

The Effectiveness of Using Virtual Laboratories to Teach Computer Networking Skills in
Zambia

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ABSTRACT

The effectiveness of using virtual labs to train students in computer networking skills, when real equipment is limited or unavailable, is uncertain. The purpose of this study was to determine the effectiveness of using virtual labs to train students in the acquisition of computer network configuration and troubleshooting skills. The study was conducted in the developing country of Zambia, where there is an acute shortage of network lab equipment. Effectiveness was determined by the transfer of skills learned in a virtual lab to a real lab. A two stage true experimental design, that compared the proficiency of randomly assigned experimental (virtual-lab) and control (no-virtual-lab) groups, was used to determine effectiveness ($N = 56$). In the first stage, the virtual-lab group practiced in a virtual lab while the no-virtual-lab group did not. Both groups were subjected to a lab test where the speed and accuracy of network configuration and troubleshooting of real equipment was measured, prior and after treatment. In the second stage, both groups practiced using real equipment and the speed and accuracy was again measured. An independent t-test was used to determine if there was a significant difference in the final performance between the two groups. It was found that there were significant differences between the groups in the configuration time ($p = 0.011$) and troubleshooting time ($p = 0.03$), favoring the virtual-lab group. On the other hand, there were no significant difference in configuration accuracy ($p = 0.06$) and troubleshooting accuracy ($p = 0.440$) between the two groups. In addition, there was positive transfer of training from the virtual lab to the real lab for configuration accuracy, configuration speed, troubleshooting accuracy and troubleshooting

speed. There was also evidence that students showed performance gains both in using virtual and real labs by comparing their pre-test and post-test results. From the results, there is evidence that the use of virtual labs contributes positively to the transfer of practical computer networking skills from the virtual to the real lab environment. Hence, virtual labs were found to be effective in the teaching of computer networking skills relating to configuration and troubleshooting.

DEDICATION

I dedicate this work to my Mom and Dad (deceased) for opening the doors of education for me.

I also want to dedicate this work to my wife Dana and son Chaswe for your encouragement, support and putting up with the long hours.

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CHAPTER 1 - INTRODUCTION

Laboratory sessions in computer networking courses are an essential part of training. They provide hands-on experiences that allow students to learn the necessary skills required to manage, configure, troubleshoot, and repair real computer networks (Anisetti et al., 2007). Laboratories also provide an opportunity for students to practice and acquire skills on real network equipment (Feisel & Rosa, 2005).

Unfortunately the equipment needed to perform hands on labs is not always available. In Zambia, the offering of computer networking technician and engineering programs in higher education institutions is limited because of the lack of capacity for providing laboratory sessions (Kessy, Kabemba, & Gachoka, 2006). According to the Zambian Ministry of Communication and Transport (2006), this lack of capacity is manifested by an extreme limit of physical network equipment and laboratory space.

Students enrolled in computer networking courses, just as in any other engineering discipline, have to attain competences that will prepare them with skills relevant to the workplace in addition to understanding the underlying principles that govern computer networking (Anisetti et al., 2007). During training, students must acquire an intuitive sense of the physical and functional nature of computer network infrastructure. Laboratories are therefore an essential part of any computer networking course. Unfortunately, the amount of time students have access to physical laboratories is limited by the cost and availability of equipment (Wolf, 2010).

Problem Statement

Virtual labs have been suggested as a way to alleviate the laboratory capacity problem by allowing students to practice critical networking skills in a virtual environment when real

physical equipment is unavailable (Wolf, 2010). Virtual laboratories have also been found useful in distance and computer assisted instruction in disciplines that require students to learn practical skills in addition to theoretical knowledge (Striegel, 2001). A number of reasons have been advanced why virtual labs are useful. These include; remote access for distance education, low cost, reliability, security, flexibility, and convenience to the student (Auer, Pester, Ursutiu, & Samoila, 2004). However, doubts on the pedagogical effectiveness of virtual labs have been raised (Corter, Nickerson, Esche, Chassapis, & Ma, 2007). It has been pointed out that the ultimate objective of the laboratory is to give students real world practical experience transferable to the work environment (Balamuralithara & Woods, 2007). The debate over the effectiveness of using virtual labs in the training of practical skills remains unabated and unresolved (Lindsay & Good, 2005; Ma & Nickerson, 2006).

