reasons* • *Sometimes too slow* • *It was often slow* • *It can be slow and unresponsive at times* • *Slow processing speed* • *Sometimes it's too slow if computer is not that good* • *Performance issues* • *Slow* • *At times the mashers were slow or unresponsive* • *The browser reviser is a little slow but still manageable* • *Can get slow when you have a lot up on the screen* • *A bit slow and easy got problem* • *Slow due to overly utilised CPU/ storage*

	• *Not on campus, off campus it can be quite slow especially installing another VM* • *No, only thing is that it is sometimes slow* • *Would be a bit slow on Mac* • *Only the few slowdowns. Should be easy to fix* • *It was slow sometimes* • *Slow, may take up resources on my computer or laptop* • *Slow at time* • *Lag! Constant slow restart* • *A little laggy at times* • *VMs usually slow compared to just running the single OS* • *Slow at times* • *Can be a bit slow at times* • *It's a bit slow at times* • *Slow* • *Slow, I mean really slow* • *Slow* • *At times can be very slow, also consistently signed me out for no reason* • *Slower and more laggy* • *Slow sometimes; couldn't connect sometimes from home at night* • *Very slow at Ourimbah. Input (like keyboard) regularly causes major issues. I missed weeks of work because of this* • *Too slow* • *Speed issues* • *Slow* • *Installation time and no help if more access at home* • *The network can get very laggy and managing computer within computer within computers*
None (8)	• *No* • *No disadvantages* • *Not sure* • *I don't think so* • *No* • *N/A* • *N/A* • *No*
Connection issues (5)	• *Sometimes you have [trouble] connecting to them and only one sandbox you can make a mess with* • *It can be time consuming who trying to connect if network is busy* • *Sometimes the VM takes a long time to connect* • *Work about works about 1/20% of the time from home* • *Stable connect*
Unreliable (3)	• *Sometimes it doesn't work* • *It would occasionally have server-side problems that I could do nothing about* • *Sometimes they crash*
Not flexible (2)	• *If it breaks you can't rebuild, you need IT support*

	• *User friendly not when you make mistake you are shutdown*
Confusing (2)	• *Using VMs inside of a VM was sometimes confusing especially when switching between the [clients] and server VMs on the one screen.* • *It is a little confused when using a windows 10 on the Mac*
Complicated to learn at the beginning (2)	• *Slightly complicated to learn in the beginning* • *Can be daunting to use at first, seems inefficient but it's not*
Not like a physical server (1)	• *Did not feel like working on real server - I guess too easy to use*
Other (2)	• *Seemed like a lot of information had to be take in small time* • *Easies[t] to learn*

The thematic analysis of the disadvantages of using virtual labs had performance as the main complaint. Upon discussing this with the practitioner, he agreed to investigate and allocate more resources to the host VM. Other responses included connection issues (5), unreliability (3), inflexibility (2), confusing with multiple VMs (1), complicated at the beginning of the semester (1) and also it wasn't like using a physical server (1).

The thematic analysis of the focus group discussion question "*What is your opinion on the virtual labs used in labs in INFT2031? Did you find the virtual labs easy to use?*" provided in Table 6.18 reaffirmed our findings above.

Table 6. 18: Focus Group Discussion – "*What is your opinion on the virtual labs used in labs in INFT2031? Did you find the virtual labs easy to use?*"

Theme (Frequency)	**Response**
Helpful in learning, good, suitable (12)	• *One thing that I was satisfied with is virtual machine. Because I am interested in cloud services, it was quite a good chance to meet virtualization technology, which is one of the important factors in cloud services. Also, it is pretty efficient because students don't need to bring external drives. I heard that few years ago, students should bring the drives and I was concerned about it when I started this course first. And I don't think slow processing speed is not that matter of it and I am sure it would be getting better* • *It was good, but in the beginning lots of hard and confusions* • *No confusion, boots fast. In general it's pretty fun* • *More engaging than lecture, I learn more here than lecture. I mean like the lecture is helpful but I pay more attention here than I had do over there* • *Because again what actually we do in hands-on work it is not just sitting in lecture I mean listening carefully every word but labs is more control* • *It is very helpful for me to understand which knowledge learning, and it can working at home, have more time study*

	• *For what we are doing the virtual labs worked fine. Didn't like having to find the deit-vdi ... link to logon every time* • *Virtual labs are very good for hands-on experience on server. However, it does not have the real experiment. Challenges of connectivity and access* • *Virtual labs were good but sometime slow* • *It is good but if there is any possibility to have actual server* • *It is very good and very easy than VMware but still all step up on virtual labs* • *It is good for, like, get access to software that cannot have in the system*
Performance (slow sometimes) (12)	• *It was slow* • *I found quite easy to use, only when we had a lot up on the screen did it become very slow* • *VMs are sometimes slow* • *Easy to use without a doubt; sometimes issues, but that's pretty much faster are being tad slow* • *Sometimes slow* • *Yes, although I didn't actually use the VMs from home, I appreciated the option. Performance was a bit slow* • *Virtual labs easy to use. Everyone talked about slow down; RAM was increased, yet still slow. CPU core could need to be increased* • *Virtual labs were good but sometimes slow* • *The nested VMs were very slow as someone who uses VMs a lot I would prefer to keep them in a USB with no login* • *It slow sometimes* • *At start, little bit is slow* • *Usually like especially my starting try to connect, they are little bit slower time. This is I think because start to connect these virtual machines things like that is usually slow*
Ease of use (10)	• *I like those VMs that all have software on it that do not necessary to have like Visio. So, used for home was easy and then you can transfer using one drive* • *Access is a lot easier and free* • *I found quite easy to use, only when we had a lot up on the screen did it become very slow* • *Easy to use without a doubt; sometimes issues, but that's pretty much faster are being tad slow* • *Virtual labs easy to use. Everyone talked about slow down; RAM was increased, yet still slow. CPU core could need to be increased* • *Easy to use* • *They were easy to use and understand* • *Very handy; easy to use at home and in labs* • *It easy to use... and no confused* • *I do not get any problem over use [of] the VMs*
Accessibility (7)	• *It is good for work at home* • *I like those VMs that all have software on it that do not necessary to have like Visio. So, used for home was easy and then you can transfer using one drive* • *Access is a lot easier and free*

	• *Yes, although I didn't actually use the VMs from home, I appreciated the option. Performance was a bit slow* • *It is very helpful for me to understand which knowledge learning, and it can be working at home, have more time study* • *Very handy; easy to use at home and in labs* • *Yes, definitely I can use my laptop to enter into these VMs. I can do that since I connect the network here I can reach and drag do not change that*
Login cumbersome (3)	• *For what we are doing the virtual labs worked fine. Didn't like having to find the dcit-vdi ... link to logon every time* • *Virtual labs are very good for hands-on experience on server. However, it does not have the real experiment. Challenges of connectivity and access* • *Which easy way to get in to because I hate entering that big long link dcit-vd etc. it is always annoying… google it like then copy the link and putting on other things (Domain name)*
Prefer physical lab (3)	• *It is good but if there is any possibility to have actual server* • *It is very good and very easy than VMware but still all step up on virtual labs* • *Virtual labs are very good for hands-on experience on server. However, it does not have the real experiment. Challenges of connectivity and access*
First labs were confusing (3)	• *I can find when I download Workspace so likely to have Microsoft Imagine than can download and use Windows 10 it's big process go through to sign in all of that but nothing appears to sign in INFT2031 labs completely in my Mac* • *It was good, but in the beginning lots of hard and confusions* • *Not always but after a few weeks I got hang of it*
Other – Access to Software + Flexibility (2)	• *We got DreamSpark (Microsoft Imagine) to download software* • *Get more and full control virtual machines*

It can be stated that most students were satisfied with the opportunities for learning that the virtual lab environment provided. Ease of use and accessibility were highly positive features of the virtual lab environment. The main concern was performance which many felt was slow sometimes. One response mentioned that it was the starting of the VMs that was slow. More resources allocated to the students' sandboxed environment and nested VMs may resolve this issue in the future. A few students felt that the login was cumbersome. After discussing this with the practitioner (the course lecturer), it was decided that the link could be published for easy access through the LMS in the future. Three responses did mention that using virtual labs felt virtual and not "real". Providing students with access to hardware components and installing and configuring on a physical machine may seem more "real" than installing and configuring a virtual machine. The first lab had students downloading ISO files and installing the VM using VMWare on lab machines (de-centralised architecture). This seems to have been confusing initially.

Table 6. 19: Thematic Analysis for "*What are the features that you would like to see implemented in future?*"

Theme (Frequency)	Response
Improve performance (13)	• *Stand-alone virtualization server to improve response time* • *Faster* • *Faster speeds* • *Server with stronger CPUs* • *Faster VM from home, had problems accessing practice test 2 from home* • *Faster, more server resources available* • *Just speed* • *Making the VMware faster* • *More resources for VMs (they can be slow sometimes)* • *Improving the virtual machines* • *More speed and less discount problems* • *Probably more power on the VMs* • *More allocated resources*
Nothing (12)	• *No idea for that. Very good now* • *Can't think of any* • *N/A* • *Not really sure to be honest* • *N/A* • *Everything was great* • *None. All the features helped in my learning* • *None that can be thought [of]* • *N/A* • *None I can think of* • *N/A* • *Keep going*
More activities similar to existing (6)	• *More practice on assignments* • *Continue using VMs on the Hyper-V manager, they are a valuable tool* • *More courses with this* • *Moe lab work like this* • *Maybe some more in-depth tutorials/ walkthrough* • *More AD features in labs*
Feedback tool expanded to all labs (3)	• *Feedback tool for every lab/work complete* • *All labs should be included in the feedback tools* • *Feedback tool earlier in the labs*
Use physical server environment as well (3)	• *Perhaps a second virtual machine to compare how changing the different system will work* • *More VMs for practical at different system* • *Using BootComp on Mac or an actual PC*

Incorporate course materials in host VM (2)	• *Access to lab and lecture notes in VMs* • *Lab and lecture information kept in folder on the main server VM*
Replace PDF lab sheets with a more interactive UI (2)	• *Maybe a system where it shows each activity completed, it unlocks next step* • *Video guides instead of paper/pdf*
Improve reliability (1)	• *More consider lab computer sometimes they don't work, which is stressful in a test*
Incorporate Linux (1)	• *Linux*
Restore/reset VM (1)	• *The ability to restore/ reset practice practical VMs*
Publish answers to review questions (1)	• *Review questions with answers*
Timetabling (1)	• *The lab and lecture are after the other with no 3 hours gap*
Private discussion board for tutor/student interaction (1)	• *A private discussion board to allow direct connect between staff and student without fear of being judged by other students*
Seamless access between dashboard and feedback tools (1)	• *Merging dashboard with the feedback tool*
More group work activities in labs (1)	• *Expansion of the feedback tool, possibly activities that involve working with a partner (using one Mac as the server and one Mac as the client) and more activities on the features that can used on*
Other/not clear (4)	• *Compare performance with other students* • *More involvement* • *Use IP configuration* • *Quick access to vdi/ tools (feedback) ways to input for offline use*

The thematic analysis of "*What features you would like to see implemented in the future?*" provided a number of insights. Improvement of performance was the most frequent response which was also mentioned as a major disadvantage of the virtual lab. Five responses wanted more labs and detailed tutorial work. This is a positive indication that students like the lab activities and preferred to do more work in the labs. Expanded use of the feedback tool (3) and use of physical machines (3) were also mentioned. Upon discussing this with the practitioner, he mentioned that some of these features would be straight-forward to incorporate in the future such as incorporating materials on the host VM for easy access and discussing how to reset VMs. Also features like incorporating Linux and adding video walk-throughs for complex configurations are aspects that the practitioner aims to add in the future. The practitioner agreed that a more integrated user interface that seamlessly incorporates course content, lab materials, dashboards and feedback would be an ideal tool for the future.

In this iteration, a server-based lab environment was used. There were two labs where students installed Windows 10 and Windows Server 2016 using VMWare platforms on lab machines. This provided students with a feel for using both the server-based environment as well as a decentralised lab environment. Very few students seem to have used their personal computers to conduct their lab work which became apparent when answering the question "*Did you use the server environment to configure INFT 2013 lab activities?"* with 71 responding positively and only 3 responding negatively. Yet for question 12, "*Given the choice to use your PC vs server environment in conducting INFT2031, which do you prefer? Why?*", only 33 students responded with a preference for the server lab environment (centralised lab environment) while 35 students responded they preferred to use the PC–based Fusion labs (decentralised lab environment). The qualitative analysis of their reasons is provided in Tables 6.20 and 6.21.

Table 6. 20: Reasons for Choosing Server-based Lab Environment

Theme (Frequency)	Response
Easy access (12)	• *It just is easier and faster it seems* • *Server environment because easier to access anywhere. But it is too slow when accessing off campus. VMware took too much time to configure* • *Easy access at any time* • *The virtual machines are much more effective than VMware Fusion. It is easy to connect to from any device and you don't have to install the system through a USB or other method* • *Both, hard choice. More CPU resources would have dramatically increased performance. Using VMware, yet the server environment gives more access for if completing tasks at home* • *Can be accessed easily for me only need to enter login* • *It's accessible from home /uni and doesn't require storing files locally. My computers don't have the space for VMs* • *I can use or login to server environment anytime and anywhere, while for Fusion I can only work during labs* • *Access anywhere so can catch up on work easy* • *Use anywhere and easy to set up* • *Access anywhere* • *Mobility and cloud computing is the future*
Ease of use (3) / Convenient (1)/ Configured for use (3) 7	• *Easy to use* • *Easy to use* • *Much easier to use* • *More convenient* • *Don't have to install any other applications* • *The server environment required less installing and had less compatibility issues. We could get straight into the work*

	• *Is already set up ready to configure. Usable at home. Bit slow though*
Lack of resources in PC (1) / Networking settings in PC (1)	• *It's accessible from home /uni and doesn't require storing files locally. My computers don't have the space for VMs* • *Setting on my personal PC might disrupt networking work*
Reliability (1)	• *It's a fairly stable environment to practice at the lab content*
Future technology/ Interesting (2)	• *Mobility and cloud computing is the future* • *Seems interesting*
Engaging (1)	• *I find a server environment makes learning more engaging*
Familiarity (1)	• *Not sure, it seems this is what I am used to now so would prefer it*
Both labs (4)	• *Because of mostly hardware can slow using VMware and such. Probably server, but really both are fine* • *Both, hard choice. More CPU resources would have dramatically increased performance. Using VMware, yet the server environment gives more access for if completing tasks at home* • *Not sure, it seems this is what I am used to now so would prefer it* • *I am indifferent*
Other (4)	• *More convinced* • *Never worked with server before. VM did not work for me outside of campus* • *Lateraled in using the technology* • *Mobility and cloud computing is the future*

It became evident that most students preferred the server lab due to its easy access. Also, the convenience of having all necessary software pre-configured and ease of use were other reasons for choosing the server-based lab environment without the need to have/use resources on students' personal machines. Two responses also mentioned that the server-based lab environment was slow. What was interesting is that 4 responses who chose the server environment still stated that they did not mind using decentralised labs.

Next, the reasons for choosing decentralised lab environment were analysed (see Table 6.21).

Table 6. 21: Reasons for Choosing PC-based Lab Environment

Theme (Frequency)	**Response**
Faster (7)	• *Faster* • *Hyper-V seems faster than running VM from the browser* • *Using my own. The virtual machine runs faster* • *The server makes using virtual lab difficult as it was very slow most at time* • *My personal PC is quite fast and virtualises well* • *Access everywhere although they are sometimes laggy* • *As it is more flexible*
Ease of use (6)	• *Easy to use* • *I found this easy to use* • *Easier to understand and more flexible* • *Easy to use and helpful to learning*

	• *The Hyper-V manager was a clean design with easy readability and functionality* • *Easier stupes, Hyper-V is great simple, easy to use, less work that needs to be done prior*
Flexibility (5)	• *Easy to control* • *I have lose control can back up my work, reset it more a mistake* • *Easier to understand and more flexible* • *More flexible and work more at home* • *Flexible for people who work*
Easy access (3)	• *Having access at home is great especially when I have a course task and couldn't attend the lab* • *Can access from anywhere* • *I can always go back to my actual PC without having to log out from VMware*
Reliability (2)	• *Server environment is very lossy. I wish I had option to use VM on USB as well as online for people with access to use USB* • *Less seems to go wrong for unknown reasons*
Familiarity (1)	• *Because I have done my practical on it*
PC has resources (1)	• *My personal PC is quite fast and virtualises well*
Technical issues (1)	• *Just some of the problems with VDI made me not want to use them, but was not a bad thing to use*
Preference (1)	• *I prefer my own PC*
Both (1)	• *Just some of the problems with VDI made me not want to use them, but was not a bad thing to use*
Other (4)	• *It allows learning of new tools that may be useful in the future* • *If something goes wrong worst case I can close the VM* • *Didn't use server environment* • *Multi-purpose*

Analysing the results, it was clear that speed was one of the main reasons for choosing the PC-based lab environment. Ease of use and flexibility were also reasons for preferring the decentralised environment. Easy access and not having to log onto a server-based environment were also considered to be advantageous. Two student responses mentioned that they felt that the server environment was less reliable while the PC-based environment had more control. It seems that if students have personal machines which have sufficient resources, the decentralised lab environment may be a good option.

Overall, from the analysis, it can be summarised that students were satisfied with the convenience of access provided by the server-based lab environment. A number of improvements such as providing additional resources to the server-based lab environments to improve performance and taking steps for providing an easy login (such as LMS integration etc.) can be considered as future improvements to the lab environment. Some students had access to personal computers with adequate resources to run virtual machines and networks. In such situations, it might be convenient and faster to use their own personal machines to conduct the lab work. Thus, after discussion with the practitioner, it was decided that the choice to use either or both centralised (server-based) and decentralised labs to conduct hands-on lab activities can be given, so students could have the choice to use either or both approaches depending on their preferences in the future.

The next section evaluates the feedback tool.

6.3.3.3. Evaluation of the Feedback Tool

This section addresses the students' perception of the feedback tool. For section 2, question 1 of the survey (see Appendix B) – "*Did you use the feedback tool?*", 44 answered yes while 28 answered no. The thematic analysis for the second part of the question – "*If no, please explain why?*" is provided in Table 6.22.

Table 6. 22: Thematic Analysis of Section 2, Question 1.

Theme (Frequency)	Responses
Don't know (9)	• *Don't know what it is* • *I was not aware of it but would have liked to have used it* • *Did not think to, I can see the benefit to it though* • *Didn't know it was there* • *Never noticed it* • *Didn't know about it* • *Didn't know about it was there* • *Didn't know about it* • *I didn't know well about it*
No time (5)	• *Never really got the time or remember. I may go back and use it be ready to exam for study* • *Haven't got a chance to use it* • *Lack of time to configure too many assignments (not this course)* • *Don't have time to use it* • *Didn't finish the lab work most of the time*
Missed the lab (3)	• *I missed out on the labs it was implemented in* • *The feedback tool activated after lab 7 (I think) where I was very busy with work and could not attend most of the labs* • *I missed the labs when it was introduced*
Not required (3)	• *It was not required* • *Wasn't mandatory to use or directed at our marks*

	• *I felt like doing it (the lab) step by step, I should have everything right anyway*
Technical difficulty (1)	• *Didn't work for me*
Other (5)	• *I am very lazy. In hindsight I should have* • *Didn't study this course enough* • *Didn't know I had to* • *I never really took notice of it* • *No particular reason*

Ten students who had not used the feedback tool stated that they were not aware of it. The feedback tool was to be executed after completing all the hands-on activities of the lab. It is possible that these students did not get far enough into the lab work to be aware of the feedback tool. Also, if students did not attend the lab class, preferring to work from home without completing the lab sheet, it is possible that they would not be aware of the feedback tool. Four students mentioned that they had no time to use it. It was common for many students to take more than the 2 hours allocated in the lab to complete the hands-on activities. This may have led students to run out of time and so they may have opted not to run the feedback tool. Three responses stated that they missed the lab and thus had not attempted to use the feedback tool. Three students felt that the feedback tool was not needed and, as it was optional, opted not to use it. There was one response where the student seems to have had difficulty in using the feedback tool. Five responses were categorised as "Other". After discussing these results with the practitioner, the practitioner felt that most students that were not aware, probably had not completed all the hands-on activities of the lab to the point of using the feedback tool. The practitioner mentioned that as a future enhancement, the feedback tool could be configured to run for particular sections of the hands-on lab activities. This will allow the feedback tool to be introduced earlier on in the lab and students would be more aware of it and its features/advantages.

The results for question 2 – *How satisfied are you with feedback generated from the tool?* are presented in Table 6.22. It can be seen that there were no responses for *Dissatisfied* or *Extremely Dissatisfied*, 4 (9%) responded *Neutral*, 22 (50%) responded *Satisfied* and 18 (41%) responded *Extremely Satisfied*. This is a highly positive result. This is also similar to the iteration 1 results (see Figure 6.8). Next, the students were asked to justify their reasons for the rating (Q3 – "*What is the primary reason for your rating in question 2 above?*"). The thematic analysis of the qualitative answers is provided in Table 6.23.

Table 6. 23: Comparison of Ratings of the Feedback Tool between the 2016 and 2017 Cohorts

Cohort	Total	Yes	Extremely Dissatisfied	Dissatisfied	Neutral	Satisfied	Extremely Satisfied
2016	90	51	0	0	3 (6%)	36 (70%)	12 (24%)
2017	72	44	0	0	4 (9%)	22 (50%)	18 (41%)

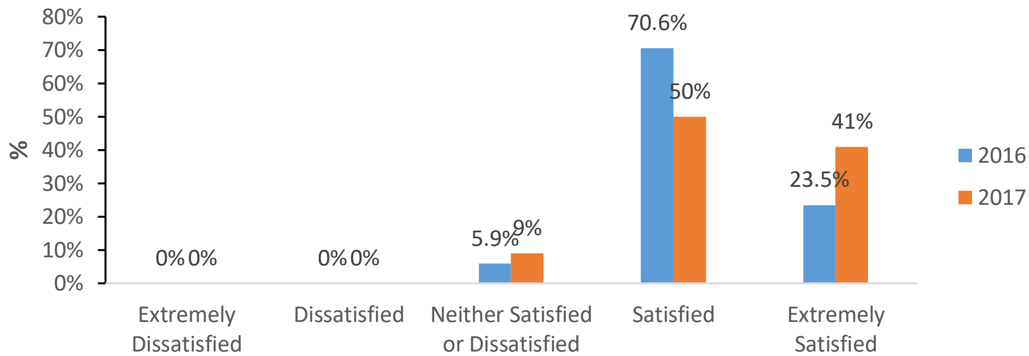


Figure 6. 7 Rating of the Feedback Tool between Iteration 1 and Iteration 2

Table 6. 24: Results for "*What is the primary reason for your rating in question 2 above*?"

Theme (Frequency)	Response
Provided clear, intuitive, easy to understand feedback that helped in learning (20)	• *Told me what I did wrong* • *Let me see what I did and correct that* • *It provided a clear tick/cross outcome for every part of the lab as well as easy to understand information about the expected configuration* • *Made checking for errors very simple* • *Could learn from faults* • *Check what I have done right or wrong in labs* • *Good to have feedback to know what you are getting right* • *Provide feedback did what it had to do* • *It helped me to see where I went wrong in the labs* • *It did exactly what was supposed to in a clear way* • *I am socially awkward and find it hard to ask for help. This tool is perfect feedback* • *Helpful to make my work when I need it* • *It was feedback straight way so mistakes could be fixed* • *Useful to see what lab you are up too* • *I can check if I completed the lab properly* • *Helped step though* • *The labs were a key part at the assignment, getting them right was crucial* • *It worked* • *I found it very useful* • *It is good to see report of what you did wrong*

Real-time feedback (6)	• *Gave real time feedback when used* • *The tool was good for receiving instant feedback* • *It is very quick and easy* • *Install feedback was great to fix any mistakes* • *It was feedback straight away so mistakes could be fixed* • *I can get the feedback on time to check my mistake*
Ease of use (4)	• *It is very quick and easy* • *Easy to submit and view* • *Easy to use* • *Simple and easy*
Kept track of progress (3)	• *Know my progress in the labs* • *Provides a quick way of checking how on track we are* • *Because it gives a progress check*
Helped in independent learning (2)	• *It helped do the work at home without the lecturer help* • *I could find the errors without tutor. Hope it can show more specifically*
Other – Bugs (4), Flexibility (1), Formatting (1) (7)	• *Few configurations different to worksheet* • *Didn't work for labs 6 and 7, worked quickly for 8 and 9* • *Come back wrong for some things that were actually correctly configured* • *It worked most of time only if was almost correct* • *Don't roles so much and often crash* • *Not flexible* • *Certain things live capital letters messed it up which is annoying*

From the thematic analysis, it can be concluded that most students rated the feedback tool highly due to the fact that it provided clear, intuitive and easy to understand feedback that helped in their learning. The fact that the feedback tool gave real-time feedback on the hands-on activities was a feature that also resulted in positive ratings. Ease of use was a reason for 4 respondents. This version of the feedback tool avoided the need to download PowerShell scripts which had been required in iteration 1 and also it had an improved interface to run the scripts. Three respondents mentioned that the feedback allowed them to keep their progress on track. Also, an interesting finding was that the feedback allowed students to learn independently as stated by 2 respondents. There were a few instances of bugs (4) reported. However, the number of reported bug instances have come down from 7 to 4 from iteration 1 (which only had 2 labs with the feedback scripts implemented). The practitioner discussed this and will look at this. The practitioner mentioned that a tool to easily configure the parameters of the feedback scripts can be looked into so that the lab sheets and feedback scripts check for the same parameters. This enhancement will be considered in future work.

The quantitative survey results to evaluate the feedback tool are presented in Tables 6.25.