The effectiveness of using virtual labs to train students in computer networking skills when real equipment is limited or unavailable is uncertain (Anisetti et al., 2007). This study was conducted to examine the effectiveness of using virtual labs in training students in computer networking skills. More specifically, the effectiveness of using virtual labs to train students in the acquisition of computer network configuration and troubleshooting skills was performed using quantitative methods. The study was conducted in the developing country of Zambia, where there is a real shortage of real computer networking equipment while personal computers are becoming more readily available.

Background of the Problem

A virtual lab is an interactive simulation of a real lab (Ma & Nickerson, 2006). A simulation is a dynamic model of a natural or engineered system that students can interact with (Anisetti et al., 2007). Simulations are based on the implementation of mathematical or logical

models of a real physical system in a computer, using programming techniques. For example, Cisco's Packet Tracer[®] is a network simulation tool used to teach students how to configure, troubleshoot, and design computer networks (Goldstein, Leisten, Stark, & Tickle, 2005). A network virtual lab has, at its core, a simulation engine that mimics the physical and logical behavior of network equipment. Students interact with the virtual equipment through a computer interface. The response of the virtual equipment is designed to be as close to the real systems as possible.

Pedagogical Debate

The question of the effectiveness of virtual labs in promoting student learning remains unresolved. Ma and Nickelson (2006), in a comparative literature review of virtual and hands-on labs, made the observation that:

...debates over laboratory technology have continued over the years without any sign of abating. Our general conclusion is that researchers are confounding many different factors, and perhaps over-attributing learning success to the technologies used. There is much in the literature to suggest that both students' preferences and learning outcomes are the result of many intertwined factors. Thus, it is sensible to suggest that researchers more carefully isolate and study the different factors which might interact with laboratory technology in determining educational effectiveness. (p. 13)

As previously mentioned, supporters of virtual labs have alluded to several advantages for using them. A major attraction is cost reduction, which can be attributed to the minimizing and sometimes total elimination of having to buy expensive equipment and software (Corter et al., 2007). In addition, virtual labs can free up physical laboratory space as the components of the physical lab are replaced by a server or a personal computer. Flexibility is achieved by the

disassociation of the laboratory activity from schedules that logistically require students, teachers, and lab assistants to be in the same time and space. Students can perform laboratory assignments on their own schedule and from remote places. In addition, savings in time consumption for the student and the teacher are possible due to the removal of setup and teardown time of the laboratory session. This allows for more time for design, experimentation, and troubleshooting practice.

Another limitation of physical labs is the inability for students to be given access to networks that are sensitive to security breaches or down time (DeLooze, McKean, Mostow, & Graig, 2004). Failure or a breach of security of operational networks could be disastrous for an organization. Therefore, network administrators fear allowing students to learn on real operating networks. Practice on real systems is also limited by the difficulty of mounting complex physical labs in a real laboratory. Simulated networks on the other hand, can be as complex as the lesson requires without any risk to the institution (DeLooze et al., 2004).

Some of the advances that have facilitated a richer and realistic simulated experience of the virtual lab include the following:

- High bandwidth Internet,
- Ubiquitous access to the internet,
- Powerful PC processing power,
- Rich Multimedia applications,
- Interactive tools, Flash®, HTML 5 etc.
- Availability of cheap or free open source and proprietary software.