Table 6. 25: Descriptive Analysis of the Feedback Script Tool (n= 44)

Dimension	Survey Question	10-point Likert Scale		
		Mean	**SD**	**Median**
Perceived ease of use	Q1. The feedback offering descriptions were easy to understand	8.27	1.301	8.00
	Q2. The feedback page on your VM was fast to load	7.09	1.840	7.00
Perceived usefulness	Q3. This feedback script encourages me to do my lab work	8.95	1.715	9.00
Attitude towards using	Q4. I prefer to have this feedback script with the labs	7.52	2.298	8.00
	Q5. Based on this script feedback, how likely are you to recommend it to students next semester?	8.73	1.436	9.00
Overall	Q6 - How satisfied are you with feedback generated from the script?	5-point Likert scale		
		4.32	0.639	4.00

The results were compared with the feedback scripts used in iteration 1 (see Figure 6.8). The means were quite similarly rated. For Q2 (“*The feedback pages on your VM were fast to load”*), it can be observed that the mean difference is 0.97. When discussing this with the practitioner, it was noted that the feedback tool maintained all scripts on the file server in iteration 2 while they were downloaded by students in iteration 1 and thus, when executing the script, there would have been an observable difference in performance. This is a balance between ease of use (not needing to download the script) vs performance. Overall students were highly satisfied with the feedback tool (Q6) – (see Figure 6.9).

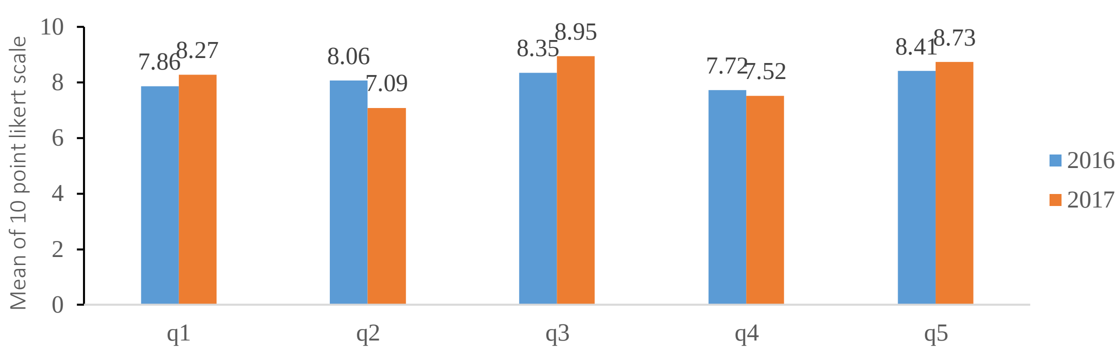


Figure 6. 8 The Mean for Survey Questions between Iteration 1 and 2 based on 10-point Scale

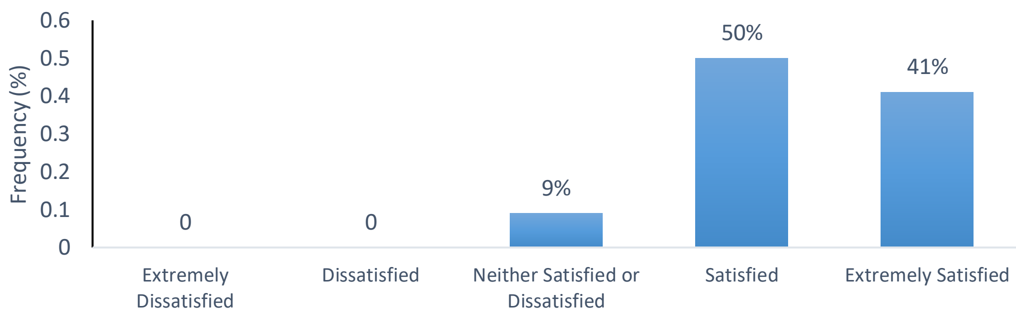


Figure 6. 9 The Overall Student Satisfaction with the Feedback Tool

Question 3 in the focus groups discussed learning support tools ("*What features did you like in the INFT2031 labs? For example, did you find the feedback and dashboard with the virtual labs easy to use and user-friendly?*"). The thematic analysis of Q3 is provided in Table 6.26. It is evident that overall, students were highly satisfied with the feedback tool.

Table 6. 26: Thematic analysis for "*What features did you like in the INFT2031 labs? For example, did you find the feedback and dashboard with the virtual labs easy to use and user-friendly?*"

Theme (Frequency)	**Response**
Positive response to feedback tool (15)	• *Feedback feature is great to see how you are going* • *When you do know what you doing. As oh when you think did everything right but in reality, you could did mistakes. But with this you can see what happen and where* • *Feedback tool was handy to check we did things right. I did not use the dashboard* • *Feedback tool an excellent addition. (Dashboard) Originally did not work, but good to see once submitted the result of others* • *Feedback tool good for detail, dashboard good in general* • *I have not used the dashboard, but the feedback tool was an easy way to immediately see how I was doing* • *The feedback system is very good. I can learn from my mistakes* • *Feedback started late but was a good option. Haven't used the dashboard* • *Feedback was very helpful, especially since it was immediate, unlike some other classes* • *Very helpful but they would be more helpful if we got feedback for all the labs not just a few of them* • *Feedback tool was really helpful and user-friendly; really helpful to see errors and mistakes* • *I think the feedback tool was more helpful, it is just more details, I mean [it] told us where gets right, what is the wrongs. Whereas the dashboard is more general that show labs where am I*

	• *I thought it is very useful. Yes, especially the feedback because it is very useful where am from, like troubleshooting if I done something wrong. Like when I excelled in mix up to which of two messages need to go to two things. Troubleshooting is very useful like to saying let me to do this; I am using feedback tool, I scroll back and set and scroll back and see where some crosses; see if any cross and where and that usually what the problem is, if I miss something* • *It was good. Sometimes when did you change the settings or something you not sure is it right; then you going a little make sure where your changes that is right things or what the document ask you to do* • *Just helpful because always we have to come to you and ask questions we can do it ourselves*
Positive response to dashboard (5)	• *Dashboard is very useful* • *Labs, using VMs to implement various think dashboard helps; a lot to see where mistakes were made; easy and user-friendly* • *Feedback tool an excellent addition. (Dashboard) Originally did not work, but good to see once submitted the result of others* • *Feedback tool good for detail, dashboard good in general* • *It's always fun more graphs. It just like minimum maximum and things like that you know it always is useful*
Suggestion for improvement (3)	• *It is good. Make it for all labs. Embed in Blackboard and just click it* • *I think like make sure it … follows the set up from lab 2 we can use it. I found some trouble to get myself registered for the dashboard as well* • *I like to start the course little quicker. A lot of people lose to use it*
Other (7)	• *Very user-friendly; the picture in the labs made thing much easier to understand* • *Comparing to other classes, we do not get any feedback* • *It is useful* • *Not much honestly* • *It is good, keep it* • *I don't care about that; I do not have problem with averages* • *I do not know what the feedback tool is*

Next, an evaluation of the dashboards is provided.

6.3.3.4. Evaluation of the Dashboards

This section evaluates the dashboards implemented in the TePF from a student perspective. Out of the 72 students who participated in the survey, 29 used the dashboard and 43 answered that they had not. The thematic analysis for the second part of the question – "*If no, please explain why?*" is provided in Table 6.27.

Table 6. 27: Thematic Analysis of Section 2, Question 1

Theme (Frequency)	Responses
Didn't know (11)	• *Didn't know them*

	• *I don't know what it is* • *I missed out on the labs it was implemented in* • *I don't remember the exact reason. Maybe, I wasn't interested in* • *I didn't know well about it* • *Again, I was not aware of it but would have liked to have used it* • *Didn't know about it* • *Didn't know about it* • *Didn't know about it* • *Not sure what it was* • *Didn't know it was there*
Didn't need it or find it useful (6)	• *Didn't seem needed* • *Didn't find it necessary* • *Didn't find it useful* • *I never needed to, nor was curious enough to look* • *Did not need to* • *Did not think to I [can] see the benefit to it though*
Access is complicated (4)	• *Didn't really learn how to access it* • *I want since now to use it - seemed complicated* • *Too many steps just to view the result* • *Had trouble setting up account*
Not happy to divulge progress (1)	• *I was intimidated by the idea my progress would be recorded and I would look bad compared to other students*
Other (7)	• *I missed the labs when it was introduced* • *It started too late in the semester* • *Didn't spend enough time studying this course* • *Didn't use* • *Very lazy, sorry* • *I have not done much labs once it activated* • *Only had a quick look*

The majority of the students did not use the dashboard (43 – not used vs 29 - used). Many students answered that they were not aware of it. Similar to the feedback tool, the dashboards were discussed at the end of the lab sheet. It is quite possible some students may not have completed the lab sheet or ignored this section as it was optional. Six responses indicated that the dashboards were not useful or needed. Four responses stated that the access was not user-friendly and complicated which was also a suggestion from that came out of the focus group discussions. When discussing this with the practitioner, he agreed that a separate login set up for dashboard access and seamless access from the LMS would be beneficial and he would address this concern. One response indicated that s/he did not wish to share their progress with others. There were also responses which classified as Other which included "*lazy*" and "*only had a quick look*".

Table 6.28 provides the descriptive results of the survey for dashboards. It is clear that among the students who used it, they are highly satisfied with the tool and its features (mean over 7.0 for all questions except Q7 - *I would like to see my rank in class using the dashboard* which scored a mean of 6.93). Qualitative analysis below provides further insights.

Table 6. 28: Descriptive Analysis on Items related to the Dashboard Tool (n= 29)

Item	10-point Likert Scale		
	Mean	**SD**	**Median**
1- The dashboard was easy to understand	8.52	1.550	9.00
2- The dashboard provides feedbacks on my learning activities and performance	8.41	1.593	9.00
3- I prefer to have this dashboard with the labs activities	8.45	1.901	9.00
4- This dashboard encourages me to do my lab work	7.52	2.385	8.00
5- How likely are you to recommend using dashboard in next semester	8.28	1.944	9.00
6- I would like to compare my performance with other students	7.21	2.769	8.00
7- I would like to see my rank in class using the dashboard	6.93	2.738	7.00
8- How satisfied are you with the Dashboard view?	5-point Likert Scale		
	3.90	1.047	4.00

The results for question 2 – "*How satisfied are you with the dashboard view?*" are presented in Table 6.29 and Figure 6.10.

Table 6. 29: Results for "*How satisfied are you with the dashboard view?*"

Scale	Frequency	Percent
Extremely Dissatisfied	1	3.5%
Dissatisfied	1	3.5%
Neither Satisfied or Dissatisfied	8	27.5%
Satisfied	9	31.0%
Extremely Satisfied	10	34.5%

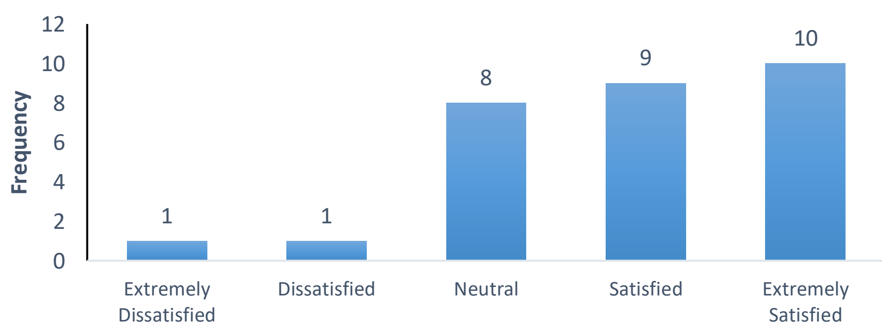


Figure 6. 10. Responses to Satisfaction with the Dashboard View

Most students who used the dashboard seemed to be satisfied or extremely satisfied (65.5%) with 27.5% neutral and 7% dissatisfied or extremely dissatisfied. The thematic analysis for the reasons for this rating is provided in Table 6.30.

Table 6. 30: Thematic Analysis for "*What is the primary reason for your rating in question 2 above?*"

Theme (Frequency)	Responses (rating)
Shows progress (8)	• *Pretty much the same as feedback tool {3}* • *My progress and where I am going {5}* • *Just to check my marks {4}* • *Easy to keep track of activities {5}* • *Gives a checklist {5}* • *Everything that is needed for labs is on the dashboard {5}* • *Didn't really bother to see nonusers, was infused to see it and where mistakes were made {3}* • *Cool but I don't really care how others are going {3}*
Easy to use (5)	• *Dashboard was easy to use and gave me the outcome I needed in real time {4}* • *Easy to view {5}* • *Easy and useful {5}* • *It was easy to use and navigate {5}* • *Easy to use, good tool {4}*
Compare with peers (3)	• *Shared how well each student did {5}* • *It allows me to compare my results to the class {4}* • *It helped compare my labs {4}*
Hard to understand (2)	• *A little hard to understand {1}* • *Messy and a little confusing {2}*
Easy to understand (1)	• *Easy to understand {3}*
Other (1)	• *Good idea {3}*

{ } Number in brackets is the rating

The main reason provided by respondents for their rating was that the dashboard showed their progress, was easy to use and compared their results with peers. The main reason for the Dissatisfied (2) or Extremely Dissatisfied (1) ratings were that these students found the dashboard hard to understand and confusing.

From the above analysis, it can be concluded that dashboard was not used by the majority of the students (as discussed earlier). Those who did use it liked it mainly because it showed their progress. A number of areas for improvement were discussed with the practitioner including seamless access to the dashboard from the LMS in the future.

6.3.3.5. Overall Evaluation

The overall evaluation of the course was analysed in the focus group discussions. The thematic analyses of "*How did you find the course INFT2031? The structure, lectures, labs, formative assessments (such as quizzes, review questions, group work, practical test, etc.)*" and "*What is your overall opinion about INFT2031? How can INFT2031 be improved? Would you recommend it to another student?*" are provided in Tables 6.31 and 6.32 respectively.

Table 6. 31: Thematic Analysis of Focus Group Question – "*How did you find the course INFT2031? The structure, lectures, labs, formative assessments (such as quizzes, review questions, group work, practical test, etc.)*"

Theme (Frequency)	Response
Practice test was helpful (9)	• *The practice test really helpful; like how the same lee is going do for next week and everything. It has just told you what going happen and get brain for it. Yes, I did* • *I really liked having practical tests before our practical test* • *I really liked the practical test before the actual ones. I thought the course content was structured very well. I liked how the labs went alongside the lectures* • *The course is well structured, practice test is excellent* • *Labs are very interesting and helpful, refer hands-on work to actually use the theory; practical tests are useful as well; quizzes and questions are good to test lecture theory* • *Practice exam because we do not have any idea what we have do in exam, so practice exam give us idea about we have to do in exam … of course help us to get high marks* • *Yes, very good I like the practice practical exam before the actual exam. It is kind of helpful. It refreshes what we learnt over the semester because a lot of it and all the time just sit down and practice it. I found it helpful. A lot of content in the lecture. Sometime a bit hard to keep up with notes. Sometimes you go very quick but not too bad* • *Keep that if you care about students, not because it's helpful but also sort of aware what practice is and refresh your memories* • *That is super useful. That is good. Easy make for next test*
Labs are useful (6)	• *The best part is doing labs where we have work that actually useful* • *Found labs very useful* • *Lab is good* • *Labs are very interesting and helpful, refer hands-on work to actually use the theory; practical tests are useful as well; quizzes and questions are good to test lecture theory* • *You can commit what to do in lab to memory it is easier* • *Preferred the labs because they are many hands-on, quizzes are better than review questions since they give feedback*

Course structure is very good (5)	• *Structure was good and practice tests and quizzes helped a lot. Labs structure was great and helped but long* • *The course was very good. Everything were linked to each other and was good. Flow from start to the end* • *I really liked the practical test before the actual ones. I thought the course content was structured very well. I liked how the labs went alongside the lectures* • *The course is well structured, practice test is excellent* • *I thought it is very structured. Maybe a lot of work like you feel it is little hard to done all in two hours but you going from the lecture to lab is good*
Review questions and quizzes are good (5)	• *Labs are very interesting and helpful, refer hands-on work to actually use the theory; practical tests are useful as well; quizzes and questions are good to test lecture theory* • *Review questions and quizzes it is okay to test your knowledge from lecture and theories* • *Just I found that having review questions is quite good. I do not think I had done any course yet with had consistent as clear questions just to help keep refresh your mind about what you been learning that quite useful* • *This will be good for final exam preparation. Usually as I did couple of questions but usually things like that I see if I leave them into to have study for the exam because is good to push to look through them and find the answers* • *Probably when we having questions where in quiz format going to answer helping us to study ... and we have go and know what right or wrong. So, online quiz format we know long to be get submit you known right or wrong*
Overall good course (5)	• *Overall good, straightforward and clearly explained; Expectations were made clear and requirements explained* • *The course was excellent. All course work (lecture material, labs and assessments tasks) was straightforward and ease to read* • *The ideas were easy to follow and straightforward in their presentation* • *As a whole, so far it is one of my more enjoyable course. I find all examinations, labs and lectures to be set out well. No complaints here* • *I am not emphasis. This course seems to look after student more like how they learn and how can pass the course. Some courses it is just do it*
Lecture recordings are good (2)	• *I though the Echo really helpful; I find it kind of hard to learn diagram and stuff watching lectures, so going though Echo couple of times help me to learn how to do it* • *Style of Echo. Really good to see in Echo. Miss the lecture and see what talking about*
Lab environment is good (1)	• *Workspace was really helpful. One environment to do labs*
Quizzes preferred over review question (1)	• *Preferred the labs because they are many hands-on, quizzes are better than review questions since they give feedback*

Suggestions for improvement - Lecture can be improved (4)	• *I found the labs were helpful than lectures, actually doing rather than in lecture just listening* • *Parry descent of length. We considering what we are learning it make sense it just lecture is very long like do of all these staff* • *Yes, very good I like the practice practical exam before the actual exam. It is kind of helpful. It refreshes what we learnt over the semester because a lot of it and all the time just sit down and practice it. I found it helpful. A lot of content in the lecture. Sometimes a bit hard to keep up with notes. Sometimes you go very quick but not too bad* • *I think the lecture were maybe a little too formal as well like sometimes I have sit in lecture like you know we need basic idea its saying behind DHCP, routing and behind ever things. That will getting quite a bit more information in that*
Suggestion for improvement – Other (tutor demos, network diagram exercises, labs are long) (3)	• *Maybe we should do some work out on networks design diagram in actual lab rather than in lecture in able to do that again* • *Some of the labs quite long and sometimes a lot of things that need to do more than what we actually doing … Yes, I think most of them it was help when brick it up* • *I just hope this looking to following the instructions sometime might a bit confused although we can ask questions, which is good. But just I am hoping to be like Demo in front that's going to do and then just kind of follow. I found that will be better that way. Still not bad following the instructions but sometimes if I miss some steps that I do not realise it and after that when I do until the halfway and go back over all of that again. If I just follow in screen appropriate will be easier and then all explanations that been given appropriately will be easier and better approach*
Other/Not clear (6)	• *First of all, I have always been asking myself why I take this course while taking this course. Of course, I enrolled this course since I am bachelor of IT for the core course, but I was suspicious of what I could get through this course* • *I was happy. I just more everybody does by themselves but this is an issues I guess discussion board* • *There were more helpful because they have the same things* • *Hard at first but as the semester progressed it become a bit easier* • *There were more helpful because they have the same things* • *You can ask many questions in labs. I mean you can ask in lecture but just different things*

Table 6. 32: Thematic Analysis for Focus Group Questions - "*What is your overall opinion about INFT2031? How can INFT2031 be improved? Would you recommend it to another student?*"

Theme (Frequency)	Response
Overall good (21)	• *Overall, it was quite good course and I am satisfied with it, although the final exam is not finished yet. And I also hope that many students take this course as many as possible. Hope this email can help for this course's future* • *Really good course. I would recommend* • *The course is good; I would recommend it to anyone studying IT*

	• *It is very good course to learn network basic knowledge* • *Not too hard but not too easy. I felt like I learn a lot which is good* • *I thought it was very good* • *I must definitely recommend to people if they doing anything like relate to IT by doing this course it will be very useful because never we can make useful skill to have* • *It is very structured and easy to follow. I think it is good as it is; not too easy but not too challenging* • *I would recommend it, lecturer and demonstrator very helpful, everything is very organised so you don't fall behind* • *I would recommend to other students* • *It is perfect just leave it as it is* • *It was a good course for introduction to networking* • *It was a good course, could be made more challenging, perhaps more Linux; would recommend* • *Simple straight forward course, good for 2nd year IT. Yes, would recommend to students interested in network admin. More LINUX. Would runs on Linux, should be more taught of uni* • *Lab VMs could be sped up. Would recommend to others. Overall, extremely impressed* • *It was a good course, could be made more challenging, perhaps more Linux; would recommend* • *I really liked this course and hand-on important beside an option for USB VMs; I would recommend to another student* • *It is very cool* • *It was a good course for introduction to networking* • *Yeah. It's interesting and gets the brain going* • *The weight of the course is pretty helpful. Like if someone has miss any, its new experience help. It is straightforward, I think it is very helpful and it is not overly hard. I think is good keep it like this. I like the way marks are distributed we got a lot of marking by doing practical exam*
Labs are good (3)	• *Lecture can be bit long, but lab themselves were great* • *Everything 2031 computer labs acer than lecture because we're actually doing useful staff and hands-on work* • *Each lab based on virtual machine or points with the lab starts then continuing from there. In this way, it will be like if you do not have done that go back and do one before. But, here if you want to continue*
Suggestion for improvement (lab work) (3)	• *More labs work and more lab time* • *More communication about what is going on in the labs. Shorter lab work, more descriptions, note on what's going on* • *Feedback on all labs, screenshots on labs activities are not always clear*
Add Linux (3)	• *It was a good course, could be made more challenging, perhaps more Linux; would recommend* • *Simple straight forward course, good for 2nd year IT. Yes would recommend to students interested in network admin. More LINUX. Would runs on Linux, should be more taught of uni* • *It was a good course, could be made more challenging, perhaps more Linux; would recommend*

Add more on network diagrams (1)	• *Maybe the way can be improved is in first assignment it was not much content on networks diagram, we had one lecture, did the example. Just add something to lectures that goes over the networks diagram little bit because I am still little confused until I saw the example. Yes, maybe in the labs*
Speed up lab VMs (1)	• *Lab VMs could be sped up. Would recommend to others. Overall, extremely impressed*
Lecture can be long (1)	• *Lecture can be bit long, but labs themselves were great*
Other/Not clear (2)	• *Probably, like mostly to me it is new concept we did know how to, especially for the first one, like I did know how find in depth make the diagram because I saw some my friends he had up to point I had but it showing different topologies for how actual computers should be set up. Just knowing what kinds of details have to going to and what type of information should be in diagrams* • *When we do the example yourself, you can watch him do it on the board or whatever. I think if you are doing the exercise by yourself it might give more better understanding*

From the evaluation, it is clear that students like the course overall and the structure of the course. Students liked the formative assessment (practice tests) prior to the actual practical tests as a form of preparation. Lab work and review questions were noted as good aspects of the course. There were suggestions for improvements such as adding Linux and lectures being shorter. Upon discussing this with the practitioner, it was clear that these suggestions will be incorporated in future. Overall, from the responses, it can be concluded that the course is well organised, students are highly satisfied, and they would recommend it to others.

6.4. **Summary**

This chapter discussed the implementation and evaluation of the entire TePF for the lab environment as proposed in Chapter 3. This chapter examined the second iteration of the DBR process. The virtual labs were implemented as a server-based private cloud implementation.

A quasi-experiment was conducted and the scores of the practical tests were compared between the control and experimental groups. It was seen that the students in the experimental group (who used the TePF) scored higher than the students who did not use TePF in the practical tests on average. This result was shown to be statistically significant.

Next, surveys were used to identify which components of the TePF actually contributed the most to learning. It was clearly indicated by the students that lab activities contributed the most to learning in the course. The lab activities incorporated a number of PLTs in their design as discussed in Chapter 3. The lab activities were evaluated using a number of survey instruments from the literature. This revealed that students were catered to by all stages of Kolb's ELC and they also were encouraged to a deeper approach to learning. These results confirm that the TePF has resulted in students achieving higher scores and their learning process was deeper in nature. The virtual labs were rated the next highest as contributing to learning. This supports the hypothesis that using sound PLTs in the design of laboratory environments using technology can result in effective learning.

A limitation of the study was that a control group (i.e. 2015 cohort) was used only to compare practical test scores. That is, it was shown that students in the experimental group (i.e., 2017 cohort) scored higher marks in practical tests than the control group (i.e., 2015 cohort) which was shown to be statistically significant. Although lab activities were evaluated using a number of survey instruments for the experimental group (6 dimension from Konak et al. (2016), Kolb's ELC stages based on Young et al. (2008) and approaches to learning (R-SPQ-2F) (Biggs et al. (2001)) and shown to be positively impacting student learning, there was no such evaluation of lab activities for the control group. Therefore, it is not possible to compare the impact of PLTs for lab activities for the experimental versus the control group. This limitation in the design of the experiment is practical in nature. The ethical considerations that an intervention whereby a group of students in a single cohort are deemed to be advantaged due to improved learning experience (i.e. experimental group) while others are not (i.e. control group) would be seen unfavourably by University Ethics committee for approval. Also, the limited time to complete the thesis project, meant there is not sufficient time to run the course in different years with different lab activities to compare. Thus, only the practical scores from 2015 cohort (i.e., control group) was obtained and compared with practical scores from 2017 cohort (i.e., experimental group) while the survey instruments evaluating lab activities was conducted only for the experimental group.

The technology artefacts of the TePF were evaluated using survey instruments. Both quantitative and qualitative data was collected and analysed. It was clear that accessibility, convenience and ease of use were the main advantages of using virtual labs. Improving the performance of the virtual labs was the main suggestion. Students were highly satisfied with the real-time feedback provided by the feedback tool. Also, although the dashboard was not as popular as the feedback tool, the participants who used it were satisfied with its functionality. A number of insights and suggestions to improve the technology artefacts were gathered and discussed with the practitioner who indicated that improvements can be implemented in the future. Overall, the application of PLTs in the design of lab environments in this course is shown to be successful as demonstrated by the results.

Chapter VII

7. Design Principles

This chapter reflects upon the findings of the previous chapters to derive design principles that would be useful in similar or related research projects and contexts. Firstly, reflections on the research project are discussed with the aim of deriving the design principles. Next, the design principles are discussed. Finally, the chapter is concluded.

7.1. **Reflections**

The research project outlined in this thesis aimed to answer the broad research question – "*How do we design a lab environment to take advantage of technology for effective learning?*" To answer this broad research question, the thesis reviewed the literature where technology-enhanced labs had been implemented and examined the lessons learnt. From the analysis, it was clear that technology advancements provide capabilities that create many new opportunities for learning. An insightful observation was that incorporating educational theories and principles (PLTs) in designing technology-enhanced lab environments can create learning environments for more effective learning. This led to the hypothesis - *Design of technology-enhanced lab environments taking a holistic view of learning incorporating curriculum design, lab activities, support tools and technology artefacts based on sound pedagogical principles and theories have a higher potential for effective learning.* A Technology-enhanced Pedagogical Framework (TePF) that incorporated curriculum design and delivery, lab activities, support tools and resources based on sound pedagogical principles and theories was built. Next, this study designed, developed and evaluated the TePF to prove the hypothesis. A context for developing a technology-enhanced lab environment was selected to be built based on the TePF. Recently, virtualization technologies have been used to create virtual labs for system-level courses in computing with many advantages and new opportunities for learning. Thus, a system-level course in computing was selected. Next, a literature review of virtual lab implementations in system-level courses was conducted. It was clear that a majority of studies had implemented technology innovations with little emphasis on educational theories and practices. These studies were categorised as Level I. A few studies had gone beyond just introducing the technology innovations. These studies considered a single or a set of PLTs when designing technology innovations for labs. These studies were categorised as Level II. There were very few (i.e., 4 studies) that can be classified as Level II in literature. It was clear that there was scope for further research in this area.

For this research project, a system-level course in computing that already was using a decentralised virtual lab for students to conduct hands-on practical work was selected. A conceptual model of the TePF for a lab environment was designed based on a number of PLTs. Biggs's Constructive Alignment was used in curriculum design. Kolb's ELC, Collaborative Learning and the Bloom and SOLO taxonomies were referenced to re-design the lab activities. Formative assessments as a form of feedback were incorporated throughout the lab activities. Technology advances allowed centralised virtual lab environments to be designed where students had remote 24/7 access to IT infrastructure labs, and artefacts such as an automated feedback tool that provided immediate feedback for hands-on configuration tasks and dashboards that provided a transparent view of student progress were included. Features in the LMS, such as discussion boards, were incorporated to enable collaborative discussion and posts.

To develop and evaluate the proposed TePF, Design-Based Research (DBR) was selected as the research methodology. In this methodology, close collaboration between the practitioner and researcher was needed. The framework was developed and evaluated in an authentic practical setting. The proposed framework was developed and evaluated iteratively using findings from the first iteration to influence the second iteration. This also provided a means for the practitioner and researcher to develop familiarity and trust in the proposed framework. A mixed methods approach was used to evaluate the framework where both quantitative and qualitative data were collected and analysed.

The results clearly identified a significant improvement in learning outcomes (i.e., statistically significantly increased scores in practical tests) for students using the proposed framework. Furthermore, students exposed to the proposed framework typically took a deeper approach to learning. These results supported and validated the hypothesis - *Design of technology-enhanced lab environments taking a holistic view of learning incorporating curriculum design, lab activities, support tools and technology artefacts based on sound pedagogical principles and theories have a higher potential for effective learning*. Next, the different components of the proposed framework were evaluated using the mixed methods approach. The re-designed lab activities were rated the highest by students for their impact on learning. The design of the hands-on activities was based on a number of PLTs. This provided further evidence to support the hypothesis that the use of educational theories in the design of lab activities in technology-enhanced lab environments support learning. The technology artefacts - the virtual labs, the feedback tool and the dashboards - were highly rated by students. Analysis of the qualitative data provided a number of useful insights and aspects that lead to the high level of satisfaction and improved learning by examining the different components, such as hands-on activities, review questions and quizzes in lab activities, immediate feedback from the feedback tool, 24/7 remote access to the virtual labs and the formative assessments such as the practice tests, as well as revealing areas for further improvement (e.g., performance improvement for the virtual labs). Overall, students were highly satisfied with the framework and the improved learning outcomes. This research project supports taking a holistic view with PLTs taken into consideration when designing technology-enhanced learning environments to provide more effective learning.

The next section discusses deriving the design principles.

7.2. **Deriving Design Principles**

An outcome of a DBR project is a set of design principles. Design principles "… can guide similar research and development endeavours" (Amiel & Reeves, 2008). The content and depth of design principles may vary. The principles may be generalised or applicable to a certain context only (Wang & Hannafin, 2005). However, in general, design principles should provide guidance and assistance to research projects of a similar nature.

A clear outcome in our analysis was that students rated lab activities higher than the virtual labs (the technology innovation) in terms of significance to their learning in the proposed framework. The design of the lab activities was based on PLTs. Thus, when considering an educational technology innovation, although the technology innovation may provide a number of advantages and opportunities for learning, it is beneficial to take a holistic view considering the learning context, any relevant PLTs and the capabilities of the technology advances in designing the technology-enhanced learning environment. So how does one go about designing such a learning environment? The approach taken in this research project can be generalised to the design of any technology innovation, intervention or learning environment aimed at improving learning. That is, the consideration of the learning context, technology advances, existing work and PLTs can improve the design of technology innovations, technology interventions and technology-enhanced learning environments to achieve improved learning goals (see Figure 7.1).

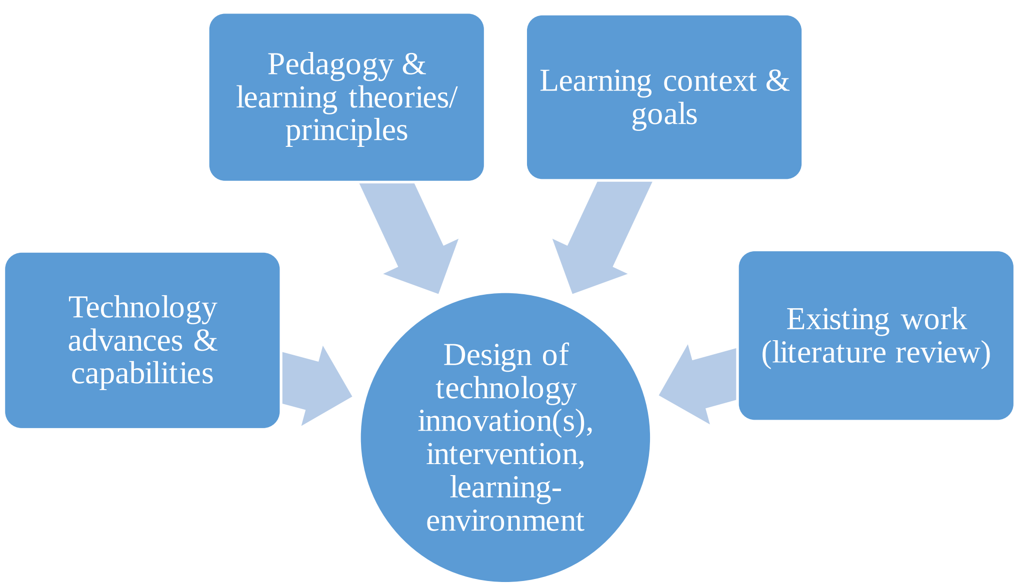


Figure 7. 1 Components for the design of Technology-enhanced Learning Environments, Interventions and Innovations in Education

From the above, the following design principle can be derived.

Design Principle 1: Consider the learning context, existing work, technology advances/capabilities and educational theories/principles in the design of technology environment, innovation or intervention.

It is clear that Design Principle 1 will result in a Level II intervention.

Next, how do we develop and evaluate such technology-enhanced learning environments? The use of the DBR methodology with close interaction between the practitioner, evaluation of the design in authentic settings, use of iterative cycles of design, implementation and evaluation, and use of mixed methods evaluation provides a sound framework for developing and evaluating technology innovations, interventions and technology-enhanced learning environments.

Design Principle 2: Use of the DBR methodology in authentic learning contexts with a mixed methods approach provides a framework for developing and evaluating technology-enhanced learning environments.

It is important to note that to evaluate the TePF, you could use other processes. Indeed, Design Principle 1 could follow a methodology other than DBR. However, this study uses both Design Principles 1 and 2 as the methodology to design and evaluate the TePF intervention study.

To answer the broad research question - "*How do we design a lab environment to take advantage of technology for effective learning?"*, the following process can be taken to derive Design Principle 3.

Design Principle 3: Follow the steps below to design and evaluate a TePF intervention:

- *Step 1: Design a TePF using Design Principle 1*
- *Step 2: Develop and evaluate the proposed TePF using an intervention study following Design Principle 2*

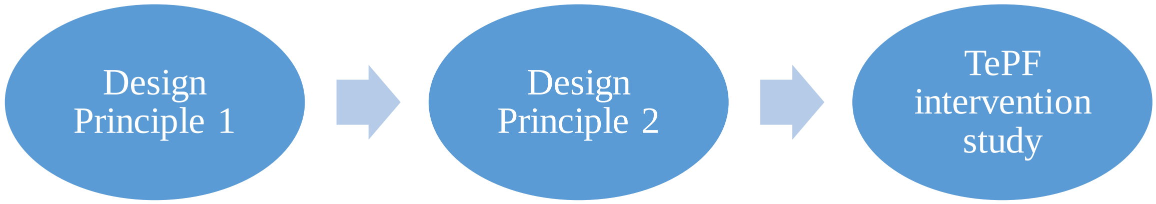


Figure 7. 2 Design Principle 3 – Process of design and evaluating the TePF

It is important to note that although this study focused on lab environments for evaluating TePFs, the design guidelines can be generalised to other learning environments. The design guidelines are intended to be applicable to general situations outside the context of this study. Further work is needed to validate these design principles in different contexts.

7.3. **Summary**

This short chapter provided a reflective view of the research project and derived the design principles. Three design principles were discussed. The next chapter concludes the thesis.

Chapter VIII

8. Conclusion

This chapter concludes the thesis. Firstly, the chapter summarises the work carried out in this thesis along with a discussion of the main findings of the DBR iterations. An outline of the key contributions of this research is presented in section 8.2. Finally, several opportunities and recommendations for future research directions are discussed in section 8.3.

8.1. Summary

In many fields of study, hands-on lab activities are paramount for learning. Technology provides many opportunities to develop lab environments that enable learners to conduct hands-on activities and experiments. Technology-enhanced labs are broadly classified in the literature as virtual and remote labs. Although there are many virtual and remote lab implementations discussed in the literature, there are still no clear guidelines or directions on how to develop such technology-enhanced labs. Thus, this thesis poses the broad research question – "*How do we design a lab environment to take advantage of technology for effective learning?*" To answer this broad research question, a literature review of virtual and remote lab implementations was undertaken. The analysis of the survey provided a number of useful insights. It was evident that technology advances enable researchers and educators to develop lab environments to provide new opportunities for learning. However, although the technology provides such opportunities, taking a holistic view of designing technology-enhanced lab environments by taking into consideration not only the design of technology artefacts but also how they can be integrated to the environment to support learning is beneficial. Pedagogy and Learning Theories and principles (PLTs) can be used as a guide to design such environments. This analysis resulted in posing the following hypothesis:

Design of technology-enhanced lab environments taking a holistic view of learning incorporating curriculum design, lab activities, support tools and technology artefacts based on sound pedagogical principles and theories have a higher potential for effective learning.

The thesis aimed to validate the above hypothesis. To validate this hypothesis, a technology-enhanced lab environment was developed using the TePF and then evaluated. To test the TePF for a lab environment, a learning context was identified. The TePF was designed for a system-level course in computing. The system-level course in computing was chosen due to the fact that in recent years, a number of virtual lab implementations for system-level courses in computing taking advantage of maturing virtualization and cloud computing technologies was observed. A literature review of virtual lab implementations in system-level courses in computing was undertaken. An observation was that, in the literature, most studies focused on technical design and evaluation while only a handful of studies considered PLTs in their designs. This confirmed that further research in this direction was needed.

In Chapter 3, a number of PLTs were reviewed in the design of the TePF for a lab environment in a systems and network administration course. PLTs considered included Bigg's Constructive Alignment, Kolb's Experiential Learning Cycle (ELC), Collaborative Learning, Bloom's and SOLO taxonomies, formative learning and others. A number of technology artefacts, such as virtual labs, a feedback tool, teacher and student dashboards and integration of LMS features, were proposed. The TPACK model provided a theoretical model for the design of the TePF. The proposed TePF was discussed in detail in Chapter 3.

The proposed TePF needs to be developed and evaluated. Chapter 4 presented Design-Based Research (DBR) as a suitable research methodology to develop and evaluate the TePF. The proposed framework was developed in close collaboration with practitioners and evaluated in authentic classroom environments. An iterative process was used to develop and evaluate the TePF providing feedback and confidence to both researcher and practitioner on the approach taken. A mixed methods approach (using both quantitative and qualitative data) was taken to evaluate the framework by providing multiple sources to validate the findings.

8.1.1. First Iteration

The main technology artefact of the TePF was the virtual lab environment. There are two main architectures to implement a virtual lab: a centralised approach and a de-centralised approach. At the time, the course was using a de-centralised approach to conduct hands-on activities. Thus, a centralised lab was provided as an option in the last few lab sessions of the first pilot study. Quantitative and qualitative data were collected through surveys to evaluate the students' perspectives of the different approaches. It was clear from the data analysis that the advantages of centralised labs far outnumbered those of the decentralised labs. Thus, it was decided to design, use and evaluate centralised labs for the next iteration, addressing some shortcomings identified through the analysis. The detailed results and analysis were presented in Chapter 5.

The next most significant technology artefact was the feedback tool. The first version of the feedback tool was implemented as a set of PowerShell scripts which students could download and run for the last few lab sessions. The feedback tool was evaluated quantitatively and qualitatively by students. It was clear that the students were highly positive about the feedback tool. The fact that the tool provided immediate, detailed, clear and useful feedback that helped in learning was appreciated. A number of suggestions for improvement were revealed which were incorporated into the development of the feedback tool in the next iteration. The detailed results and analysis can be found in Chapter.

Finally, a quasi-experiment was conducted to discover if there was any identifiable impact on learning outcomes based on the technology artefacts introduced in the last few lab sessions. No impact was detected based on the practical test scores. It was noted that the technology artefacts were implemented for only the last few lab sessions and that not all students participated in the intervention.

This iteration provided feedback and suggestions for improvement which were incorporated to the development of the technology artefacts in the next iteration. The next iteration was implemented to evaluate the entire TePF.

8.1.2. Second Iteration

The second iteration was implemented to evaluate the entire TePF for the lab environment as presented in Chapter 3. Firstly, this iteration was evaluated for any observable impact to learning outcomes by the TePF. A quasi-experiment was carried out with the experimental group using the TePF and control group who did not use the TePF. The mean scores of the practical tests were higher for the experimental group than the control group and the differences were statistically significant between the groups. This provided strong evidence that the learning outcomes were positively impacted by the TePF.

Next, surveys were used to identify which components of the TePF actually contributed the most to learning. The students rated lab activities as contributing the most to learning. The lab activities were evaluated using a number of survey instruments from the literature (Konak & Bartolacci, 2016; Kolb, 1981; Biggs et al., 2001). The findings indicated that the lab activities catered to all stages of Kolb's ELC and that the learning process encouraged a deep approach to learning. These results not only provided evidence of higher learning outcomes due to the TePF but also that a deeper learning process was encouraged. The lab activities incorporated a number of PLTs in their design and the benefit of this approach was validated, supporting the hypothesis presented earlier. Section 6.3.3.1 provided the detailed results and analysis of the lab activities.

The virtual labs were rated as the next highest contributor to learning. Students were highly positive in their rating of virtual labs (above 4.0 on a 5-Likert scale for all survey questions). The virtual labs were implemented using a server-based private cloud implementation. The qualitative results showed that accessibility, convenience, ease of use and helpfulness in learning were the main advantages of using virtual labs. Improving the performance of the virtual labs was the main suggestion for improvement. Although most students preferred to use the centralised labs, a few students preferred to use the decentralised labs due to performance, convenience and flexibility. Section 6.3.3.2 provided the detailed results and analysis of the virtual labs.

The students were highly satisfied with the real-time feedback provided by the feedback tool. Although the dashboard was not as popular as the feedback tool, the participants who used it were satisfied with its functionality. Sections 6.3.3.3 and 6.3.3.4 provided the detailed results and analyses of the feedback tool and the dashboards.

A number of insights and suggestions to improve the technology artefacts were gathered. Discussions with the practitioner indicated that many improvements could be implemented in the future.

Chapter 6 concluded that the TePF design, based on PLTs and using technology artefacts, yielded significantly higher levels of learning and student satisfaction. Overall, the application of PLTs in the design of lab environments in this course has been successful as demonstrated by the results.

8.1.3. Design Principles

The results and analysis of Chapter 6 validated the hypothesis by providing an instance where the TePF for a lab environment was designed and evaluated taking a holistic view of learning incorporating curriculum design, lab activities, support tools and technology artefacts based on sound pedagogical principles and theories resulting in effective learning – i.e., higher learning outcomes and a deeper approach to learning. However, the process of designing such lab environments was not addressed. This is needed to completely answer the overall research question - "*How do we design a lab environment to take advantage of technology for effective learning?*".

In Chapter 7, we reflected on the overall process used in the design, implementation and evaluation of the TePF. From this activity, we derived the following design principles that provides guidelines to designing TePF for lab environments.

- *Design Principle 1: Consider the learning context, review of existing work, technology advances/capabilities and educational theories/principles in the design of technology environment, innovation or intervention.*
- *Design Principle 2: Use of DBR methodology in authentic learning contexts with mixed methods approach provides a framework for developing and evaluating technology-enhanced learning environments.*
- *Design Principle 3: Follow the steps below to design and evaluate a TePF intervention study:*
    - *Step 1: Design a TePF using Design Principle 1*
    - *Step 2: Develop and evaluate the proposed TePF using an intervention study following Design Principle 2*

The above design principles have provided basic guidelines to answering the main research question – "*How do we design a lab environment to take advantage of technology for effective learning?"*. Further work is needed to gather additional evidence to support while extending/refining the above design principles to address the broad research question.

It is important to note that an endeavour such as designing and deploying TePF mentioned in this thesis has undertakings in terms of costs and overheads. The proposed TePF had overheads and costs including development of technology artefacts; revision of course materials; acquiring, configuring, managing and deployment of virtual lab infrastructure; management of meta-data, and others. The management of virtual lab infrastructure include network access and connectivity to lab resources, back-ups, etc. A close collaboration with technical teams, management and academics is encouraged in such endeavours. The use public cloud providers such as Amazon's AWS (https://aws.amazon.com/), Microsoft's Azure (https://azure.microsoft.com/en-us/), may be deemed effective and effective to deploy virtual computing labs in particular contexts.

The next section presents the main contributions of the thesis.

8.2. Main Contributions

The main contributions of this research project include:

- *Literature review on technology-enhanced labs in different disciplines*: A comprehensive literature review of virtual and remote labs implemented in different disciplines was performed. This review provided a number of insights on the benefits of technology-enhanced labs.
- *Identified research gaps*: From the literature review, it was clear that there were no clear guidelines, methodologies or frameworks to follow when integrating technology-enhanced labs in different educational contexts in order to enhance learning.
- *An approach to designing technology-enhanced lab environments geared towards achieving learning goals*: The analysis of the literature review provided pointers to address the research gap. The use of PLTs in the design of technology-enhanced lab environments geared towards achieving learning goals was proposed and evaluated in this study.
- *Comprehensive literature review of virtual labs using virtualization in system-level courses in computing:* A literature review of virtual labs in system-level courses in computing utilising virtualization and cloud computing technologies was conducted. The studies were classified into Level I and Level II studies. Level I – Technical Design and/or Evaluation – included studies that focused on technical design and evaluation (and optionally evaluated learning impact). Level II – Technology, Pedagogy and Evaluation – included studies that considered PLTs in the design of virtual labs. It is important to note that only a few studies were classed as Level II compared to Level I, indicating that further work in Level II studies is needed.
- *A TePF was designed for a lab environment in a systems and network administration course*. This study provided a comprehensive architecture, implementation and evaluation of the TePF for a lab environment in a systems and network administration course. The TePF applied PLTs in its design. The students

achieved higher learning outcomes and also took a deeper approach to learning using the TePF.

- *Innovative Technology Artefacts – virtual labs, feedback tools and dashboards*. The thesis proposed, implemented and evaluated a number of technology artefacts using a mixed methods approach. A virtual lab based on nested virtualization using Microsoft's Hyper-V platform was implemented and evaluated. An innovative feedback tool that provided instant feedback for hands-on lab activities was implemented and evaluated. Teacher and student dashboards that provided students' progress on lab work were implemented and evaluated.
- *A methodology to implement the TePF*: The DBR methodology was applied along with a mixed methods approach to an intervention study to design, develop and evaluate the TePF.
- *Design Principles*: A number of design principles were derived that can be help and guide future development and application of technology interventions in education contexts including lab environments. .

The next section concludes the chapter by outlining future research directions.

8.3. Future Work

We can classify future work into two categories: Future work to improve the proposed framework for Systems and Network Administration course based on the TePF evaluation; and future work to improve the guidelines, methodologies to enable technology innovations in educational context.

Evaluation of the TePF provided a number of suggestions and improvements for the future. Upon discussion with the practitioner, it was clear that many of these suggestions can be taken on board in future iterations.

- *Provide choice of centralised and decentralised labs:* It was clear that although centralised labs provided a number of advantages over decentralised labs, some students preferred to use decentralised labs, especially where their personal machines had sufficient resources to run multiple VMs and the lab environment.

This may provide more flexibility and better performance while also reducing the resources needed to provide centralised labs. Thus, in the future, the practitioner agreed to provide both options for students with lab instructions that will clearly state that students can use either centralised or decentralised labs. The feedback tool and dashboards will be updated to work on decentralised architectures.

- *Address performance issues in centralised labs*: A major concern with the centralised labs was intermittently slow performance on host VMs. To overcome this, the practitioner agreed to provide more resources to the host VM, especially in terms of virtual CPUs and memory.
- *Flexibility with features such as checkpoints*: To provide students with flexibility, the practitioner agreed to discuss and provide documentation for features such as checkpointing to allow students to rollback to a previous state of the VMs (i.e., how to reset/restore a VM state).
- *Improved interface*: A seamless interface integrating course content, lab materials, virtual labs, the feedback tool and the dashboards will be provided.
- *Incorporate Unix-based labs*: The practitioner agreed that content needs to be updated so as to cover Unix-based labs.
- *Improvement of lectures*: Students commented that the lectures are lengthy and could be improved. The practitioner agreed that, given that the labs had been revised and improved, the lectures could also be improved in the future.
- *Improve labs*: A few students suggested having short video tutorials on configurations and tutor demonstrations. This was discussed with the practitioner.

The other category of future work is to provide further evidence in support methodologies and guidelines for designing technology interventions in educational contexts. A limitation of the design principles derived in this research project addressing methods/guidelines for technology interventions in educational contexts is that the design principles were derived based on a single intervention study for a lab environment in a system-level course in computing. Further work in applying the design principles in other contexts and intervention studies will enable to further refine and develop guidelines for such technology interventions. Future research directions can include extending to other subject areas (not necessarily systems-level courses in computing), not limited to lab environments but also technology innovations in education in general and evaluating with different cohorts – online/distance learning.

References

Abdulwahed, M., & Nagy, Z. K. (2009). Applying Kolb's experiential learning cycle for laboratory education. Journal of Engineering Education, 98(3), 283-294.

Achuthan, K., Sreelatha, K., Surendran, S., Diwakar, S., Nedungadi, P., Humphreys, S., . . . Deepthi, A. (2011). The VALUE@ Amrita Virtual Labs Project: Using web technology to provide virtual laboratory access to students. Paper presented at the Global Humanitarian Technology Conference (GHTC), 2011 IEEE.

Alam, F., Hadgraft, R. G., & Subic, A. (2014). Technology-enhanced laboratory experiments in learning and teaching. In Using Technology Tools to Innovate Assessment, Reporting, and Teaching Practices in Engineering Education (pp. 289-302). IGI Global.

Alharbie, N., Athauda, R., & Simon, S. (2012). An Analysis of Students' Perspectives in using Virtual Labs in an Undergraduate IT Course. ACTA international conferences in the general areas of engineering and computer science.

Alkhaldi, T., Pranata, I., & Athauda, R. I. (2016). A review of contemporary virtual and remote laboratory implementations: observations and findings. Journal of Computers in Education, 3(3), 329-351.

Anderson, L. & Krathwohl, D. (2001). A Taxonomy for Learning, Teaching and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives. New York: Longman.

Anderson, L. W., Krathwohl, D. R., Airiasian, W., Cruikshank, K. A., Mayer, R. E., & Pintrich, P. R. (2001). A taxonomy for learning, teaching and assessing: A revision of Bloom's Taxonomy of educational outcomes: Complete edition. NY: Longman.