(Duarte et al., 2008)

Despite all the accolades of the virtual laboratory, there have been questions raised by some about the real pedagogical value of using virtual labs (Lindsay & Good, 2005). Opponents point out that all the advantages allude to refer to efficiency, convenience, and cost of using virtual labs but do not address the core objective of the laboratory, which is its effectiveness in helping students learn practical skills. It is felt that in order to get a deep understanding of the basis and limitations of theory, real observations through contact is needed. “Engineers need to have contact with the apparatus and materials they will design for and that labs should include the possibility of unexpected data occurring as a result of apparatus, problems, noise, or other uncontrolled real-world variables” (Corter, Nickerson, Esche, & Chassapis, 2004, p. TIA-1). In addition, some have argued that when executing hands-on labs, students can access information that may not have been part of the original intention of the laboratory. Such encounters would be missing in the idealized world of the virtual lab. Another deficiency of the virtual lab is the seemingly absence of the attainment of psychomotor skills when using virtual labs (Feisel & Rosa, 2005). It is pointed out that hands-on labs give students sensory and situational awareness which a virtual environment cannot reproduce (Corter et al., 2007). Some researchers refer to this as the authenticity of the education experience (Petraglia, 1998). An experience in an artificial environment is considered to be authentic if the learner performs cognitive processes that they would go through in a real environment. These cognitive processes link their virtual lab experiences to experiences in the real world. This in turn helps build on their existing mental schema or model of the system under investigation. Skeptics of virtual labs believe that the lack of real physical contact leads to deficiencies in the attainment of key competencies that are necessary to operate in a real environment. The question that arises then is, can practice on

virtual equipment in a virtual lab have a positive additive contribution in a student's path to proficiency in a skill?

Purpose of the Study

The study was conducted to answer the question of whether time spent training in a virtual laboratory has a positive additive contribution to the acquisition of practical skills needed in computer networking. Specifically, the study was conducted to determine the effectiveness of virtual labs in the transfer of computer networking skills to real hands-on labs.

Research Questions

1. Is there a significant difference in the accuracy of configuring real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and students who did not practice in a virtual lab prior to practicing in a real lab?
2. Is there a significant difference in the time taken to configure real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and students who did not practice in a virtual lab prior to practicing in a real lab?
3. Is there a significant difference in the troubleshooting accuracy of real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and students who did not practice in a virtual lab prior to practicing in a real lab?
4. Is there a significant difference in the time taken to troubleshoot real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and students who did not practice in a virtual lab prior to practicing in a real lab?

Null Hypotheses

1. There is no significant difference in the accuracy of configuring real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and those who did not practice in a virtual lab prior to practicing in a real lab.
2. There is no significant difference in the time taken to configure real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and those who did not practice in a virtual lab prior to practicing in a real lab.
3. There is no significant difference in the troubleshooting accuracy of real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and those who did not practice in a virtual lab prior to practicing in a real lab.
4. There is no significant difference in the time taken to troubleshoot real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and those who did not practice in a virtual lab prior to practicing in a real lab.

Overview of Research Design

A quantitative two stage pure experiment method was used to conduct this study. The pure experimental method is considered to be the most powerful empirical method in comparative studies (Ross and Morrison, 2004). The use of random assignments of participants to different groups, as prescribed in this method, insures that confounding variables that may arise due to biases in the population are statistically eliminated. In this study, which was conducted at the University of Zambia, a two stage true experimental design that compared the proficiency of randomly assigned virtual-lab and no-virtual-lab groups was used (N = 56). Before the training commenced both groups were subjected to a pre-test on real equipment. In the first stage, the virtual-lab group practiced in a virtual lab while the no-virtual-lab group did

not. Both groups were then subjected to a lab test (post-test), where the speed and accuracy of configuration and troubleshooting was measured. In the second stage, both groups practiced on real equipment and the speed and accuracy was again measured. An independent t-test was used to determine if there was a significant difference in the final performance between the two groups. Students in the no-virtual-lab group then practiced in the virtual lab. This insured that all the students had the chance to get the benefits of both methods in compliance with Internal Review Board (IRB) requirements. In addition, this insured that students got comparative experience of the two lab environments.