Anisetti, M., Bellandi, V., Colombo, A., Cremonini, M., Damiani, E., Frati, F., ... & Rebeccani, D. (2007). Learning computer networking on open paravirtual laboratories. IEEE Transactions on Education, 50(4), 302-311.

Athauda, R., Alkhaldi, T., Pranata, I., Daniel, D., Frank, C., Thorne, W. & Dean, R., (2018). "Design of a Technology-Enhanced Pedagogical Framework for a Systems and Networking Administration course incorporating a Virtual Laboratory". Paper accepted at the Frontiers in Education Conference (FIE), Vol. 2018.

Barab, S. (2014). Design-based research: A methodological toolkit for engineering change The Cambridge Handbook of the Learning Sciences (Second ed., pp. 151-170): Cambridge University Press.

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. The journal of the learning sciences, 13(1), 1-14.

Bayer, A. S. (1990). Collaborative-apprenticeship learning: Language and thinking across the curriculum, K-12. WCB/McGraw-Hill.

Bazzaza, M. W., & Salah, K. (2015). Using the Cloud to Teach Computer Networks. In *Utility and Cloud Computing (UCC), 2015 IEEE/ACM 8th International Conference* on (pp. 310-314). IEEE.

Bennett, R. E. (2011). Formative assessment: A critical review. Assessment in Education: Principles, Policy & Practice, 18(1), 5-25.

Bergman, M. M. (Ed.). (2008). Advances in mixed methods research: Theories and applications. Sage.

Biggs, J. (1979). Individual differences in study processes and the quality of learning outcomes. Higher education, 8(4), 381-394.

Biggs, J. (1999). What the student does: Teaching for enhanced learning. Higher education research & development, 18(1), 57-75.

Biggs, J. B. (1987). Student approaches to learning and studying. Research monograph. Hawthorn, Vic: Australian Council for Educational Research.

Biggs, J. B. (2011). Teaching for quality learning at university: What the student does. McGraw-Hill Education (UK).

Biggs, J. B., & Collis, K. F. (2014). Evaluating the quality of learning: The SOLO taxonomy (Structure of the Observed Learning Outcome). Academic Press.

Biggs, J., Kember, D., & Leung, D. Y. (2001). The revised two-factor study process questionnaire: R-SPQ-2F. British journal of educational psychology, 71(1), 133-149.

Black, P. & Wiliam, D. (2005). Inside the black box: Raising standards through classroom assessment. Granada Learning.

Black, P., & Wiliam, D. (1998). Assessment and classroom learning. Assessment in Education: principles, policy & practice, 5(1), 7-74.

Black, P., & Wiliam, D. (2004). Working inside the black box: Assessment for learning in the classroom. Phi delta kappan, 2004. 86(1): p. 8-21.

Border, C. (2007). The development and deployment of a multi-user, remote access virtualization system for networking, security, and system administration classes. ACM SIGCSE Bulletin, 39(1), 576-580.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative research in psychology, 3(2), 77-101.

Braun, V., & Clarke, V. (2013). Successful qualitative research: a practical guide for beginnners. London: Sage Publications Ltd.

Brenner, M. E. (2006). Interviewing in educational research. In J. L. Green, G. Camilli, & P. B. Elmore (Eds.), Handbook of complementary methods in education research, Mahwah, NJ: Lawrence Erlbaum.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. Journal of the Learning Sciences, 2(22), 141-178.

Bryman, A. (2016). Social research methods. Oxford university press.

Bryman, A., & Burgess, R. (Eds.) (1994). Analyzing qualitative data. London, England: Routledge.

Burns, R. B. (2000). Introduction to research methods (4th ed.). Frenchs Forest, NSW: Pearson Education Australia.

Caminero, A. C., Ros, S., Hernández, R., Robles-Gómez, A., Tobarra, L., & Granjo, P. J. T. (2016). VirTUal remoTe labORatories managEment System (TUTORES): Using cloud computing to acquire university practical skills. IEEE transactions on Learning Technologies, 9(2), 133-145.

Chamberlin, J., Hussey, J., Klimkowski, B., Moody, W., & Morrell, C. (2017). The Impact of Virtualized Technology on Undergraduate Computer Networking Education. In Proceedings of the 18th Annual Conference on Information Technology Education (pp. 109-114). ACM.

Chao, L. (2014). Application of Infrastructure as a Service in IT Education. American Journal of Information Systems, 2(2), 42-48.

Chaos, D., Chacon, J., Lopez-Orozco, J. A., & Dormido, S. (2013). Virtual and remote robotic laboratory using EJS, MATLAB and LabVIEW. Sensors, 13(2), 2595-2612.

Chen, W., & Looi, C. K. (2007). Incorporating online discussion in face to face classroom learning: a new blended learning approach. Australasian Journal of Educational Technology, 23(3), 307-326.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. Journal of the Learning Sciences, 13(1), 15-42.

Creswell, J. W. (2013). Research design: Qualitative, quantitative, and mixed methods approaches. Thousand Oaks, CA: Sage Publications.

Creswell, J. W. (2015). Educational research: Planning, conducting, and evaluating quantitative (5th ed.). Sydney: Pearson Australia.

Creswell, J. W., & Plano Clark, V. (2007). Designing and conducting mixed methods research. Thousand Oaks, CA: Sage.

Creswell, J. W., & Tashakkori, A. (2007). Editorial: differing perspectives on mixed methods research. Journal of Mixed Methods Research, 1(4), 303-308.

Davis Jr, F. D. (1985). A technology acceptance model for empirically testing new end-user information systems: Theory and results. (Doctoral Thesis), Massachusetts Institute of Technology.

Davis, F. D. (1986). A technology acceptance model for empirically testing new end-user information systems: theory and results. Doctoral dissertation, Sloan School of Management, Massachusetts Institute of Technology, Cambridge, MA.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Quarterly, 13(3), 319-340.

Davis, F. D., & Venkatesh, V. (1996). A critical assessment of potential measurement biases in the technology acceptance model: three experiments. International Journal of Human-Computer Studies, 45(1), 19-45.

de Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. Science, 340(6130), 305-308.

de Jong, T., Sotiriou, S., & Gillet, D. (2014). Innovations in STEM education: the Go-Lab federation of online labs. Smart Learning Environments, 1(1), 1-16.

Design-Based Research Collective (2003). Design-based research: An emerging paradigm for educational inquiry. Educational Researcher, 32(1), 5-8.

Ding, Y., & Fang, H. (2009). Using a simulation laboratory to improve physics learning: a case exploratory learning of diffraction grating. Paper presented at the Education Technology and Computer Science, 2009. ETCS'09. First International Workshop on.

Dinita, R. I., Wilson, G., Winckles, A., Cirstea, M., & Jones, A. (2012). A cloud-based virtual computing laboratory for teaching computer networks. In Optimization of Electrical and Electronic Equipment (OPTIM), 2012 13th International Conference on (pp. 1314-1318). IEEE.

Doyle, L., Brady, A. M., & Byrne, G. (2009). An overview of mixed methods research. *Journal of Research in Nursing*, 14(2), 175-185.

Duffy, T., & Cunningham, D. (1996). Constructivism: implications for the design and delivery of instruction. Context, 171(4), 170-198.

Duignan, S., & Hall, T. (2008). Using Platform Virtualization to Teach System Architectures in Undergraduate Computer Science–An Evaluation of Student Learning Experiences. In Innovative Techniques in Instruction Technology, E-learning, E-assessment, and Education (pp. 479-484). Springer, Dordrecht.

Elawady, Y., & Tolba, A. (2009). Educational objectives of different laboratory types: A comparative study. arXiv preprint arXiv:0912.0932.

Gaspar, A., Langevin, S., Armitage, W., Sekar, R., & Daniels, T. (2008). The role of virtualization in computing education. In ACM sIGCsE bulletin (Vol. 40, No. 1, pp. 131-132). ACM.

Gatignon, H. (2010). Confirmatory factor analysis. In Statistical analysis of management data (pp. 59-122). Springer, New York, NY.

Gercek, G., Saleem, N., & Steel, D. (2016). Implementing cloud based virtual computer network labs for online education: Experiences from a phased approach. International Journal of Online Engineering (iJOE), 12(03), 70-76.

Gibbs, G. (2010). Using assessment to support student learning. Leeds Met Press.

Glasersfeld, E. von (1995). Radical constructivism: a way of knowing and learning. London, England: RoutledgeFalmer.

Gokhale, A. A. (1995). Collaborative learning enhances critical thinking. Volume 7 Issue 1 (fall 1995).

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a conceptual framework for mixed-method evaluation designs. Educational Evaluation and Policy Analysis, 11(3), 255-274.

Guba, E. G., & Lincoln, Y. S. (2004). Competing paradigms in qualitative research. In S. Hesse-Biber, & P. Leavy (Eds.), Approaches to qualitative research: a reader on theory and practice. New York, NY: Oxford University Press.

Hair, J. F., Anderson, R. E., Tatham, R. L. & Black, W. C. (2003). Multivariate Data Analysis (5th Ed.), Pearson Education, India.

Hardré, P. L. (2005). Instructional design as a professional development tool-of-choice for graduate teaching assistants. Innovative Higher Education, 30(3), 163-175.

Harward, V. J., Del Alamo, J., Lerman, S. R., Bailey, P. H., Carpenter, J., DeLong, K., . . . Jabbour, I. (2008). The ilab shared architecture: A web services infrastructure to build communities of internet accessible laboratories. Proceedings of the IEEE, 96(6), 931-950.

Hattie, J. and Timperley, H. (2007). The power of feedback. Review of educational research. 77(1): p. 81-112.

Heritage, M. (2007). Formative assessment: What do teachers need to know and do?. Phi Delta Kappan, 89(2), 140-145.

Herrington, J., McKenney, S., Reeves, T., & Oliver, R. (2007). Design-based research and doctoral students: Guidelines for preparing a dissertation proposal. Paper presented at the World Conference on Educational Multimedia, Hypermedia and Telecommunications 2007 Chesapeake, VA.

Herrmann, N. (1995). The Creative Brain. Quebecor Printing Book Group: Kingsport, TN.

Hossain, Z., Jin, X., Bumbacher, E., Chung, A., Koo, S., Shapiro, J. D., . . . Blikstein, P. (2015). Interactive Cloud Experimentation for Biology: An Online Education Case Study. Paper presented at the Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems.

Hu, D. & Wang, Y. (2008). Teaching computer security using Xen in a virtual environment. in International Conference on Information Security and Assurance (ISA 2008), *IEEE*.

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural equation modeling: a multidisciplinary journal*, 6(1), 1-55.Abdulwahed, M., & Nagy, Z. K. (2009). Applying Kolb's experiential learning cycle for laboratory education. Journal of Engineering Education, 98(3), 283-294.

Hwang, W.-Y., Kongcharoen, C., & Ghinea, G. (2014). To enhance collaborative learning and practice network knowledge with a virtualization laboratory and online synchronous discussion. The International Review of Research in Open and Distributed Learning, 15(4).

Javid, S. R. (2014). Role of Packet Tracer in learning Computer Networks. International Journal of Advanced Research in Computer and Communication Engineering, 3(5), 6508-6511.

Johnson, B. & Christensen, L. (2008). Educational research: quantitative, qualitative, and mixed approaches (3rd ed.). Thousand Oaks, CA: Sage.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. Educational researcher, 33(7), 14-26.

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. Journal of mixed methods research, 1(2), 112-133.

Johnson, R., & Onwuegbuzie, A. (2004). Mixed methods research: a research paradigm whose time has come. Educational Researcher, 33(7), 14-26.

Jonassen, D. H., & Grabowski, B. L. (1993). Handbook of Individual Differences, Learning, and Instruction. New Jersey: Lawrence Erlbaum Associates.

Jung, I., Choi, S., Lim, C., & Leem, J. (2002). Effects of different types of interaction on learning achievement, satisfaction and participation in web-based instruction. Innovations in Education and Teaching International, 39(2), 153-162.

Kaplan, B., & Maxwell, J. A. (2005). Qualitative research methods for evaluating computer information systems. In Evaluating the organizational impact of healthcare information systems (pp. 30-55). *Springer*, New York, NY.

Kearsley, G. & Culatta., R. . (2011). Instructional Design.org from http://www.instructionaldesign.org/(Retrieved March 24, 2016).

Khan, B. H. (2005). Managing e-learning: design, delivery, implementation, and evaluation. Hershey, PA: Information Science.

Kolb, A. Y., & Kolb. D. A. (2005). Learning styles and learning spaces: enhancing experiential learning in higher education. Academy of Management Learning & Education, 4(2), 193-212.

Kolb, D. A. (2014). Experiential learning: Experience as the source of learning and development. FT press.

Kolb, D. A., Boyatzis, R. E., & Mainemelis, C. (2001). Experiential Learning Theory: Previous Research and New Directions in Perspectives on Thinking, Learning, and Cognitive Styles (Educational Psychology Series).

Kolb, David A. (1984). Experiential Learning: Experience as the Source of Learning and Development. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Kolloffel, B., & Jong, T. (2013). Conceptual understanding of electrical circuits in secondary vocational engineering education: Combining traditional instruction with inquiry learning in a virtual lab. Journal of Engineering Education, 102(3), 375-393.

Konak, A. & Bartolacci, M. R. (2016). Using a virtual computing laboratory to foster collaborative learning for information security and information technology education. Journal of Cybersecurity Education, Research and Practice. 2016(1): p. 2.

Konak, A., Clark, T. K., & Nasereddin, M. (2014). Using Kolb's Experiential Learning Cycle to improve student learning in virtual computer laboratories. Computers & Education, 72, 11-22.

Kongcharoen, C., Hwang, W. Y., & Ghinea, G. (2017). Synchronized pair configuration in virtualization-based lab for learning computer networks. *Journal of Educational Technology & Society*, *20*(3), 54-68.

Kraiger, K., Ford, J. K., & Salas, E. (1993). Application of cognitive, skill-based, and affective theories of learning outcomes to new methods of training evaluation. Journal of applied psychology, 78(2), 311.

Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. Theory into practice, 41(4), 212-218.

Kuh, G. D. (2008). High-impact educational practices: what they are, who has access to them, and why they matter. Washington, DC: Association of American Colleges and Universities.

Laal, M. (2013). Positive interdependence in collaborative learning. *Procedia-Social and Behavioral Sciences*, *93*, 1433-1437.

Laal, M., & Ghodsi, S. M. (2012). Benefits of collaborative learning. *Procedia-social and behavioral sciences*, *31*, 486-490.

Lahoud, H. A., & Krichen, J. P. (2010). Networking labs in the online environment: Indicators for success.

Lee, J., & Jang, S. (2014). A methodological framework for instructional design model development: Critical dimensions and synthesized procedures. Educational Technology Research and Development, 62(6), 743-765.

Lewis, D. I. (2014). The pedagogical benefits and pitfalls of virtual tools for teaching and learning laboratory practices in the Biological Sciences.

Li, P. (2009). Exploring virtual environments in a decentralized lab. *ACM SIGITE Research in IT*, *6*(1), 4-10.

Li, P. and T. (2008). Mohammed. Integration of virtualization technology into network security laboratory. in Frontiers in Education Conference, 2008. (FIE 2008). IEEE.

Li, P., & Toderick, L. W. (2010). Cloud in cloud: approaches and implementations. In Proceedings of the 2010 ACM conference on Information technology education (pp. 105-110). ACM.

Li, P., Toderick, L. W., & Lunsford, P. J. (2009). Experiencing virtual computing lab in information technology education. In *Proceedings of the 10th ACM conference on SIG-information technology education* (pp. 55-59). ACM.

Likert, R. (1931). A technique for the measurement of attitudes. Archives of Psychology. New York: *Columbia University Press*.

Lowe, D., Conlon, S., Murray, S., Weber, L., De La Villefromoy, M., Lindsay, E., . . . Nageswaran, W. (2011). Labshare: Towards Cross-Institutional. Internet Accessible Remote Laboratories: Scalable E-Learning Tools for Engineering and Science Disciplines: Scalable E-Learning Tools for Engineering and Science Disciplines, 453.

Lustigova, Z., & Novotna, V. (2013). The Role of e-laboratories in Science Education. World Conference on Computers in Education, 2-8.

Ma, J., & Nickerson, J. V. (2006). Hands-on, simulated, and remote laboratories: A comparative literature review. ACM Computing Surveys (CSUR), 38(3), 7.

Mackenzie, N., & Knipe, S. (2006). Research dilemmas: Paradigms, methods and methodology. Issues in educational research, 16(2), 193-205.

Makasiranondh, W., Maj, S. P., & Veal, D. (2011, January). A pedagogically rich interactive on-line learning platform for network technology students in Thailand. In Proceedings of the Thirteenth Australasian Computing Education Conference-Volume 114 (pp. 161-168). Australian Computer Society, Inc.

Marques, M. A., Viegas, M. C., Costa-Lobo, M. C., Fidalgo, A. V., Alves, G. R., Rocha, J. S., & Gustavsson, I. (2014). How Remote Labs Impact on Course Outcomes: Various Practices Using VISIR. Education, IEEE Transactions on, 57(3), 151-159.

Mason, D. (2013). Design, Implementation and Evaluation of Virtual Learning Environments. Online Information Review, 37(2), 340-340.

Microsoft, https://docs.microsoft.com/en-us/virtualization/hyper-v-on-windows/user-guide/nested-virtualization. 2016 b.

Microsoft, https://technet.microsoft.com/en-us/library/mt169373(v=ws.11).aspx. 2016 a

Mishara, P., & Koehler, M. (2006). Technological pedagogical content knowlwdge: A Framework for teacher knowlwdge. *Teacher College Record*, 108(6): p. 1017-10541017.

Mishra, P., & Koehler, M. J. (2007). Technological pedagogical content knowledge (TPCK): Confronting the wicked problems of teaching with technology. In *Society for Information Technology & Teacher Education International Conference* (pp. 2214-2226). Association for the Advancement of Computing in Education (AACE).

Moore, D. S., Craig, B. A., & McCabe, G. P. (2012). Introduction to the Practice of Statistics. WH Freeman.

Mujkanovic, A., Lowe, D., & Willey, K. (2012). Adaptive group formation to promote desired behaviours. Paper presented at the Profession of Engineering Education: Advancing Teaching, Research and Career.

Mujkanovic, A., Lowe, D., Guetl, C., & Kostulski, T. (2011). An architecture for automated group formation within remote laboratories. Remote Engineering & Virtual Instrumentation, 91-100.

Nedic, Z., Machotka, J., & Nafalski, A. (2003). Remote laboratories versus virtual and real laboratories. *IEEE*, Vol. 1, pp. T3E-T3E.

Newman, D. (1990). Opportunities for research on the organizational impact of school computers. *Educational Researcher*, *19*(3), 8-13.

Nickerson, J. V., Corter, J. E., Esche, S. K., & Chassapis, C. (2007). A model for evaluating the effectiveness of remote engineering laboratories and simulations in education. Computers & Education, 49(3), 708-725.

Nicol, D. J., & Macfarlane-Dick, D. (2006). Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Studies in higher Education*, 31(2), 199-218.

Nunnally, J. C., & Bernstein, I. H. (1994). Psychometric theory (3rd ed.). New York: *McGrawHill*.

Oates, B. J. (2005). Researching information systems and computing. Sage.

Pérez, C., Orduña, J. M., & Soriano, F. R. (2016). A nested virtualization tool for information technology practical education. *SpringerPlus*, *5*(1), 443.

Plomp, T. (2013). Educational design research: An introduction. *Educational design research*, 11-50.

PowerShell, https://docs.microsoft.com/en-us/powershell/.

Prieto-Blázquez, J., Arnedo-Moreno, J., & Herrera-Joancomartí, J. (2008). An integrated structure for a virtual networking laboratory. IEEE transactions on Industrial Electronics, 55(6), 2334-2342.

Prieto-Blazquez, J., Herrera-Joancomarti, J., & Guerrero-Roldán, A. (2009). A virtual laboratory structure for developing programming labs. International Journal of Emerging Technologies in Learning (iJET), 4(2009), 47-52.

Quest vWorkspace - https://support.quest.com/vworkspace/8.6.3.2017

Ramalingam, D. (2007). Practicing computer hardware configuration and network installation in a virtual laboratory environment: A case study. In *Frontiers In Education Conference-Global Engineering. FIE'07. 37th Annual* (pp. F3G-21). IEEE.

Razvan, I., Wilson, G., Winckles, A., Cirstea, M., & Jones, A. (2012). A cloud-based virtual computing laboratory for teaching computer networks. Paper presented at the Optimization of Electrical and Electronic Equipment (OPTIM), 2012 13th International Conference on.

Reeves, T. (2006). Design research from a technology perspective. In *Educational design research* (pp. 64-78). Routledge.

Reeves, T., Herrington, J., & Oliver, R. (2005). Design research: A socially responsible approach to instructional technology research in higher education. Journal of Computing in Higher Education, 16(2), 97-116.

Ruiz-Martínez, P. M., & Skarmeta-Gomez, A. F. (2013). Teaching advanced concepts in computer networks: Vnuml-um virtualization tool. *IEEE Transactions on Learning Technologies*, *6*(1), 85-96.

Sadler, D. R. (1998). Formative assessment: Revisiting the territory. *Assessment in education: principles, policy & practice*, 5(1), 77-84.

Salah, K., Hammoud, M., & Zeadally, S. (2015). Teaching Cybersecurity Using the Cloud. *IEEE Transactions on Learning Technologies*, 8(4), 383-392.

Sancristobal, E., Castro, M., Harward, J., Baley, P., DeLong, K., & Hardison, J. (2010). Integration view of web labs and learning management systems. Paper presented at the Education

Engineering (EDUCON), 2010 IEEE.

Sarkar, N. I., & Petrova, K. (2011). Design and evaluation of a web-based tool for teaching computer network design to undergraduates. In *Web-Based and Blended Educational Tools and Innovations* (pp. 214-234). IGI Global.

Schaffer, H. E., Averitt, S. F., Hoit, M., Peeler, A., Sills, E. D., & Vouk, M. (2009). NCSU's virtual computing lab: a cloud computing solution. Computer, 42(7), 94-97.

Seiler, S. (2013). Current Trends in Remote and Virtual Lab Engineering. Where are we in 2013? iJOE, 9(6), 12-16.

Sicker, D. C., Lookabaugh, T., Santos, J., & Barnes, F. (2005). Assessing the effectiveness of remote networking laboratories. In Frontiers in Education, 2005. FIE'05. Proceedings 35th Annual Conference (pp. S3F-S3F). IEEE.

Smith, A., & Bluck, C. (2010). Multiuser collaborative practical learning using packet tracer. In Networking and Services (ICNS), 2010 Sixth International Conference on (pp. 356-362). IEEE.

Soceanu, A., Vasylenko, M., & Gradinaru, A. (2017). Improving Cybersecurity Skills Using Network Security Virtual Labs. In *Proceedings of the International MultiConference of Engineers and Computer Scientists 2017 Vol II, IMECS*.

Steffe, L. P., & Gale, J. (Eds.) (1995). Constructivism in education. Hillsdale, NJ: Lawrence Erlbaum.

Stewart, K. E., Humphries, J. W., & Andel, T. R. (2009, March). Developing a virtualization platform for courses in networking, systems administration and cyber security education. In *Proceedings of the 2009 Spring Simulation Multiconference* (p. 65). Society for Computer Simulation International.

Strauss, A., & Corbin, J. (1998). Basics of qualitative research: Procedures and techniques for developing grounded theory.

Tashakkori, A., & Teddlie, C. (1998). Mixed methodology: combining qualitative and quantitative approaches. London, England: Sage.

Tawfik, M., Sancristobal, E., Martin, S., Gil, R., Diaz, G., Colmenar, A., . . . Gustavsson, I. (2013). Virtual Instrument Systems in Reality (VISIR) for Remote Wiring and Measurement of Electronic Circuits on Breadboard. Learning Technologies, IEEE Transactions on, 6(1), 60-72. doi:10.1109/TLT.2012.20

Tuysuz, C. (2010). The effect of the virtual laboratory on students’ achievement and attitude in chemistry. International Online Journal of Educational Sciences, 2(1), 37-53.

van den Akker, J. (1999). Principles and methods of development research. In J. van den Akker, R. Branch, K. Gustafson, N. Nieveen, & T. Plomp (Eds.), Design approaches and tools in education and training (pp. 1-14). Dordrecht: Kluwer Academic Publishers.

van den Akker, J., Branch, R., Gustafson, K., Nieveen, N., & Plomp, T. (Eds.) (1999). Design approaches and tools in education and training. Dordrecht: Kluwer Academic Publishers.

Vaughan, B. (2016). Confirmatory factor analysis of the Study Process Questionnaire in an Australian osteopathy student population. *International Journal of Osteopathic Medicine*, *20*, 62-67.

Vygotsky, L. S. (1978). Mind in society: the development of higher psychological processes. (M. Cole, V. John-Steiner, S. Scribner & E. Souberman Eds.). Cambridge: Harvard University Press.

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational technology research and development*, *53*(4), 5-23.

Wannous, M., & Nakano, H. (2010). Constructing and Tuning a Web-based Virtual Computer-Networks Laboratory. *IEEE Multidisciplinary Engineering Education Magazine*, *5*(2), p.1-6.

Wannous, M., Nakano, H., Kita, T., & Sugitani, K. (2007). A core system for a webbased virtual computer laboratory. In *Proc. Eighth Int'l Conf. Information Technology in Higher Education and Training* (pp. 196-199).

Willems, C., & Meinel, C. (2012). Online assessment for hands-on cyber security training in a virtual lab. In Global Engineering Education Conference (EDUCON), 2012 IEEE (pp. 1-10). IEEE.

Wohlin, C., & Aurum, A. (2015). Towards a decision-making structure for selecting a research design in empirical software engineering. Empirical Software Engineering, 20(6), 1427-1455.

Wolf, T. (2010). Assessing student learning in a virtual laboratory environment. Education, IEEE Transactions on, 53(2), 216-222.

Woodfield, B. F., Andrus, M. B., Andersen, T., Miller, J., Simmons, B., Stanger, R., . . . Allen, R. (2005). The virtual ChemLab project: A realistic and sophisticated simulation of organic synthesis and organic qualitative analysis. Journal of Chemical Education, 82(11), 1728.

Woodfield, B. F., Catlin, H. R., Waddoups, G. L., Moore, M. S., Swan, R., Allen, R., & Bodily, G. (2004). The virtual ChemLab project: a realistic and sophisticated simulation of inorganic qualitative analysis. Journal of Chemical Education, 81(11), 1672.

Xu, L., Huang, D., & Tsai, W. T. (2014). Cloud-based virtual laboratory for network security education. IEEE Transactions on Education, 57(3), 145-150.

Yalcin, Nursel, Yalcin Altun, and Utku Kose. (2015. "Educational material development model for teaching computer network and system management." Computer Applications in Engineering Education 23, no. 4 (2015): 621-629.

Yan, C. (2011). Bulid a laboratory cloud for computer network education. In Computer Science & Education (ICCSE), 2011 6th International Conference on (pp. 1013-1018). IEEE.

Young, M. R., Caudill, E. M., & Murphy, J. W. (2008). Evaluating experiential learning activities. *Journal for Advancement of Marketing Education*, *13*(Winter), 28-40.

Zhang, Y., Liang, R., & Ma, H. (2012). Teaching innovation in computer network course for undergraduate students with packet tracer. IERI Procedia, 2, 504-510.

Zhao, G., & Yuan, S. (2010). Key factors of effecting blended learning satisfaction: a study on Peking University students. Hybrid Learning, 6248, 282-295.

Zhu, W. (2015). Hands-on network programming projects in the cloud. *In Proceedings of the 46th ACM Technical Symposium on Computer Science Education* (pp. 326-331). ACM.

Appendix A: Survey– 2016

Comparison of Virtual Lab Environments

As you be familiar with INFT2031, you have the option of doing your labs 8 and 9 work using external drive (as per the previous labs) as well as the option of using a cloud lab hosted on Microsoft Azure Dev/Test Lab. In addition, you can run PowerShell feedback scripts after each lab, which will provide you feedback on your lab work.

1. Did you use the Azure cloud lab?	o Yes o No If no, please explain why?

Section A: Lab Environment - External Drive vs Azure Cloud

Please rate your satisfaction with the following aspects of both lab environments you are using in weeks 8 & 9:

(SD = Strongly Disagree, D= Disagree, N=Neutral, A= Agree, SA= Strongly Agree)

Questions	**VMware Fusion with external drive**					**Cloud lab hosted on Microsoft Azure Dev/Test Lab**				
	SD	D	N	A	SA	SD	D	N	A	SA
2. The lab environment helped me to learn in INFT2031										
3. The lab environment improved my performance										
4. The lab environment helped me to achieve learning outcomes										
5. The lab environment provided easy access to the lab (24x7)										
6. Having access to the lab environment from any device/location (i.e. home etc.) is helpful to me										
7. I find it easy to use the lab environment										
8. I find the lab setting flexible to conduct my lab work										
9. I am satisfied with using the lab environment for my practical work in INFT2031										
10. I would like to use the lab environment in future networking and systems administration courses										
11. Overall, how would you rate the lab environment	Very Poor	Poor	Neutral	Good	Excellent	Very Poor	Poor	Neutral	Good	Excellent
12. If given the choice to use external drive vs Azure cloud lab in conducting INFT2031 labs, which do you prefer?	o External drive o Azure cloud lab Why?									

Section B: Suggestions for Improvement

Please write your comments for the following questions:

13. Any disadvantages of using External Drive / Azure Cloud labs?	
14. Please provide any suggestions that you would like to see implemented in the cloud lab in future?	

Section C: PowerShell Feedback Script

In the following questions, we would like to hear about your recent use the feedback script with the labs 7, 8 &9 configuration.

15. Did you use the PowerShell feedback scripts?	o Yes o No If no, please explain why?									
16. How satisfied are you with feedback generated from the script?	Extremely Dissatisfied		Dissatisfied		Neither Satisfied or Dissatisfied		Satisfied		Extremely Satisfied	
	o		o		o		o		o	
17. What is the primary reason for your rating in question 16?	Explain your rating:									
	Not at all Likely									Extremely Likely
	1	2	3	4	5	6	7	8	9	10
18. The feedback descriptions were easy to understand										
19. The feedback page on your VM were fast to load										
20. I prefer to have this feedback script in the labs										
21. This feedback script encouraged me to do my lab work										
22. Based on this script feedback, how likely are you to recommend it to students in the next semester?										
23. Are there any suggestions for how the feedback script could be improved?										

Thank you again for taking the time to provide feedback. INFT2031 values your opinion!

Appendix B: Survey– 2017

Evaluation of INFT2031 Networking Lab Environment

Section 1: Virtualization Technologies in INFT2031

1. Did you use server environment to configure INFT2031 lab activities?	o Yes	o No

Please rate your satisfaction with the following aspects of the virtual IT infrastructure labs:
(SD = Strongly Disagree, D= Disagree, N=Neutral, A= Agree, SA= Strongly Agree)

Scale	Items	SD	D	N	A	SA
Usefulness	2. Using virtual lab helped me to learn in INFT2031	o	o	o	o	o
	3. The virtual lab improved my lab performance	o	o	o	o	o
	4. The virtual lab helped me achieve learning outcomes	o	o	o	o	o
Ease of Use	5. The virtual lab provided easy access to the lab at any time of the day (24x7)	o	o	o	o	o
	6. Having access to the virtual lab from any device/location (i.e. home etc.) is helpful to me	o	o	o	o	o
	7. I find it easy to use the virtual lab	o	o	o	o	o
	8. I find the virtual lab flexible to conduct my lab work	o	o	o	o	o
Attitude	9. I am satisfied with using the virtual lab for my practical work in INFT2031	o	o	o	o	o
	10. I would like to use Virtual labs in future networking and systems administration courses	o	o	o	o	o
Overall	11. Overall, how would you rate the INFT2031 virtual laboratories	o Very poor	o Poor	o Neutral	o Good	o Excellent

12. If given the choice to use your PC like Fusion in labs vs server environment in conducting INFT2031 labs, which do you prefer?	o Server environment	o PC (VMware Fusion, Hyper-V)
	Why?	

Section 2: Feedback Tool

In the following question, we would like to hear about your views on the use of the feedback tool with the INFT2031 lab configuration.

1. Did you use the feedback tool?	o Yes					o No If no, please explain why? (Go to Section 3)
2. How satisfied are you with feedback generated from the tool.	o Extremely Dissatisfied	o Dissatisfied	o Neutral	o Satisfied	o Extremely Satisfied	
3. What is the primary reason for your rating in question 2 above?	Explain your rating:					

Questionnaire item	Not at all likely 1	2	3	4	5	6	7	8	9	Extremely likely 10
4. The feedback offering descriptions were easy to understand	o	o	o	o	o	o	o	o	o	o
5. The feedback page on your VM were fast to load	o	o	o	o	o	o	o	o	o	o
6. I prefer to have this feedback tool with the labs	o	o	o	o	o	o	o	o	o	o
7. This feedback tool encourage me to do my lab work	o	o	o	o	o	o	o	o	o	o
8. Based on this feedback tool, how likely are you to recommend it to students in next semester?	o	o	o	o	o	o	o	o	o	o

Section 3: Dashboard

In the following question, we would like to hear about your views on the use of the dashboard.

1. Did you use the dashboard tool?	o Yes					o No If no, please explain why? (Go to Section 4)
2. How satisfied are you with dashboard view.	o Extremely Dissatisfied	o Dissatisfied	o Neutral	o Satisfied	o Extremely Satisfied	
3. What is the primary reason for your rating in question 2 above?	Explain your rating:					

Questionnaire item	Not at all likely 1	2	3	4	5	6	7	8	9	Extremely likely 10
4. The dashboard was easy to understand	o	o	o	o	o	o	o	o	o	o
5. The dashboard provides feedbacks on my learning activities and performance	o	o	o	o	o	o	o	o	o	o
6. I prefer to have this dashboard with the labs activities	o	o	o	o	o	o	o	o	o	o
7. This dashboard encourage me to do my lab work	o	o	o	o	o	o	o	o	o	o
8. How likely are you to recommend using dashboard in next semester	o	o	o	o	o	o	o	o	o	o
9. I would like to compare my performance with other students	o	o	o	o	o	o	o	o	o	o
10. I would like to see my rank in class using the dashboard	o	o	o	o	o	o	o	o	o	o

Section 4: Suggestions for improvement

Please write your comments for the following questions:

1. What do you like most in the virtual IT infrastructure lab (I.e. virtual lab environment, feedback tool and dashboard)? Why? Explain your answer.	
2. Which kind of activities helped you most in learning? (i.e. group work, review questions, online quizzes, reading activities, discussion boards) Explain your answer.	
3. Any disadvantages of using virtual IT infrastructure lab?	
4. What are the features that you would like to see implemented in future?	

Section 5: Lab Activities

Please rate your satisfaction with the following aspects of the lab activities: (SD = Strongly Disagree, D= Disagree, N=Neutral, A= Agree, SA= Strongly Agree)

Scale	Questionnaire item	SD	D	N	A	SA
Usefulness	1. The time I spent for the lab activity was worthwhile	o	o	o	o	o
	2. I find the lab activity useful to me	o	o	o	o	o
	3. I would like to do more of similar activities, even if it is time consuming	o	o	o	o	o
	4. The lab activity was very engaging	o	o	o	o	o
	5. The lab activity was pleasurable	o	o	o	o	o
Interaction	6. Interacting with other students helped me complete the lab activity	o	o	o	o	o
	7. I learned new concepts/skills by interacting with other students	o	o	o	o	o
	8. The lab activity encouraged me to ask questions to others	o	o	o	o	o
Competency	9. The lab activity helped me improved my problem solving skills	o	o	o	o	o
	10. The lab activity improved my technical skills and competency in the subject area	o	o	o	o	o
	11. I felt a sense of accomplishment after completing the lab activity	o	o	o	o	o
	12. I will be able to use what I learned in the lab activity in other courses or the future	o	o	o	o	o
Interest	13. The lab activity increased my curiosity and interest in this area	o	o	o	o	o
	14. The lab activity encouraged me to learn more about this topic	o	o	o	o	o
	15. I was very motivated for completing the lab activity	o	o	o	o	o
Reflection	16. The review questions were helpful to reinforce what was performed in the lab activity	o	o	o	o	o
	17. The lab activity provided opportunities to reflect back what was learned in the activity	o	o	o	o	o
	18. The lab activity promoted helpful discussions about what was performed in the activity	o	o	o	o	o
Challenge	19. The lab activity was challenging	o	o	o	o	o
	20. The activity review questions were difficult and time consuming	o	o	o	o	o
	21. The lab activity instructions were confusing	o	o	o	o	o

Section 6: Experiential learning stages

Please rate your satisfaction with the following aspects of the Experiential Learning Stages (Four Sub Dimensions Combined): (SD = Strongly Disagree, D= Disagree, N=Neutral, A= Agree, SA= Strongly Agree)

Sub Dimension	Questionnaire item	SD	D	N	A	SA
Concrete Experience	1. The lab activities provided me with a direct practical experience to help understand the course concepts	o	o	o	o	o
	2. The lab activities gave me a concrete experience that helped me learn the class material	o	o	o	o	o
	3. The lab activities presented me with a "real world" experience related to this course	o	o	o	o	o
Reflective Observation	4. The lab activities assisted me in thinking about what the course material really means to me	o	o	o	o	o
	5. The lab activities helped me relate my personal experiences to the content of this course	o	o	o	o	o
	6. The lab activities aided me in connecting the course content with things I learned in the past	o	o	o	o	o
Abstract Conceptualization	7. The lab activities required me to think how to correctly use the terms and concepts from this class	o	o	o	o	o
	8. The lab activities caused me to think how the class concepts were inter-related	o	o	o	o	o
	9. The lab activities made me organize the class concepts into a meaningful format	o	o	o	o	o
Active Experimentation	10. The lab activities made it possible for me to try things out for myself	o	o	o	o	o
	11. The lab activities permitted me to actively test my ideas of how the course material can be applied	o	o	o	o	o
	12. The lab activities allowed me to experiment with the course concepts in order to understand them	o	o	o	o	o

Section 7: Measures of students' approaches to learning

Please rate your satisfaction with the following aspects of your approaches to learning:
(SD = Strongly Disagree, D= Disagree, N=Neutral, A= Agree, SA= Strongly Agree)

Questionnaire item	SD	D	N	A	SA
1. The lab activities gave me a feeling of deep personal satisfaction	o	o	o	o	o
2. The lab activities helped me create questions that I wanted answered	o	o	o	o	o
3. The lab activities made me work hard because I found the material interesting	o	o	o	o	o
4. The lab activities was at times as exciting as a good novel or movie	o	o	o	o	o
5. The lab activities was interesting once I got into it	o	o	o	o	o
6. The lab activities provided me with enough work on the topic so I could form my own conclusions	o	o	o	o	o
7. The lab activities caused me to look at most of the suggested readings that pertained to the activity	o	o	o	o	o
8. The lab activities caused me to spend time relating its topics to other topics, which have been discussed in different classes	o	o	o	o	o
9. The lab activities allowed me to test myself on important topics until I understood them completely	o	o	o	o	o
10. The lab activities' topics were interesting and I often spent extra time trying to obtain more information about them	o	o	o	o	o
11. For the lab activities, it was not helpful to study topics in depth because all you needed was a passing acquaintance with topics	o	o	o	o	o
12. I was able to get by in the lab activities by memorizing key sections rather than trying to understand them	o	o	o	o	o
13. For the lab activities, there was no point in learning material, which was not likely to be on the exam	o	o	o	o	o
14. I did not find the lab activities very interesting so I kept my work to a minimum	o	o	o	o	o
15. My aim for the lab activities was to complete it while doing as little work as possible	o	o	o	o	o
16. The lab activities suggests the best way to pass exams is to try to remember answers to likely test questions	o	o	o	o	o
17. I believe that the instructor should not expect me to spend significant amounts of time on the lab activities if it is not on an exam	o	o	o	o	o
18. For these lab activities, I restricted my study to what was specifically required as it was unnecessary to do anything extra	o	o	o	o	o
19. For the lab activities, I learned things by going over and over them until I knew them by heart even if I did not understand them	o	o	o	o	o
20. For the lab activities, I only applied what was given in class or on the course outline	o	o	o	o	o

Section 8: Overall Evaluation

Overall, what contributed most significantly to your learning in INFT2031? In other words, what are the important features to help in learning INFT2031? (Select all that apply)

□ Feedback tool	□ Quizzes and review questions	□ Lectures
□ Dashboard	□ Lab activities	□ Other (please specify)
□ Group work	□ Virtual labs	________________
□ Discussion board	□ Assignments	

Please give on overall rating of each aspect of learning INFT2031:

	Poor				Excellent
	1	2	3	4	5
Lectures	o	o	o	o	o
Discussion board	o	o	o	o	o
Review question and quizzes	o	o	o	o	o
Virtual labs	o	o	o	o	o
Lab activities	o	o	o	o	o
Assignments	o	o	o	o	o
Feedback tool	o	o	o	o	o
Dashboard	o	o	o	o	o
Group work	o	o	o	o	o

Section 9: Student Information

1. Main reason for taking INFT2031 course:	o Required	o Interested	o Required and Interested	o Other ___________	
2. % of lab sessions attended for this course	o 0-20%	o 21-40%	o 41-60%	o 61-80%	o 81-100%
3. About how many hours do you spend in a typical 7-days week preparing for class (studying, reading, configuring labs, and other activities related to course)	o 1-2	o 3-5	o 6-10	o 11-15	o More than 15
4. Expected grading in the INFT2031course	o HD	o D	o C	o Pass	o Fail
5. How well has this course met your expectations?	o Not at all	o Not very well	o Adequately	o Well	o Very well

Thank you again for taking the time to provide feedback. INFT2031 values your opinion!

Appendix C: Focus Group Discussion

Research Project:
Design, Implementation and Evaluation of a Learning Support Module for Virtual IT Infrastructure Laboratory to increase Learning Outcomes

Focus Group Discussion

Sample Discussion Questions:

	Question
Course Organization	Question 1: How did you find the course INFT2031? The structure, Lectures, Labs, formative assessments (such as quizzes, review questions, group work, Practical test, etc.).
Virtualization Technology used in labs	Question 2: What is your opinion on the technology used in labs in INFT2031? That is, IT infrastructure such as server environment, nested virtualization etc.? What is your opinion on the virtual labs used in labs in INFT2031? Did you find the virtual labs easy to use?
Learning Support Tools	Question 3: What features did you like in the INFT2031 labs? For example, did you find the feedback and dashboard with the virtual labs easy to use and user-friendly?
Overall Evaluation	Question 4: What is your overall opinion about INFT2031? How can INFT2031 be improved? Would you recommend it to another student?

Appendix D: Screenshots from the Feedback tool and Dashboard

This appendix presents screenshots that show samples of the INFT2031 feedback and dashboard tool that are provided in the TePF.

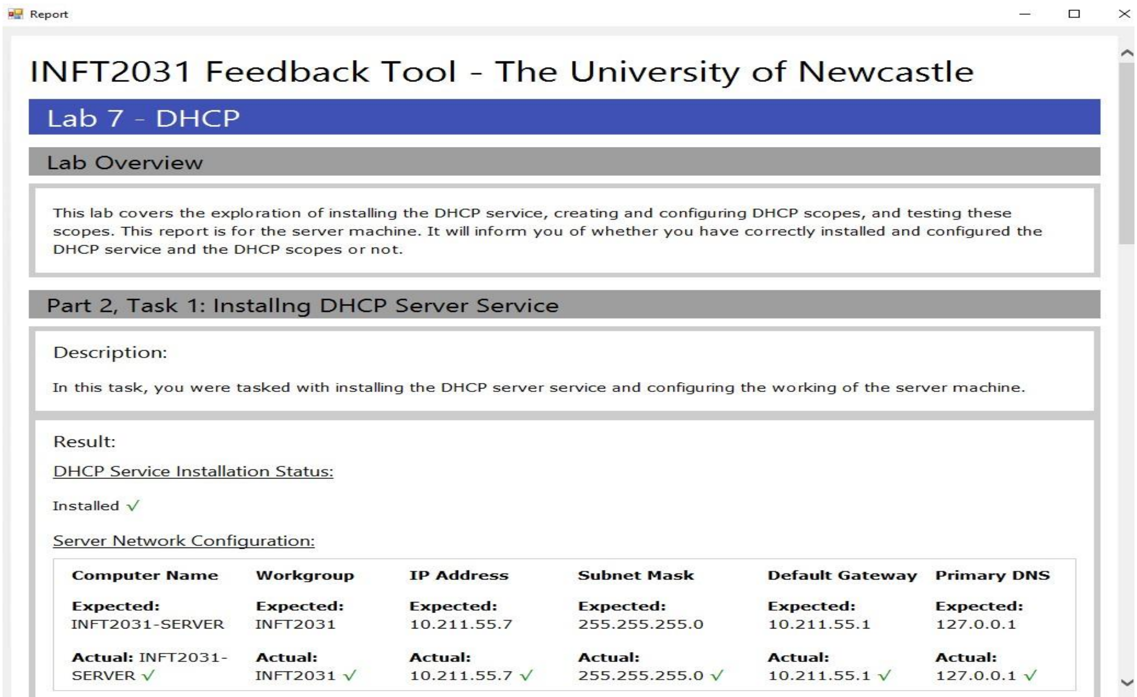


Figure D.1 A sample report from feedback tool

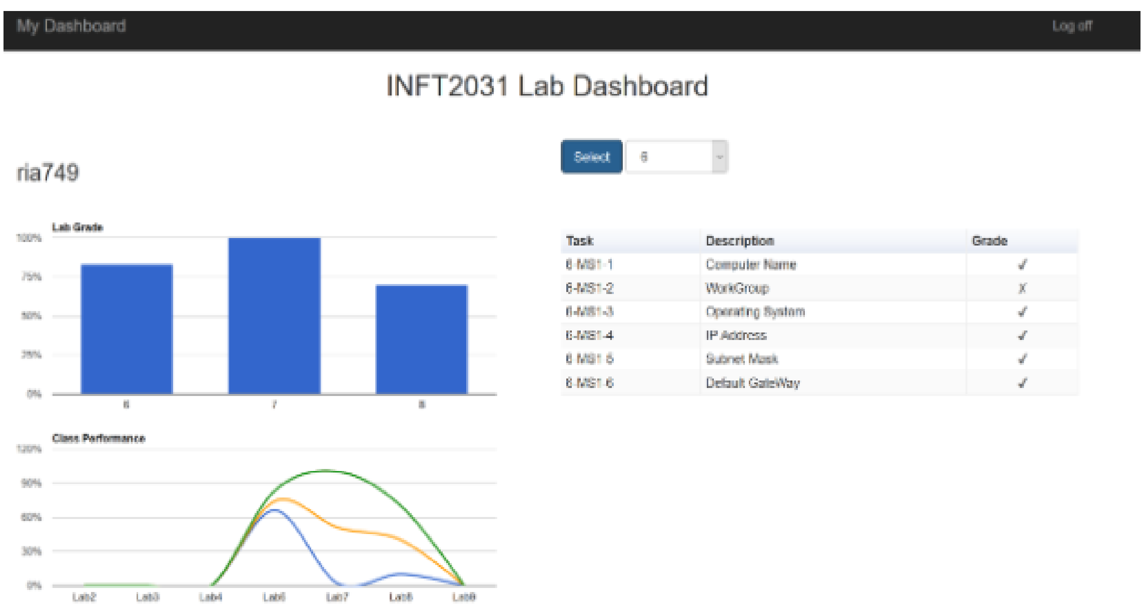


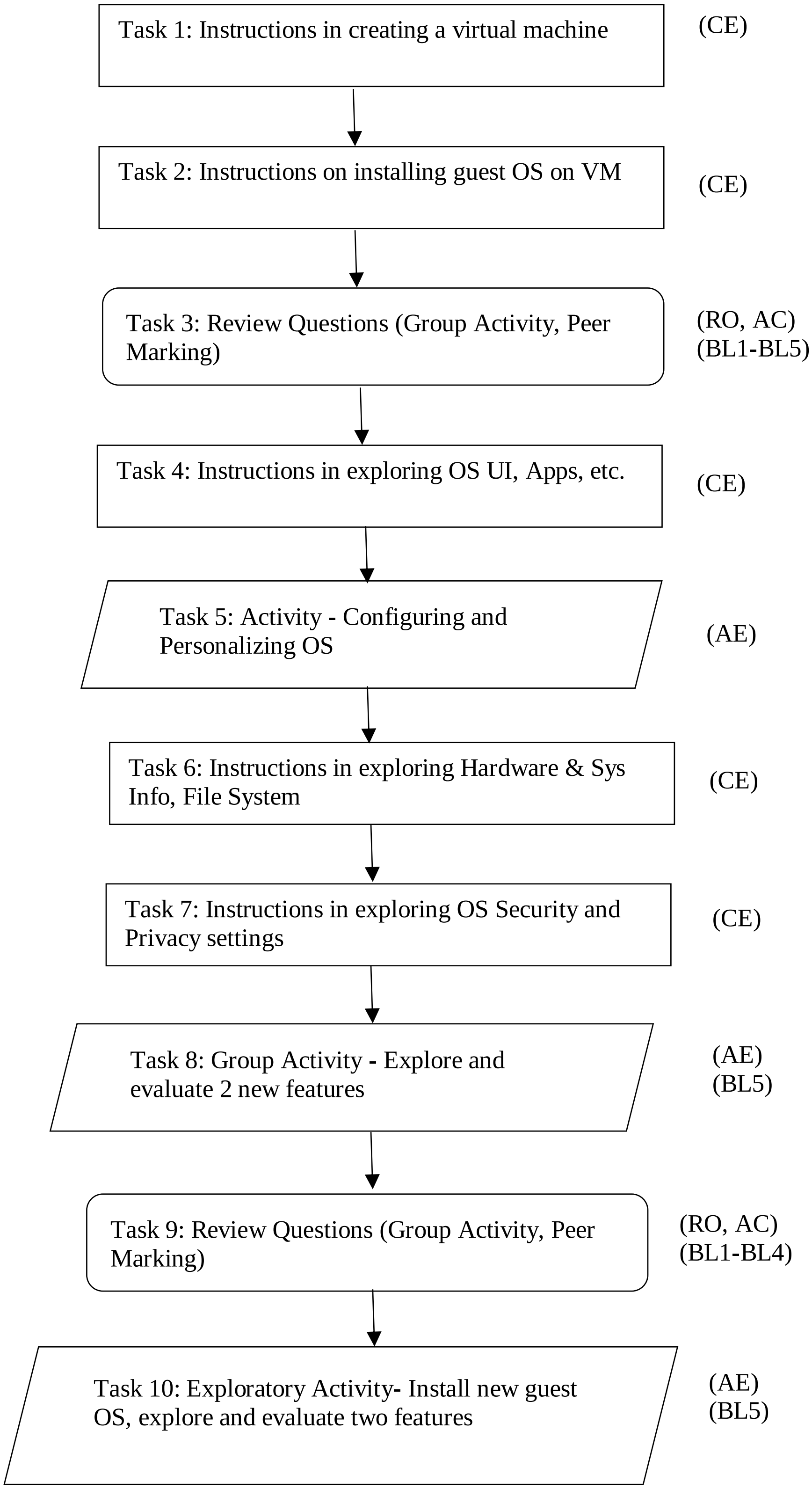
Figure D.2 A sample report from student's dashboard