Students' proficiency in acquiring routine networking skills was measured by their ability to efficiently and correctly configure real networking equipment. The acquisition of adaptive skills was determined by students' ability to use innovation in solving problems that arise while troubleshooting real network connectivity outages. To this end, the accuracy and the time it took to complete the configuration and troubleshooting tasks were measured in the pre-test and post-test. Transfer was determined by the extent to which prior training in virtual labs contributed to speed and accuracy of completing tasks using the real equipment.

The instrument for the lab test was based on a key competency list recommended for the CISCO® certification lab exam used for industrial certification in computer networking. Industrial certifications are considered to be benchmarks of the competencies that training for the workplace is supposed to produce.

Significance of the Study

Empirical investigations which are used to eliminate confounding factors are rarely found in this field (Ma & Nickerson 2006). The vast majority of the work has been on the design and development of virtual labs and their usefulness in reinforcing theoretical understanding of

physical and engineered models (Ma & Nickerson 2006; Lee, 1999). Studies of the acquisition of job transferable practical skills in a virtual lab are generally missing in the literature. There seems to be a divide in the educational and engineering communities on the focus of using technologies in teaching engineering. Engineers seem to have the “if it can be done through technical innovation then let’s go ahead and do it” (Lindsay & Good, 2005). There is a lack of concern for a systematic and rigorous analysis of the educational claims that these methods are purported to solve. Instructional designers on the other hand are concerned about the quality of technology based solutions to education.

An investigation of the effectiveness of virtual labs in the learning of computer networking skills is important for several reasons:

1. The question of the effectiveness of using virtual labs as a practical technology remains unresolved and contentious despite their growing usage. It is hoped that this investigation, which is confined to a clearly demarcated domain of skills training, can shed light on this issue. In conducting the investigation, empirical methods, which are widely desired but rare in the literature, are used.
2. A similar study on the effectiveness of transfer of configuration and troubleshooting skills in computer networking has not been conducted.
3. There is a need for mass education of competent computer networking engineers in Zambia. The use of virtual labs is one of the solutions that could reduce the costs of mounting training programs in this profession. However, it is important that in this endeavor the effort is not undermined by providing training that may be ineffective.

Theoretical Framework

Laboratory activities for teaching practical skills are essentially a form of experiential learning (Abdulwahed & Nagy, 2009). In experiential learning students learn by actively interacting with their environment as opposed to theoretical classroom learning. Kolb (1984) described experiential learning as a cyclic process of gaining concrete experiences, observing and reflecting, forming abstract concepts, and testing these concepts in new situations. Learning of skills often involve practice, which essentially is a feedback learning process that requires experience through active interaction, internalization, readjustment, and testing (Ericson, 1993). Of particular interest to this study is whether experiential interaction with a proxy reality such as a virtual lab is effective in teaching target skills. Can experience in a virtual lab be transferred to the real lab?

Virtual labs are essentially synthetic environments with attributes that include interactivity and real time feedback (Kozma, 2000; Zacharia, 2005). These attributes make virtual labs attractive for any teaching strategy that requires hands-on practice such as vocational skills training. Practice for skills attainment involves interaction with equipment and work environment. Virtual lab activities can be considered as a form of experiential learning as they allow students to either reinforcement or discover knowledge and skills through personal interaction (Kolb, Boyatzis, & Mainemelis, 2001).