Appendix E: The Redesigned Labs for INFT2031

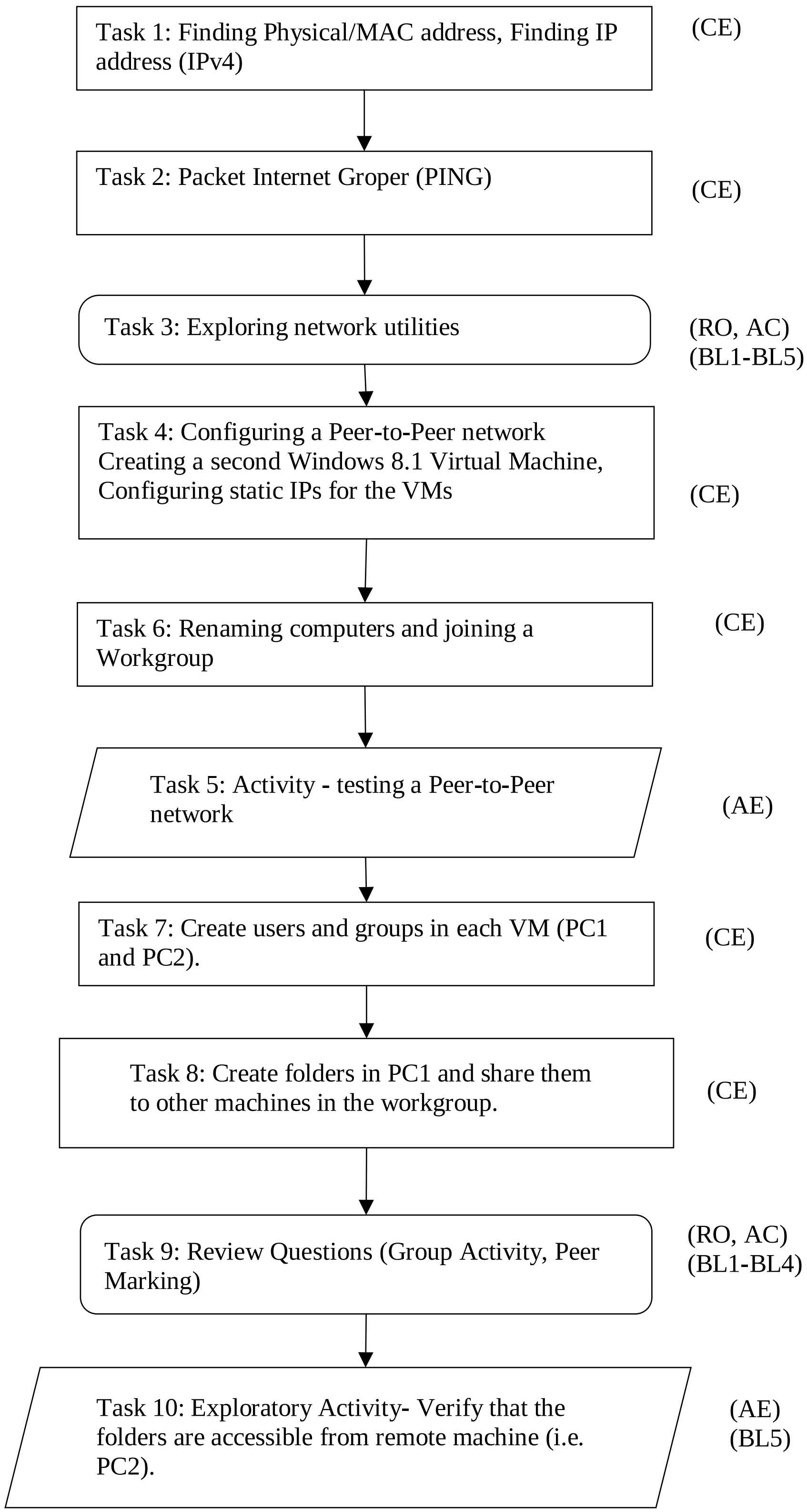
Table F.1: Teaching and Learning Plan for Systems and Network Administration course

Week	Lecture Topics	Lab Activities	Summative Assessments
1	L1: Introduction to course, Introduction to Hardware, OS, Network and Virtualization basics		
2	L2: ISO/OSI Model, TCP/IP Protocol Suite & OSI Model, Network models, Windows Shared Folder & NTFS Permissions	T1: VMs, Win10 installation, review exercises	
3	L3: Network Layer – Logical Addressing with IPv4	T2: P2P, Shares, review exercises	
4	L4: IPv4 Address Allocation, Internet Protocol, Routing	T3: Share + NTFS permissions, review exercises	
5	L5: Topologies, Network Hardware, Ethernet, Wireless LAN,	T4: Formative Assessments - Practice Test 1 + review exercises	
6	L6: Network Operating System	T5: Practical Test 1 (PT1) + review exercises	**Practical Test 1**
7	L7: DNS Class Exercise: Network Diagrams	T6: NOS, PowerShell, review exercises	
8	L8: Active Directory	T7: DHCP, review exercises	A1– Network Design
9	L9: Process-to-process Delivery: TCP & UDP	T8: Active Directory, review exercises	
10	L10: Network Security Part 1 – Cryptography, Message confidentiality, integrity, authentication & non-repudiation, key management	T9: Group Policy, review exercises	
11	L11: Network Security Part 2 – IPSec, VPN, SSL, Firewalls, Proxies, VLANs Class Exercise: AD Network Diagrams	T10: Formative Assessment - Practice Test 2, review exercises	
12	L12: Review, Q&A	T11: Practical Test 2 (PT2), review exercises	A2: AD Design, **Practical Test 2**
Exam Period			Formal Exam

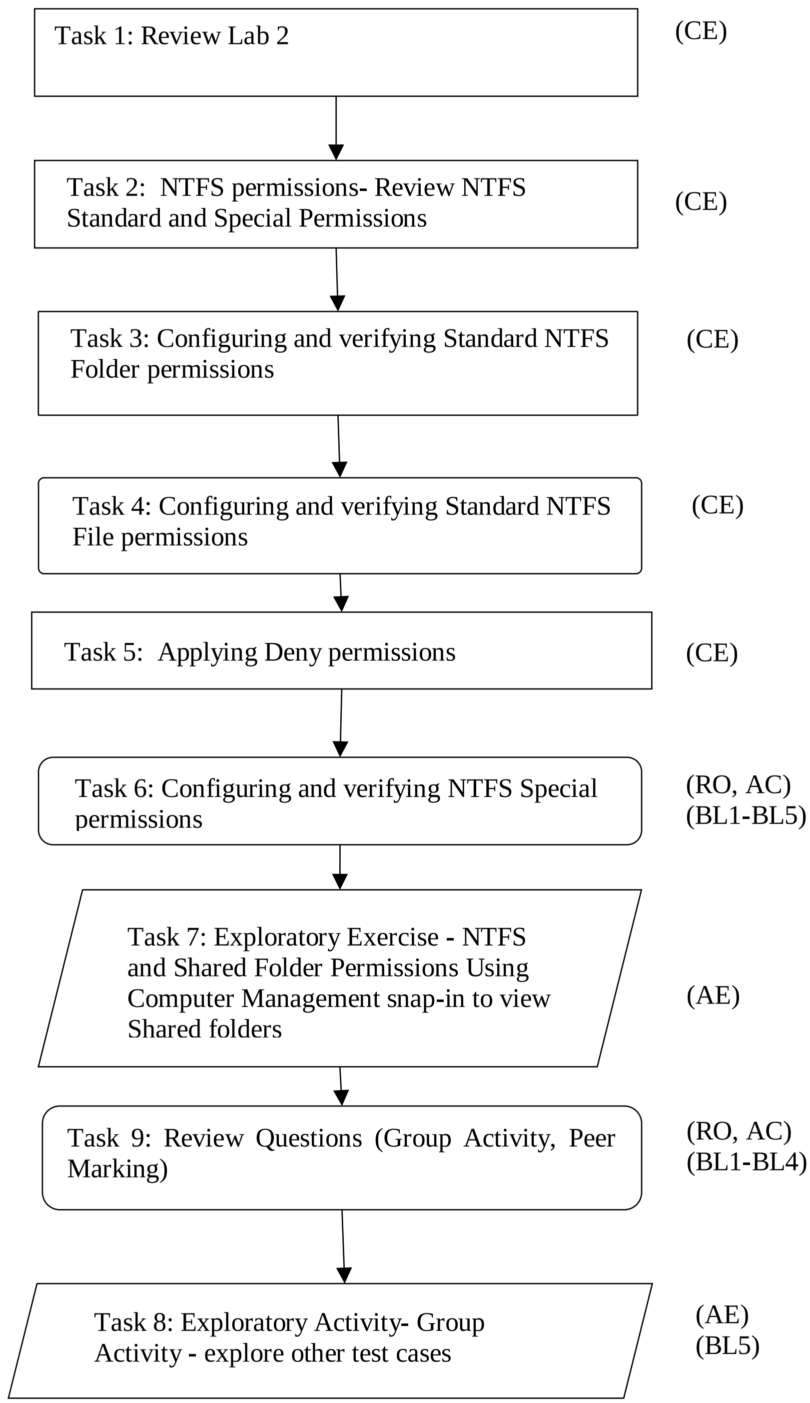
Lab 1: Instructions in creating a virtual machine



Lab 2: P2P


Task 1: Finding Physical/MAC address, Finding IP address (IPv4)
(CE)
Task 2: Packet Internet Groper (PING)
(CE)
Task 3: Exploring network utilities
(RO, AC)
(BL1-BL5)
Task 4: Configuring a Peer-to-Peer network Creating a second Windows 8.1 Virtual Machine, Configuring static IPs for the VMs
(CE)
Task 6: Renaming computers and joining a Workgroup
(CE)
Task 5: Activity - testing a Peer-to-Peer network
(AE)
Task 7: Create users and groups in each VM (PC1 and PC2).
(CE)
Task 8: Create folders in PC1 and share them to other machines in the workgroup.
(CE)
Task 9: Review Questions (Group Activity, Peer Marking)
(RO, AC)
(BL1-BL4)
Task 10: Exploratory Activity- Verify that the folders are accessible from remote machine (i.e. PC2).
(AE)
(BL5)

Lab 3: NTFS permissions



Lab 4: Practice Practical Test 1 & Review Questions

Part I: Practice Practical Test

Part III: Review Exercises

Lab 5: Practical Test 1 + Review Questions

Lab 6: Windows Server 2012 R2 installation

Task 1: Installation – Server Core (CE)

Task 2: Configuring and exploring Windows Server 2012 R2 Standard Edition (CE)

Task 3: Windows Server 2012 R2 installation (CE)

Task 4: Configure and explore *Server_2016* Windows Server 2016 VM. (CE)

Task 5: Explore roles and features. Post your answers to the questions on Blackboard Discussion Board. (RO, AC) (BL1-BL5)

Task 6: Activity - UNIX commands (AE)

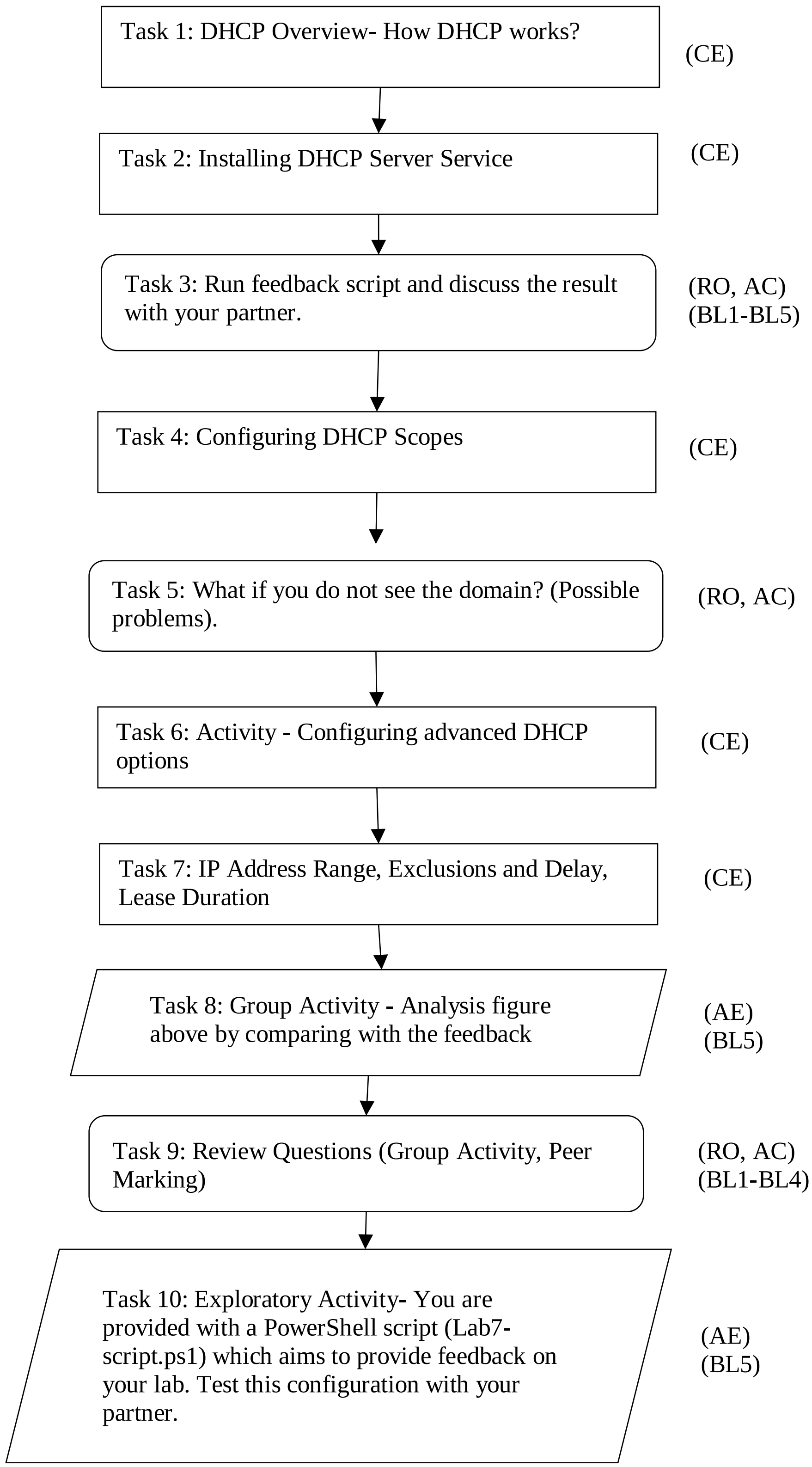
Task 7: Open Windows PowerShell by search for *PowerShell* (CE)

Task 8: Explore Windows PowerShell commands: (AE) (BL5)

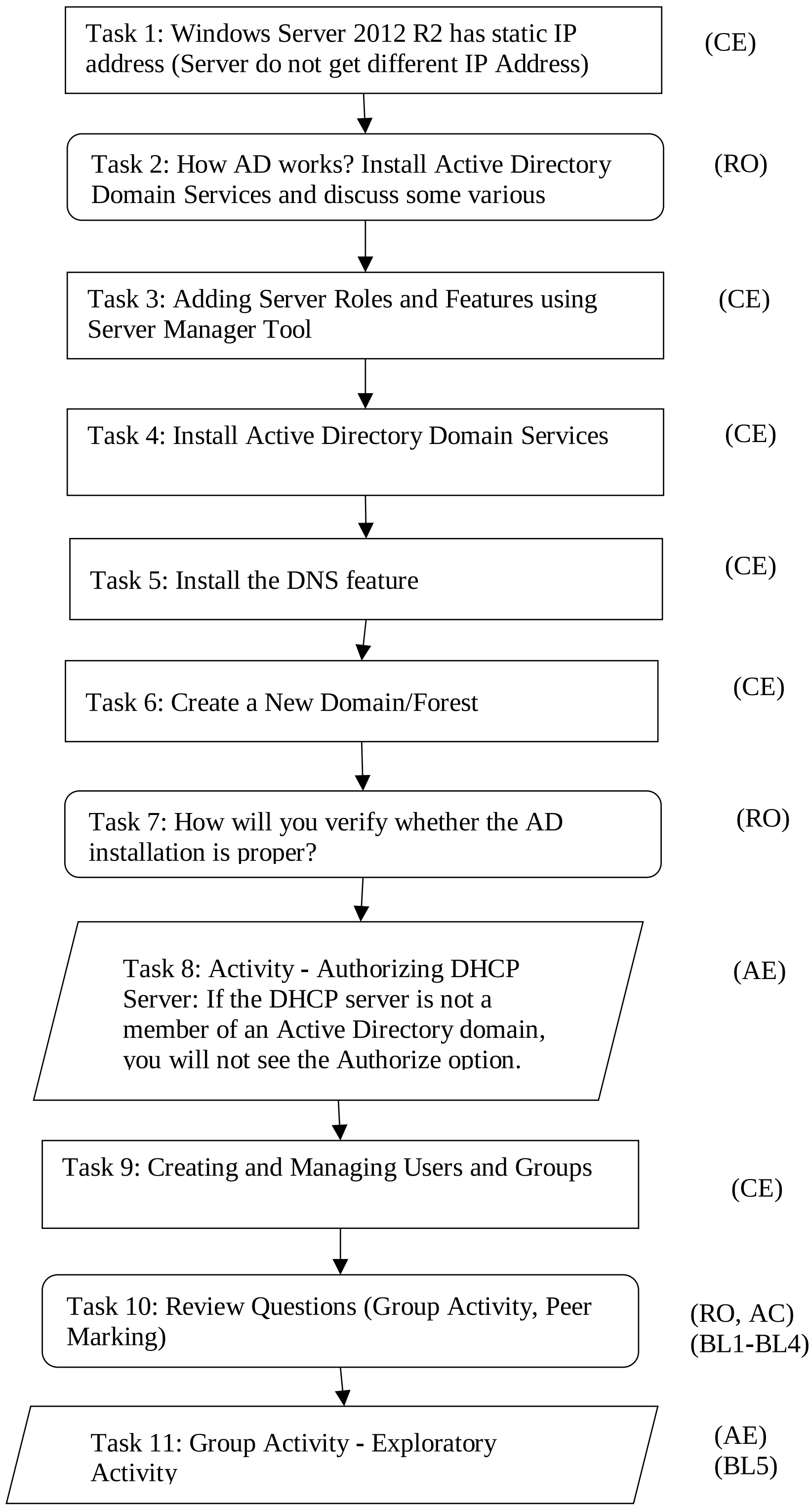
Task 9: Review Questions (Group Activity, Peer Marking) (RO, AC) (BL1-BL4)

Task 10: Exploratory Activity- Complete Tasks 1-3 in Part 3 (UNIX commands above) using PowerShell commands. (AE) (BL5)

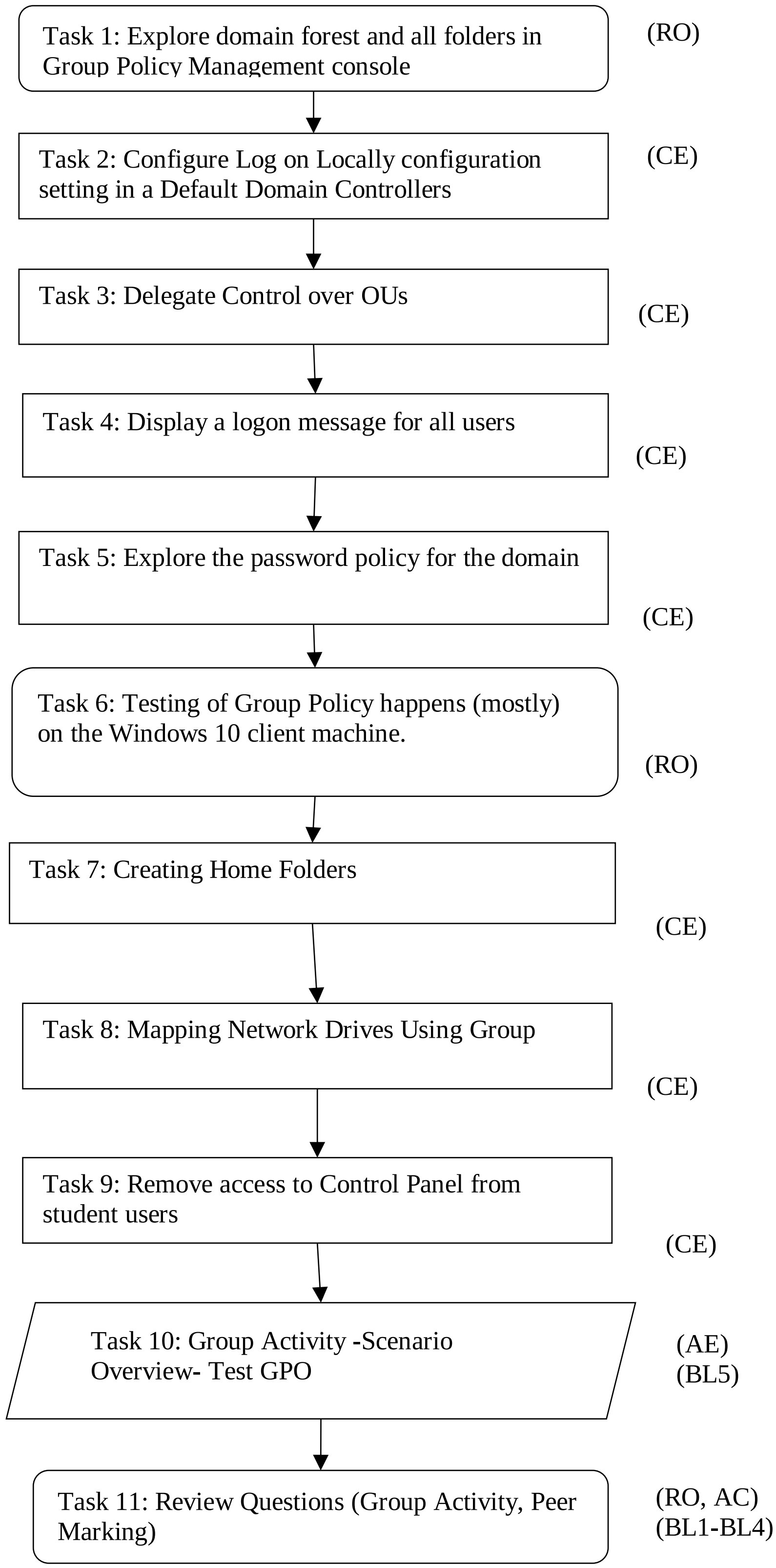
Lab 7: DHCP


Task 1: DHCP Overview- How DHCP works?
(CE)
Task 2: Installing DHCP Server Service
(CE)
Task 3: Run feedback script and discuss the result with your partner.
(RO, AC)
(BL1-BL5)
Task 4: Configuring DHCP Scopes
(CE)
Task 5: What if you do not see the domain? (Possible problems).
(RO, AC)
Task 6: Activity - Configuring advanced DHCP options
(CE)
Task 7: IP Address Range, Exclusions and Delay, Lease Duration
(CE)
Task 8: Group Activity - Analysis figure above by comparing with the feedback
(AE)
(BL5)
Task 9: Review Questions (Group Activity, Peer Marking)
(RO, AC)
(BL1-BL4)
Task 10: Exploratory Activity- You are provided with a PowerShell script (Lab7-script.ps1) which aims to provide feedback on your lab. Test this configuration with your partner.
(AE)
(BL5)

Lab 8: Active Directory



Lab 9: Group Policy



Lab 10: Practice Practical Test 2 & Review Questions

Part I: Practice Practical Test

Part III: Review Exercises

Lab 11: Practical Test 2 + Review Questions

Appendix F: Reliability Statistics

Correlations Matrix, Factor Analysis and Reliability of the Latent Variables

Pearson correlations among the items for the VMware virtual lab version (n = 83) - 2016

	PU1	PU2	PU3	PEU1	PEU2	PEU3	PEU4	AT1	AT2
1. The lab environment helped me to learn in INFT2031	1.000	.650	.748	.344	.319	.574	.491	.511	.429
2. The lab environment improved my performance		1.000	.666	.320	.405	.459	.371	.646	.493
3. The lab environment helped me to achieve learning outcomes			1.000	.239	.255	.506	.387	.442	.291
4. The lab environment provide easy access to the lab (24x7)				1.000	.471	.387	.577	.446	.459
5. Having access to the lab environment from device/cloud (home etc.) is helpful to me					1.000	.344	.329	.419	.410
6. I find it easy to use the lab environment						1.000	.623	.595	.411
7. I find the lab setting flexible to conduct my lab work							1.000	.603	.476
8. I am satisfied with using the lab environment for my practical work in INFT2031								1.000	.697
9. I would like to use the lab environment in future networking and systems administration courses									1.000

Cronbach's Alpha = .870

1) Inter-Item Correlation Matrix Perceived Usefulness

Cronbach's Alpha = .868	PU1	PU2	PU3
PU1	1.000	.650	.748
PU2		1.000	.666
PU3			1.000

2) Inter-Item Correlation Matrix Perceived Ease of Use

Cronbach's Alpha = .751	PEU1	PEU2	PEU3	PEU4
PEU1	1.000	.471	.387	.577
PEU2		1.000	.344	.329
PEU3			1.000	.623
PEU4				1.000

3) Inter-Item Correlation Matrix Attitude toward using

Cronbach's Alpha=.810	AT1	AT2
AT1	1.000	.697
AT2		1.000

Pearson correlations among the items for the Azure virtual lab version (n = 64) - 2016

	PU1	PU2	PU3	PEU1	PEU2	PEU3	PEU4	AT1	AT2
1. The lab environment helped me to learn in INFT2031	1.000	.569	.553	.530	.389	.661	.539	.462	.652
2. The lab environment improved my performance		1.000	.717	.546	.296	.533	.387	.518	.447
3. The lab environment helped me to achieve learning outcomes			1.000	.361	.515	.652	.506	.524	.480
4. The lab environment provide easy access to the lab (24x7)				1.000	.425	.501	.529	.352	.400
5. Having access to the lab environment from device/cloud (home etc.) is helpful to me					1.000	.478	.506	.533	.566
6. I find it easy to use the lab environment						1.000	.773	.572	.576
7. I find the lab setting flexible to conduct my lab work							1.000	.624	.578
8. I am satisfied with using the lab environment for my practical work in INFT2031								1.000	.580
9. I would like to use the lab environment in future networking and systems administration courses									1.000

Cronbach's Alpha = .905

1) Inter-Item Correlation Matrix Perceived Usefulness

Cronbach's Alpha = .824	PU1	PU2	PU3
PU1	1.000	.569	.553
PU2		1.000	.717
PU3			1.000

2) Inter-Item Correlation Matrix Perceived Ease of Use

Cronbach's Alpha = .816	PEU1	PEU2	PEU3	PEU4
PEU1	1.000	.425	.501	.529
PEU2		1.000	.478	.506
PEU3			1.000	.773
PEU4				1.000

3) Inter-Item Correlation Matrix Attitude toward using

Cronbach's Alpha=.734	AT1	AT2
AT1	1.000	.580
AT2		1.000

CFA – TAM model

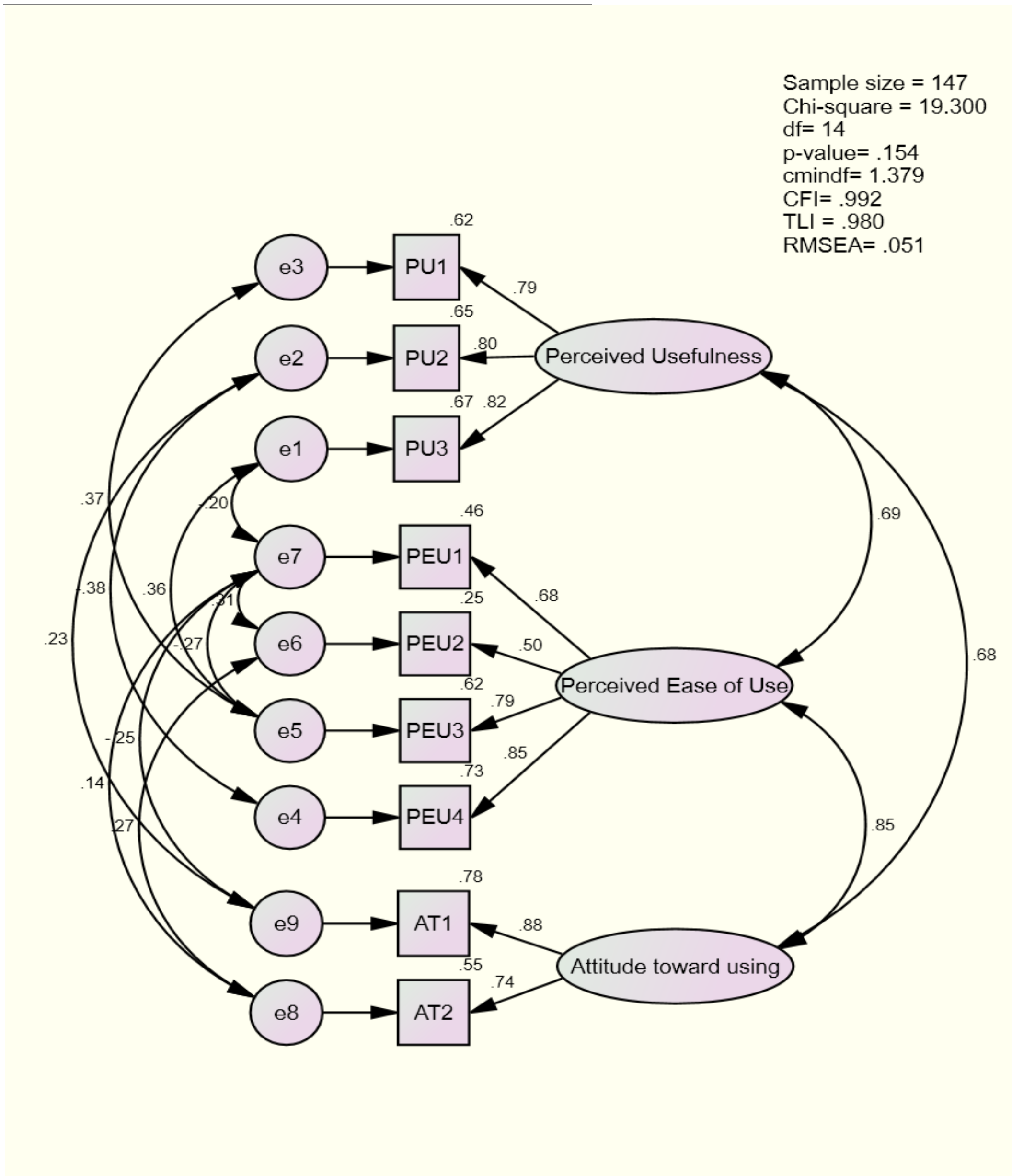


Figure F.1 Path diagram of confirmatory factor analysis of the TAM items and their respective factors. The three factors of the TAM represented by the circles. Each rectangle represents one item of the questionnaire, linked to its parent factor by a single-headed arrow. We use IBM-SPSS Amos to conduct a confirmatory factor analysis (CFA). There were three latent variables, perceived usefulness; perceived ease of use; and attitudes and nine manifest variables in the model: (PU = Perceived Usefulness), PU1, PU2, PU3; (PEU = Perceived Ease of Use) PEU1, PEU2, PEU3, PEU4; and (AT = Attitude) AT1, AT2.

Model Fit Summary

CMIN

Model	NPAR	CMIN	DF	P	CMIN/DF
Default model	62	53.058	28	.003	1.895
Saturated model	90	.000	0		
Independence model	18	772.982	72	.000	10.736

RMR, GFI

Model	RMR	GFI	AGFI	PGFI
Default model	.039	.931	.778	.290
Saturated model	.000	1.000		
Independence model	.333	.329	.161	.263

Baseline Comparisons

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.931	.823	.966	.908	.964
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000

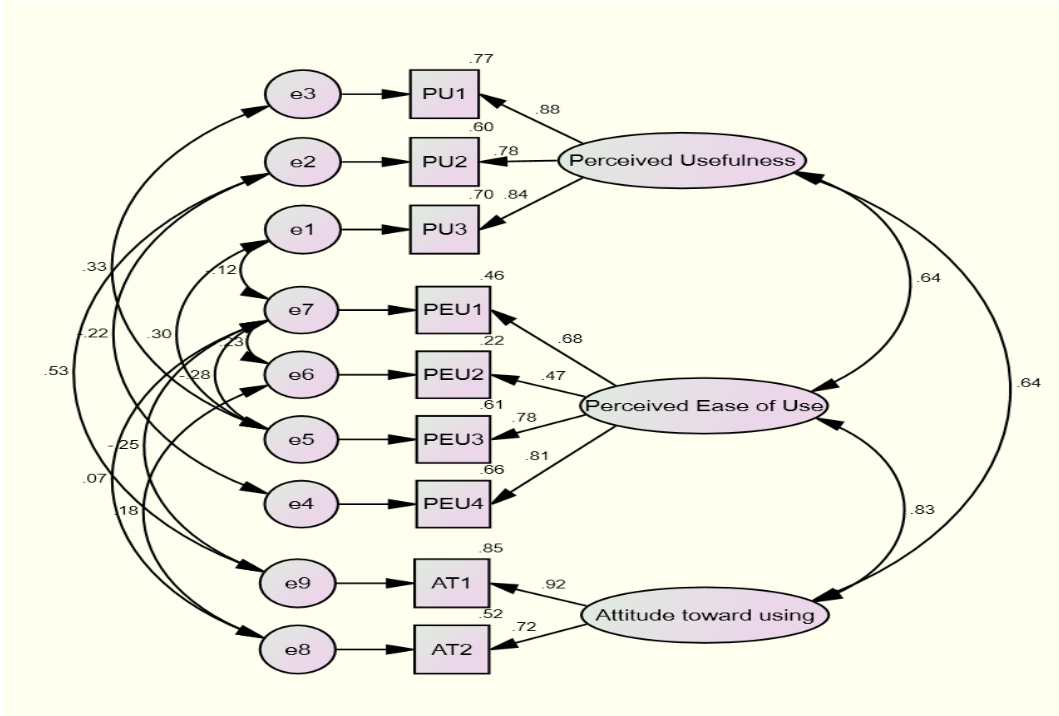
RMSEA

Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	.079	.045	.111	.075
Independence model	.259	.243	.276	.000

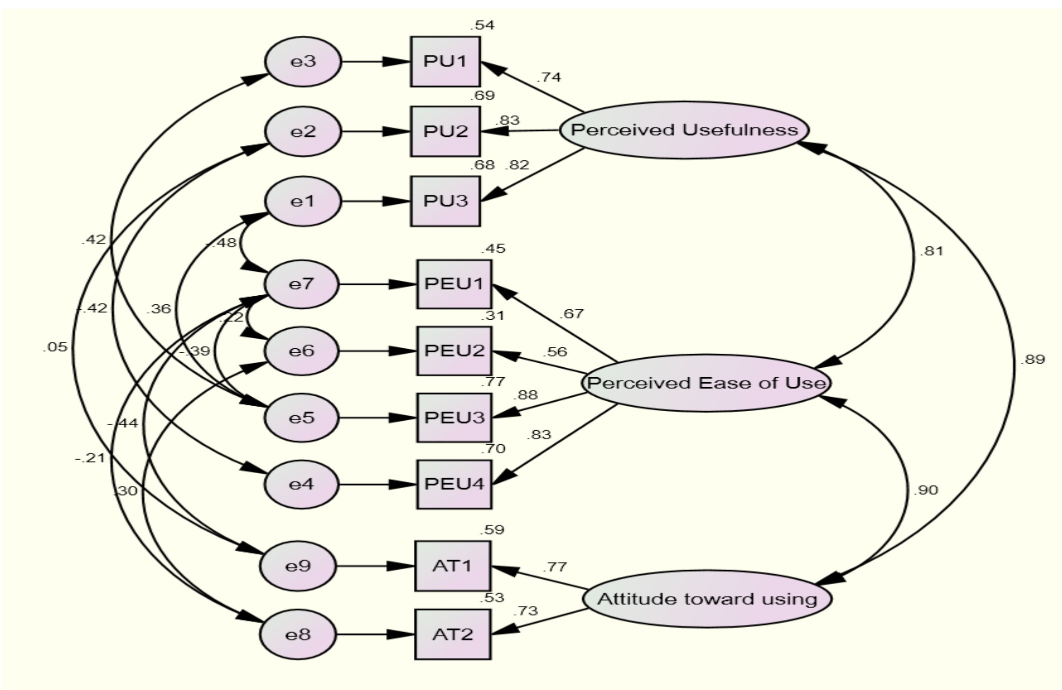
Results of Multi group confirmatory factor analysis (CFA)

Item	**Perceived Usefulness**		**Perceived Ease of Use**		**Attitude towards usage**	
1	.876	.738				
2	.776	.831				
3	.835	.824				
4			. 679	.671		
5			.470	.555		
6			.781	.876		
7			.815	.834		
8					.924	.769
9					.724	.725

Multiple Group CFA:



(a) CFA of TAM model – Vmware - 2016



(b) CFA of TAM model – Azure - 2016

CFA–Lab Activities

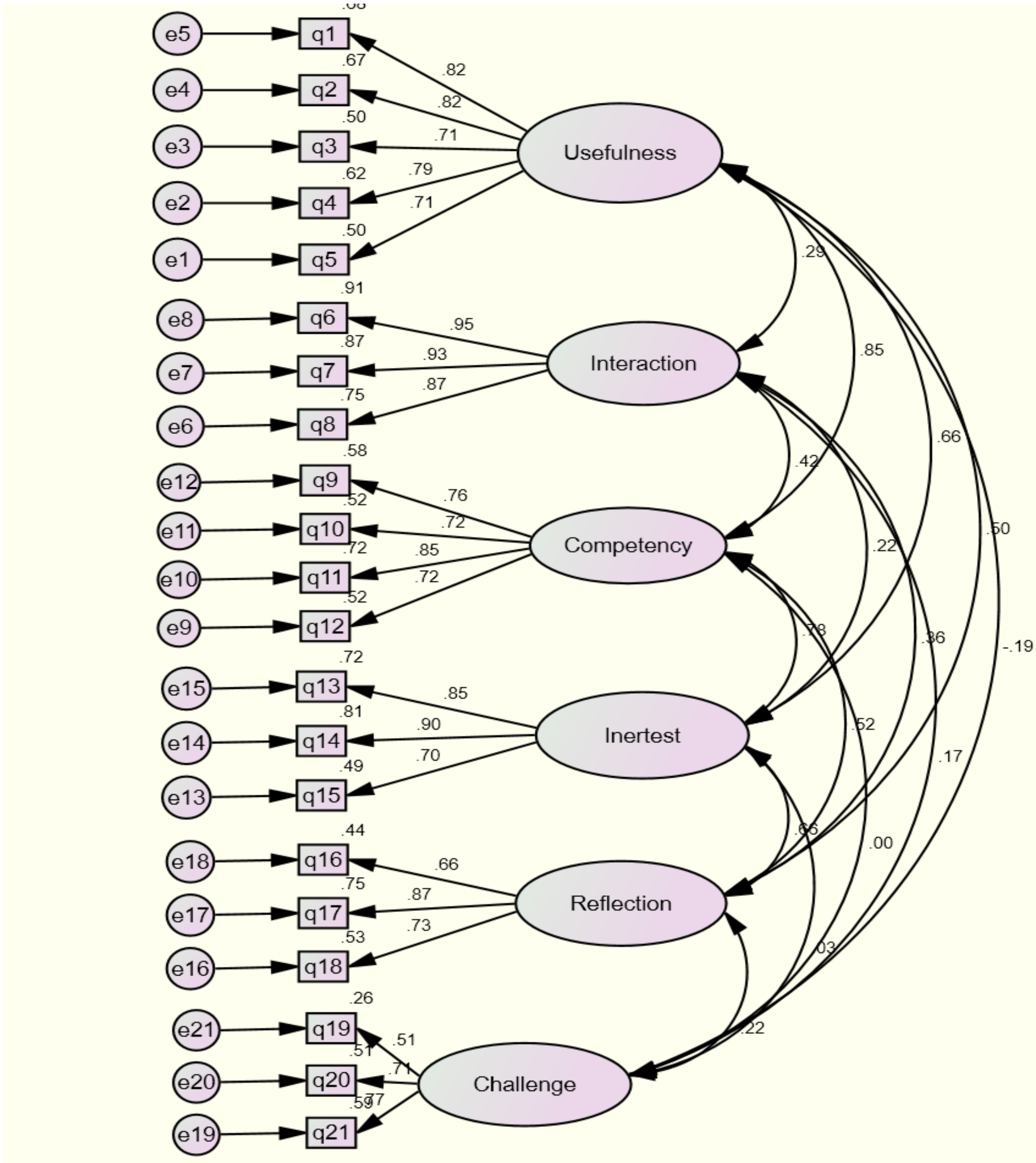


Figure F.2 Path diagram of confirmatory factor analysis of the lab activities items and their respective factors. The six factors of the lab activities (Konak & Bartolacci, 2016) represented by the circles. Each rectangle represents one item of the questionnaire, linked to its parent factor by a single-headed arrow.

The survey questions, latent variables, and the reliability measures - 2017

Latent Variable (Cronbach's α)	Questions	Descriptive Statistics		Factor loadings (CFA)					
		Mean	SD	1	2	3	4	5	6
1. Usefulness	q1	4.55	.555	.877					
(.867)	q2	4.44	.626	.837					
	q3	4.01	.853	.599					
	q4	4.10	.831	.730					
	q5	3.90	.831	.706					
2. Interaction	q6	3.32	1.079		.954				
(.940)	q7	3.11	1.178		.937				
	q8	3.24	1.152		.867				
3. Competency	q9	4.04	.783			.809			
(.835)	q10	4.51	.582			.686			
	q11	4.35	.612			.829			
	q12	4.27	.675			.774			
4. Interest	q13	4.18	.833				.843		
(.844)	q14	4.04	.836				.899		
	q15	3.86	.883				.685		
5. Reflection	q16	3.86	.961					.641	
(.779)	q17	4.01	.819					.873	
	q18	3.58	.905					.696	
6. Challenge	q19	3.61	1.021						.561
(.693)	q20	3.21	.940						.735
	q21	2.34	1.146						.705

Cronbach's Alpha = .893 (No of items=21)

Standardized Regression Weights:

			Estimate
q5	<---	USE	.706
q4	<---	USE	.730
q3	<---	USE	.599
q2	<---	USE	.837
q1	<---	USE	.877
q8	<---	ACT	.867
q7	<---	ACT	.937
q6	<---	ACT	.954
q12	<---	COM	.774
q11	<---	COM	.829
q10	<---	COM	.686
q9	<---	COM	.809
q15	<---	INT	.685
q14	<---	INT	.899
q13	<---	INT	.843
q18	<---	REF	.696
q17	<---	REF	.873
q16	<---	REF	.641
q21	<---	CHA	.705
q20	<---	CHA	.735
q19	<---	CHA	.561

Correlations:

			Estimate
USE	<-->	ACT	.254
USE	<-->	COM	.798
USE	<-->	INT	.639
USE	<-->	REF	.483
USE	<-->	CHA	-.111
ACT	<-->	COM	.413
ACT	<-->	INT	.233
ACT	<-->	REF	.346
ACT	<-->	CHA	.177
COM	<-->	INT	.786
COM	<-->	REF	.608
COM	<-->	CHA	.076
INT	<-->	REF	.657
INT	<-->	CHA	.056
REF	<-->	CHA	.246

Model Fit Summary

CMIN

Model	NPAR	CMIN	DF	P	CMIN/DF
Default model	69	233.131	162	.000	1.439
Saturated model	231	.000	0		
Independence model	21	1163.067	210	.000	5.538

RMR, GFI

Model	RMR	GFI	AGFI	PGFI
Default model	.087	.794	.707	.557
Saturated model	.000	1.000		
Independence model	.268	.246	.170	.223

Baseline Comparisons

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.800	.740	.929	.903	.925
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000

RMSEA

Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	.079	.055	.101	.026
Independence model	.255	.240	.269	.000

Inter-Item Correlation Matrix – Section 5 in 2017 survey

	q1	q2	q3	q4	q5	q6	q7	q8	q9	q10	q11	q12	q13	q14	q15	q16	q17	q18	q19	q20	q21
q1	1.000	.779	.556	.624	.460	.128	.122	.149	.439	.584	.600	.593	.335	.380	.568	.254	.297	.156	.136	-.198	-.229
q2		1.000	.603	.575	.523	.274	.223	.249	.486	.520	.562	.666	.337	.374	.578	.127	.294	.204	.228	-.086	-.049
q3			1.000	.562	.546	.212	.169	.229	.341	.417	.510	.464	.318	.440	.685	.264	.245	.174	.220	-.164	-.122
q4				1.000	.677	.283	.149	.273	.543	.515	.549	.411	.407	.447	.701	.322	.418	.417	.148	-.155	-.261
q5					1.000	.291	.216	.219	.468	.400	.491	.430	.542	.521	.721	.376	.464	.533	.105	-.138	-.175
q6						1.000	.892	.821	.389	.258	.322	.291	.140	.143	.363	.114	.253	.449	.273	.101	.049
q7							1.000	.811	.367	.228	.261	.249	.139	.140	.290	.140	.191	.407	.239	.069	.077
q8								1.000	.369	.221	.325	.320	.162	.212	.357	.134	.314	.455	.300	.085	.111
q9									1.000	.516	.714	.438	.536	.543	.587	.350	.445	.469	.432	.027	.032
q10										1.000	.614	.558	.483	.454	.419	.155	.284	.304	.341	-.068	-.261
q11											1.000	.599	.544	.529	.516	.280	.246	.273	.317	-.106	-.091
q12												1.000	.470	.537	.519	.323	.406	.258	.259	-.090	.011
q13													1.000	.789	.540	.390	.415	.426	.304	-.068	.024
q14														1.000	.608	.452	.500	.402	.288	-.084	.030
q15															1.000	.431	.457	.425	.207	-.101	-.136
q16																1.000	.602	.424	.263	-.172	.070
q17																.	1.000	.625	.263	.126	.147
q18																		1.000	.358	.056	.085
q19																			1.000	.371	.372
q20																				1.000	.556
q21																					1.000

Rotated Component Matrix for section 6 in the 2017 survey

Questions	Component	
	1	2
q4	.795	
q2	.775	
q6.	.752	
q5	.687	
q9	.685	.416
q7	.660	.398
q1	.603	.478
q8	.595	.446
q3	.542	
q11		.832
q12	.303	.818
q10		.792

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 3 iterations.

Inter-Item Correlation Matrix

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000											
2	.648	1.000										
3	.479	.565	1.000									
4	.435	.582	.290	1.000								
5	.453	.454	.330	.591	1.000							
6	.498	.566	.457	.500	.621	1.000						
7	.570	.526	.496	.471	.456	.567	1.000					
8	.565	.601	.380	.415	.432	.453	.650	1.000				
9	.546	.594	.349	.530	.545	.687	.546	.559	1.000			
10	.549	.408	.406	.258	.372	.438	.465	.374	.487	1.000		
11	.470	.423	.314	.334	.479	.406	.425	.525	.510	.568	1.000	
12	.483	.461	.354	.381	.455	.466	.489	.497	.538	.602	.735	1.000

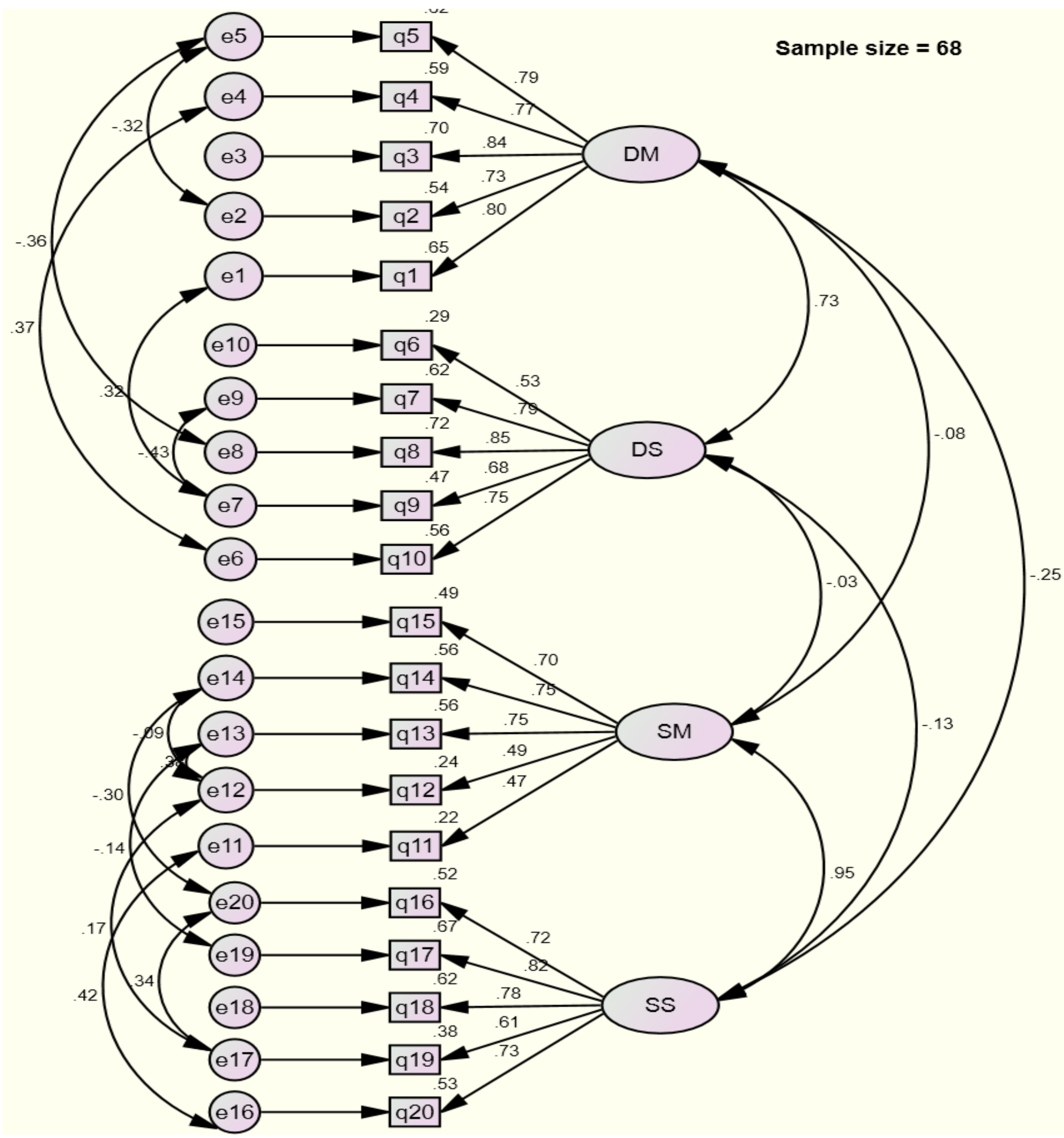


Figure 3: Path diagram of confirmatory factor analysis of the R-SPQ-2F items and their respective factors. The four factors of the R-SPQ-2F represented by the circles. Each rectangle represents one item of the questionnaire, linked to its parent factor by a single-headed arrow.

Rotated Component Matrix for the R-SPQ-2F using Exploratory Factor Analysis - 2017

Questions -the R-SPQ-2F		Component			
		1	2	3	4
Deep Motivation (DM)	1. The lab activities gave me a feeling of deep personal satisfaction	.804			
	2. The lab activities helped me create questions that I wanted answered	.734			
	3. The lab activities made me work hard because I found the material interesting	.836			
	4. The lab activities was at times as exciting as a good novel or movie	.766			
	5. The lab activities was interesting once I got into it	.786			
Deep Strategies (DS)	6. The lab activities provided me with enough work on the topic so I could form my own conclusions		.535		
	7. The lab activities caused me to look at most of the suggested readings that pertained to the activity		.785		
	8. The lab activities caused me to spend time relating its topics to other topics, which have been discussed in different classes		.847		
	9. The lab activities allowed me to test myself on important topics until I understood them completely		.684		
	10. The lab activities' topics were interesting and I often spent extra time trying to obtain more information about them		.746		
Surface Motivation (SM)	11. For the lab activities, it was not helpful to study topics in depth because all you needed was a passing acquaintance with topics			.474	
	12. I was able to get by in the lab activities by memorizing key sections rather than trying to understand them			.491	
	13. For the lab activities, there was no point in learning material, which was not likely to be on the exam			.752	
	14. I did not find the lab activities very interesting so I kept my work to a minimum			.748	
	15. My aim for the lab activities was to complete it while doing as little work as possible			.703	
Surface Strategies (SS)	16. The lab activities suggests the best way to pass exams is to try to remember answers to likely test questions				.720
	17. I believe that the instructor should not expect me to spend significant amounts of time on the lab activities if it is not on an exam				.818
	18. For these lab activities, I restricted my study to what was specifically required as it was unnecessary to do anything extra				.784
	19. For the lab activities, I learned things by going over and over them until I knew them by heart even if I did not understand them				.614
	20. For the lab activities, I only applied what was given in class or on the course outline				.725

Cronbach's α= .837, N of items = 20

Standardized Regression Weights:

			Estimate
q1	<---	DM	.804
q2	<---	DM	.734
q3	<---	DM	.836
q4	<---	DM	.766
q5	<---	DM	.786
q10	<---	DS	.746
q9	<---	DS	.684
q8	<---	DS	.847
q7	<---	DS	.785
q6	<---	DS	.535
q11	<---	SM	.474
q12	<---	SM	.491
q13	<---	SM	.752
q14	<---	SM	.748
q15	<---	SM	.703
q20	<---	SS	.725
q19	<---	SS	.614
q18	<---	SS	.784
q17	<---	SS	.818
q16	<---	SS	.720

Correlations:

			Estimate
DM	<-->	DS	.733
DM	<-->	SM	-.080
DM	<-->	SS	-.251
DS	<-->	SM	-.034
DS	<-->	SS	-.134
SM	<-->	SS	.952

Model Fit Summary

CMIN

Model	NPAR	CMIN	DF	P	CMIN/DF
Default model	58	195.660	152	.010	1.287
Saturated model	210	.000	0		
Independence model	20	888.246	190	.000	4.675

RMR, GFI

Model	RMR	GFI	AGFI	PGFI
Default model	.099	.788	.708	.571
Saturated model	.000	1.000		
Independence model	.359	.297	.223	.268

Baseline Comparisons

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.780	.725	.941	.922	.937
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000

RMSEA

Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	.065	.034	.091	.181
Independence model	.234	.219	.250	.000

Inter-Item Correlation Matrix for section 7 in the 2017 survey

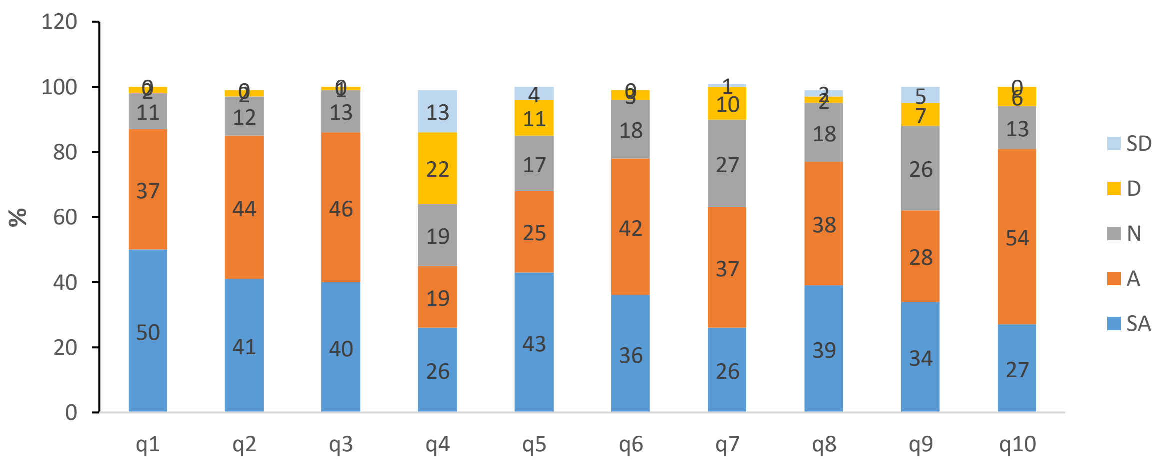
	q1	q2	q3	q4	q5	q6	q7	q8	q9	q10	q11	q12	q13	q14	q15	q16	q17	q18	q19	q20
q1	1.000	.627	.708	.644	.582	.505	.356	.445	.544	.488	-.054	.006	-.054	-.380	.064	.016	-.189	-.224	-.090	-.255
q2		1.000	.537	.544	.429	.492	.442	.555	.456	.516	.099	.006	-.004	-.243	.048	-.015	-.144	-.319	-.092	-.244
q3			1.000	.660	.677	.439	.395	.538	.437	.537	.044	-.077	-.043	-.347	.017	-.021	-.214	-.167	-.097	-.201
q4				1.000	.671	.421	.303	.376	.380	.589	.044	-.003	.111	-.202	.178	-.006	-.021	-.037	-.048	-.156
q5					1.000	.432	.331	.357	.429	.554	.066	.001	.069	-.203	.147	-.040	-.130	-.084	-.124	-.083
q6						1.000	.375	.361	.446	.447	.136	.073	.001	-.223	.058	.049	.041	-.175	-.118	.096
q7							1.000	.746	.326	.527	.111	.170	.116	-.029	-.060	.081	.034	-.179	.155	.051
q8								1.000	.506	.562	.150	.119	-.009	-.218	.020	.029	-.153	-.217	.067	-.061
q9									1.000	.544	.040	.184	.034	-.281	-.031	.093	-.150	-.206	.003	-.087
q10										1.000	.094	.117	-.023	-.225	.014	.023	-.028	-.179	.031	-.091
q11											1.000	.358	.476	.309	.323	.282	.290	.324	.308	.552
q12												1.000	.611	.249	.273	.470	.385	.261	.521	.362
q13													1.000	.515	.509	.613	.533	.501	.603	.466
q14														1.000	.522	.391	.647	.612	.377	.598
q15															1.000	.522	.545	.509	.370	.380
q16																1.000	.556	.509	.659	.466
q17																	1.000	.655	.449	.567
q18																		1.000	.498	.635
q19																			1.000	.405
q20																				1.000

Appendix G: Descriptive Analysis of Quantitative Data

Frequency of student responses to the decentralised virtual lab environment (n=90)

Item - VMware Fusion labs -2016	Likert Scale- Frequency (%)					
	n	**SD (%)**	**D (%)**	**N (%)**	**A (%)**	**SA (%)**
1. The lab environment helped me to learn in INFT2031	90	0 (0%)	2 (2%)	10 (11%)	33 (37%)	45 (50%)
2. The lab environment improved my performance	90	0 (0%)	2 (2%)	11 (12%)	40 (44%)	37 (41%)
3. The lab environment helped me to achieve learning outcomes	89	0 (0%)	1 (1%)	11 (13%)	41 (46%)	36 (40%)
4. The lab environment provided easy access to the lab (24x7)	89	12(13%)	20 (22%)	17 (19%)	17 (19%)	23 (26%)
5. Having access to the lab from any device/location is helpful to me	89	4 (4%)	10 (11%)	15 (17%)	22 (25%)	38 (43%)
6. I find it easy to use the lab environment	88	0 (0%)	3 (3%)	16 (18%)	37 (42%)	32 (36%)
7. I find the lab setting flexible to conduct my lab work	90	1 (1%)	9 (10%)	24 (27%)	33 (37%)	23 (26%)
8. I am satisfied with using the lab environment for my practical work in INFT2031	89	2 (2%)	2 (2%)	16 (18%)	34 (38%)	35 (39%)
9. I would like to use the lab environment in future networking and systems administration courses	88	4 (5%)	6 (7%)	23 (26%)	25 (28%)	30 (34%)
10. Overall, how would you rate the lab environment	70	0 (0%)	4 (6%)	9 (13%)	38 (54%)	19 (27%)

(SD = Strongly Disagree, D= Disagree, N=Neutral, A= Agree, SA= Strongly Agree)

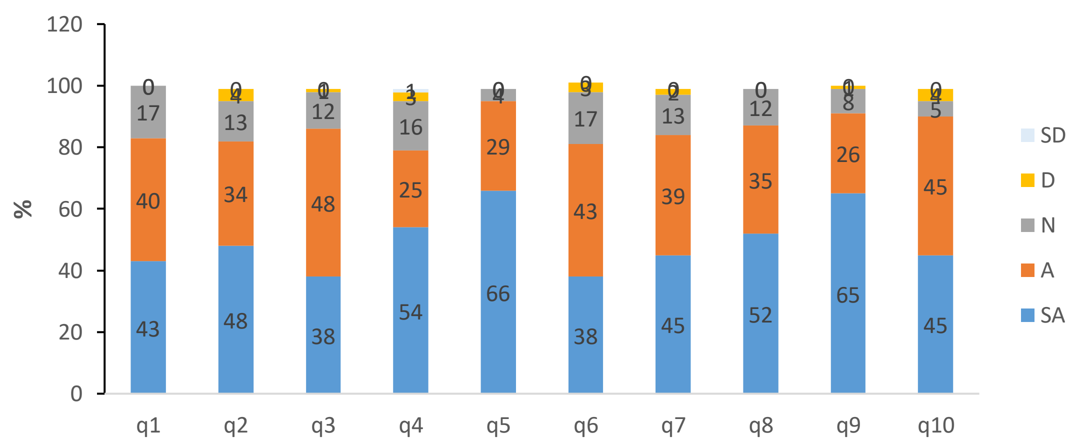


Students' responses and percentages about using the decentralised virtual lab environment

Frequency of student responses to the centralised virtual lab environment (n=69)

Item – Azure cloud labs – 2016	Likert Scale- Frequency (%)					
	n	**SD (%)**	**D (%)**	**N (%)**	**A (%)**	**SA (%)**
1. The lab environment helped me to learn in INFT2031	67	0%	0%	11 (17%)	27 (40%)	29 (43%)
2. The lab environment improved my performance	67	0%	3 (4%)	9 (13%)	23 (34%)	32 (48%)
3. The lab environment helped me to achieve learning outcomes	66	0%	1 (1%)	8 (12%)	32 (48%)	25 (38%)
4. The lab environment provided easy access to the lab (24x7)	68	1 (1%)	2 (3%)	11 (16%)	17 (25%)	37 (54%)
5. Having access to the lab from any device/location is helpful to me	68	0%	0%	3 (4%)	20 (29%)	45 (66%)
6. I find it easy to use the lab environment	66	0%	2 (3%)	10 (17%)	29 (43%)	25 (38%)
7. I find the lab setting flexible to conduct my lab work	67	0%	3 (2%)	9 (13%)	26 (39%)	30 (45%)
8. I am satisfied with using the lab environment for my practical work in INFT2031	67	0%	0%	8 (12%)	24 (35%)	35 (52%)
9. I would like to use the lab environment in future networking and systems administration courses	66	0%	1 (1%)	5 (8%)	17 (26%)	43 (65%)
10. Overall, how would you rate the lab environment	53	0%	2 (4%)	3 (5%)	24 (45%)	24 (45%)

(SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree)

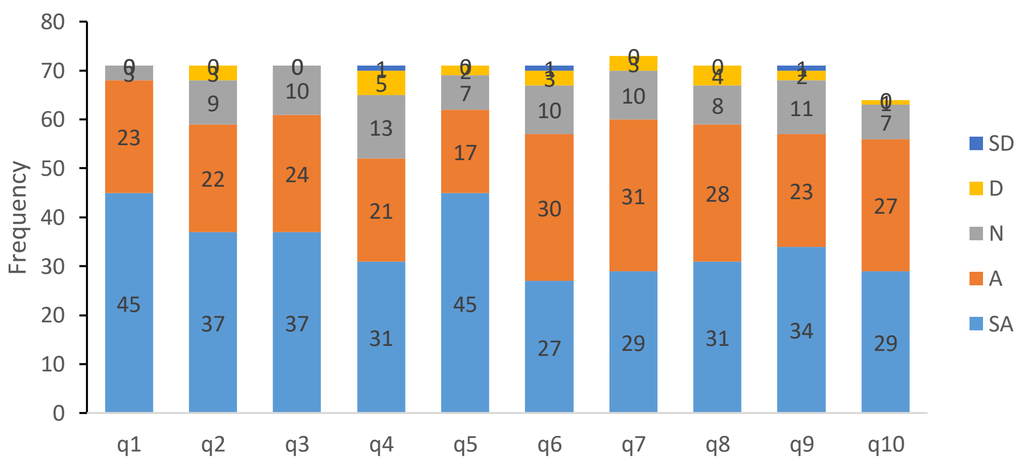


Students’ responses and percentages about using the centralised virtual lab environment

Frequency of Student Responses to the Server-based Lab Environment

Item – Server-based labs – 2017	Likert Scale- Frequency (%)					
	n	**SD (%)**	**D (%)**	**N (%)**	**A (%)**	**SA (%)**
1. The lab environment helped me to learn in INFT2031	71	0	0	3 (4%)	23 (32.5%)	45 (62.5%)
2. The lab environment improved my performance	71	0	3 (4.5%)	9 (12.5%)	22 (31%)	37 (52%)
3. The lab environment helped me to achieve learning outcomes	71	0	0	10 (14%)	24 (34%)	37 (52%)
4. The lab environment provided easy access to the lab (24x7)	71	1 (1.5%)	5 (7%)	13 (18%)	21 (29.5%)	31 (44%)
5. Having access to the lab from any device/location is helpful to me	71	0	2 (2.5%)	7 (10%)	17 (24%)	45 (63.5%)
6. I find it easy to use the lab environment	71	1 (1.5%)	3 (4%)	10 (14%)	30 (43%)	27 (36.5%)
7. I find the lab setting flexible to conduct my lab work	71	0	3 (4%)	10 (14%)	31 (42.5)	29 (38.5)
8. I am satisfied with using the lab environment for my practical work in INFT2031	71	0	4 (5.5)	8 (13.5)	28 (39%)	31 (44%)
9. I would like to use the lab environment in future networking and systems administration courses	71	1(1.4%)	2 (2.8%)	11(15.5%)	23 (32.5%)	34 (48%)
10. Overall, how would you rate the lab environment	64	0	1 (1.5)	7 (10%)	27 (42%)	29 (45.5%)

(SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree)



Students' Responses and Percentages about using the Server-based Lab Environment

Responses and Percentages for Feedback Tool - Frequency (%) - 2016

Dimension	Survey Question	n	Not at all Likely									Extremely Likely
			1	2	3	4	5	6	7	8	9	10
Perceived ease of use	Q1. The feedback offering descriptions were easy to understand	51	0 0%	0 0%	0 0%	0 0%	2 3.9%	9 17.7%	11 21.6%	11 21.6%	8 15.7%	10 19.6%
	Q2. The feedback page on your VM was fast to load	51	0 0%	0 0%	0 0%	1 2%	2 3.9%	5 9.8%	7 13.7%	15 29.4%	12 23.5%	9 17.7%
Perceived usefulness	Q3. This feedback script encourages me to do my lab work	51	0 0%	0 0%	0 0%	1 2%	4 7.8%	9 17.7%	8 15.7%	12 23.5%	4 7.8%	12 23.5%
Attitude towards using	Q4. I prefer to have this feedback script with the labs	51	0 0%	0 0%	0 0%	0 0%	3 5.9%	6 11.8%	7 13.7%	5 9.8%	14 27.5%	16 31.4%
	Q5. Based on this script feedback, how likely are you to recommend it to students next semester?	51	0 0%	0 0%	0 0%	0 0%	1 2%	6 11.8%	6 11.8%	14 27.5%	6 11.8%	18 35.3%
Overall	Q6 - How satisfied are you with feedback generated from the script?	51	1 – Extremely Dissatisfied		2 - Dissatisfied		3 – Neither Satisfied nor Dissatisfied		4 - Satisfied		5 – Extremely Satisfied	
			0 (0%)		0 (0%)		3 (5.9%)		36 (70.6%)		12 (23.5%)	

Descriptive Analysis of Items Related to the Feedback Tool - 2017

Dimension	Survey Question	n	Not at all Likely									Extremely Likely
			1	2	3	4	5	6	7	8	9	10
Perceived ease of use	Q1. The feedback offering descriptions were easy to understand	44	0 0%	0 0%	0 0%	0 0%	1 2%	1 2%	12 0%	12 0%	7 0%	11 0%
	Q2. The feedback page on your VM was fast to load	44	0 0%	0 0%	0 0%	0 0%	5 10%	2 4%	1 2%	0 0%	0 0%	0 0%
Perceived usefulness	Q3. This feedback script encourages me to do my lab work	44	0 0%	0 0%	0 0%	0 0%	6 12%	3 6%	0 0%	0 0%	0 0%	0 0%
Attitude towards using	Q4. I prefer to have this feedback script with the labs	44	0 0%	0 0%	0 0%	0 0%	9 18%	4 8%	1 2%	0 0%	0 0%	0 0%
	Q5. Based on this script feedback, how likely are you to recommend it to students next semester?	44	0 0%	0 0%	0 0%	0 0%	6 12%	1 2%	0 0%	0 0%	0 0%	0 0%
Overall	Q6 - How satisfied are you with feedback generated from the script?	44	1 – Extremely Dissatisfied		2 - Dissatisfied		3 – Neither Satisfied nor Dissatisfied		4 - Satisfied		5 – Extremely Satisfied	
			0		0		4 (9%)		22 (50%)		18 (41%)	

Descriptive Analysis on Items related to the Dashboard Tool - 2017

Item	n	Not at all Likely									Extremely Likely
		1	2	3	4	5	6	7	8	9	10
1- The dashboard was easy to understand	**29**	0 0%	0 0%	0 0%	0 0%	1 3%	3 10%	4 14%	4 14%	6 20%	11 38%
2- The dashboard provides feedbacks on my learning activities and performance	**29**	0 0%	0 0%	0 0%	0 0%	3 10%	0 0%	4 14%	7 24%	5 17%	10 35%
3- I prefer to have this dashboard with the labs activities	**29**	0 0%	0 0%	0 0%	2 7%	2 7%	0 0%	3 10%	4 14%	6 20%	12 41%
4- This dashboard encourages me to do my lab work	**29**	1 3%	0 0%	1 3%	1 3%	2 7%	4 14%	4 14%	5 17%	2 7%	9 31%
5- How likely are you to recommend using dashboard in next semester	**29**	0 0%	0 0%	1 3%	0 0%	3 10%	1 3%	3 10%	5 17%	5 17%	11 38%
6- I would like to compare my performance with other students	**29**	2 7%	0 0%	0 0%	2 7%	6 20%	1 3%	3 10%	3 10%	2 7%	10 34%
7- I would like to see my rank in class using the dashboard	**29**	2 7%	0 0%	0 0%	2 7%	7 24%	3 10%	1 3%	4 14%	1 3%	9 31%

8- How satisfied are you with the Dashboard view?	**29**	1 – Extremely Dissatisfied	2 - Dissatisfied	3 – Neither Satisfied nor Dissatisfied	4 - Satisfied	5 – Extremely Satisfied
		1 3.5%	1 3.5%	8 27.5%	9 31.0%	10 34.5%

Frequencies of Responses for Evaluation of Lab Activities

Scale	item	SD	D	N	A	SA
Usefulness	1. The time I spent for the lab activity was worthwhile	0	0	3	29	41
	2. I find the lab activity useful to me	0	0	5	30	37
	3. I would like to do more of similar activities, even if it is time consuming	0	3	16	28	24
	4. The lab activity was very engaging	0	3	12	31	26
	5. The lab activity was pleasurable	0	1	25	25	20
Interaction	6. Interacting with other students helped me complete the lab activity	2	16	22	20	12
	7. I learned new concepts/skills by interacting with other students	7	13	26	15	11
	8. The lab activity encouraged me to ask questions to others	5	13	25	16	13
Competency	9. The lab activity helped me improved my problem solving skills	0	2	13	34	23
	10. The lab activity improved my technical skills and competency in the subject area	0	0	2	29	41
	11. I felt a sense of accomplishment after completing the lab activity	0	0	5	37	29
	12. I will be able to use what I learned in the lab activity in other courses or the future	0	1	8	34	29
Interest	13. The lab activity increased my curiosity and interest in this area	0	4	10	28	30
	14. The lab activity encouraged me to learn more about this topic	0	2	19	26	25
	15. I was very motivated for completing the lab activity	0	4	24	23	21
Reflection	16. The review questions were helpful to reinforce what was performed in the lab activity	1	5	22	22	22
	17. The lab activity provided opportunities to reflect back what was learned in the activity	0	1	20	26	25
	18. The lab activity promoted helpful discussions about what was performed in the activity	1	3	34	20	14
Challenge	19. The lab activity was challenging	1	9	20	27	15
	20. The activity review questions were difficult and time consuming	2	12	33	18	7
	21. The lab activity instructions were confusing	19	25	15	9	4

Frequencies of Responses for each Question in the Experiential learning stages

Sub Dimension	item	SD	D	N	A	SA	M (SD)
Concrete Experience	1. The lab activities provided me with a direct practical experience to help understand the course concepts	0	0	2	36	36	4.46 (.554)
	2. The lab activities gave me a concrete experience that helped me learn the class material	0	1	8	31	34	4.32 (.724)
	3. The lab activities presented me with a “real world” experience related to this course	0	2	9	24	39	4.35 (.801)
Reflective Observation	4. The lab activities assisted me in thinking about what the course material really means to me	1	1	16	38	17	3.95 (.797)
	5. The lab activities helped me relate my personal experiences to the content of this course	0	1	31	26	15	3.75 (.795)
	6. The lab activities aided me in connecting the course content with things I learned in the past	1	4	22	27	20	3.82 (.942)
Abstract Conceptualization	7. The lab activities required me to think how to correctly use the terms and concepts from this class	0	2	10	35	27	4.18 (.765)
	8. The lab activities caused me to think how the class concepts were inter-related	0	4	12	33	25	4.07 (.849)
	9. The lab activities made me organize the class concepts into a meaningful format	0	4	27	22	21	3.81 (.917)
Active Experimentation	10. The lab activities made it possible for me to try things out for myself	0	2	7	27	38	4.36 (.769)
	11. The lab activities permitted me to actively test my ideas of how the course material can be applied	1	4	20	24	25	3.92 (.976)
	12. The lab activities allowed me to experiment with the course concepts in order to understand them	0	1	20	24	29	4.09 (.847)

Cronbach's Alpha=.916 (No of Items=12)

Frequencies of Responses for each Question in the Student's Approach to Learning

Scale	Question	SD	D	N	A	SA
Deep Motivation	1. The lab activities gave me a feeling of deep personal satisfaction	1	4	25	30	12
	2. The lab activities helped me create questions that I wanted answered	1	4	24	31	12
	3. The lab activities made me work hard because I found the material interesting	0	6	12	34	19
	4. The lab activities was at times as exciting as a good novel or movie	9	19	23	14	6
	5. The lab activities was interesting once I got into it	0	5	11	33	22
Deep Strategies	6. The lab activities provided me with enough work on the topic so I could form my own conclusions	0	1	15	35	20
	7. The lab activities caused me to look at most of the suggested readings that pertained to the activity	5	22	20	14	11
	8. The lab activities caused me to spend time relating its topics to other topics, which have been discussed in different classes	1	19	17	22	13
	9. The lab activities allowed me to test myself on important topics until I understood them completely	0	5	17	28	21
	10. The lab activities' topics were interesting and I often spent extra time trying to obtain more information about them	3	14	26	16	13
Surface Motivation	11. For the lab activities, it was not helpful to study topics in depth because all you needed was a passing acquaintance with topics	4	22	23	16	6
	12. I was able to get by in the lab activities by memorizing key sections rather than trying to understand them	5	23	18	18	8
	13. For the lab activities, there was no point in learning material, which was not likely to be on the exam	16	28	19	4	5
	14. I did not find the lab activities very interesting so I kept my work to a minimum	21	31	10	8	2
	15. My aim for the lab activities was to complete it while doing as little work as possible	18	30	12	8	4
Surface Strategies	16. The lab activities suggests the best way to pass exams is to try to remember answers to likely test questions	20	23	17	7	5
	17. I believe that the instructor should not expect me to spend significant amounts of time on the lab activities if it is not on an exam	20	27	18	2	5
	18. For these lab activities, I restricted my study to what was specifically required as it was unnecessary to do anything extra	18	22	14	13	5
	19. For the lab activities, I learned things by going over and over them until I knew them by heart even if I did not understand them	12	26	22	7	4
	20. For the lab activities, I only applied what was given in class or on the course outline	10	17	22	15	8