Effectiveness of using virtual labs is dependent on the transfer of skills from the virtual to the real lab (Morrison & Hammon, 2000). Transfer of skills from the virtual lab to the real lab is dependent on the authenticity of the learning experience (Jonassen, 2000). Authenticity of learning is the extent to which interaction within the virtual environment is cognitively equivalent to interaction in a real environment (Jonassen, 2000). Learners engaged in authentic

learning perform cognitive tasks that make meaningful connections to real experiences (Petraglia, 1998). Cognitive processes include information processing, inductive and deductive reasoning, executive control, and procedural action (Burton, Moore, & Magliaro, 2004). To gain expertise in a technical skill, the learning environment must provide instances that contribute to a students' ability to recognize critical cues for action which they can act on. This is often referred to as situational awareness (Klein & Peio, 1989). The feedback from a virtual lab must be functionally equivalent to the real lab for authentic learning to occur (Petraglia, 1998).

Assumptions

The following assumptions were made for this study;

1. The empirical method used is the most powerful method for testing effectiveness of using virtual labs.
2. The number of participants is sufficient to come to a significant result.

Delimitations

The following delimitations were made on the study;

- 1) The study was limited to the use of virtual labs in computer networking.
- 2) The participants were University of Zambia students enrolled in a course in computer networking.
- 3) The study only investigated skills training.
- 4) The study will used free virtual lab software that has already been developed and tested.
- 5) The network equipment that was used were Cisco[®] routers. These were already available in the department of computer studies at the University of Zambia.
- 6) The study controlled for most confounding explanations found in the literature, such as teaching method, learner types, prior knowledge and context

Limitations

The following limitations were faced in this study;

1. The number of participants was limited by the amount of equipment, lab space and enrolled students of the computer science students at the University of Zambia.
2. The length of the lab tests was limited by the number of equipment available.
3. The training period was constrained by the time available for students to participate in this study (two weeks).
4. In order to keep the population homogeneous, participants were drawn from students studying computer science in at the University of Zambia.

Definitions

1. Computer network - a group of computer systems and other computing hardware devices that are linked together through communication channels to facilitate communication and resource-sharing among a wide range of users.
2. Virtual laboratory – an interactive computer simulation of a real laboratory.
3. Simulation – A representation of a dynamic system using a computer program.
4. Network Configuration – assignningment of network protocol values to a network device.
5. Troubleshooting – diagnosis and repair of computer network faults.
6. Internet - a globally connected network system that uses TCP/IP to transmit data via various types of media.
7. Internet – network of networks in a wide area network.
8. Local area network – a computer network that is geographically located to a small area.

Summary

This chapter included: (a) an introduction to the study; (b) a statement of the problem; (c) a background to the problem; (d) the research questions and null hypotheses; (e) an introduction to the research methodology; (f) the theoretical framework (g) the assumptions, delimitations, and limitations of the study, and (h) definitions. The remainder of the dissertation will; (a) review the associated literature; (b) describe the research methodology; (c) present the results; and (d) make conclusions, discuss the results; and make recommendations.

CHAPTER 2 - REVIEW OF LITERATURE

The purpose of this study was to determine the effectiveness of using virtual labs in students' acquisition of fundamental computer networking skills. Over the last decade there has been a growing trend of using computer-based technologies to foster student learning (Lee, 1999). The virtual lab is one of the computer-based technology that is receiving a great deal of attention with regards to fostering student learning of scientific, engineering, and vocational skills (Cannon-Bowers & Bowers, 2007). A wide variety of virtual labs have been developed in different disciplines. They serve as teaching aids in student's acquisition of practical skills that are traditionally performed in a physical lab (Ma & Nickerson, 2006). It has been observed however that many technology based educational tools have been driven by the technology rather than by pedagogical effectiveness (Naidu, 2007). Developers of virtual labs often promote their efficiency, convenience, low cost and the pleasurable nature of the technology rather than the educational objectives of the technology (Feisel & Rosa, 2005).

It is imperative before utilization of any technology to determine that it achieves what it purports to achieve. In the case of a virtual lab, its purpose is to give students experiential interaction that will lead to learning. In career and technical education, learning is measured by the attainment of key competencies necessary for the execution of job related tasks (Gordon, 1999). Therefore, when considering the utilization of virtual labs in an educational training program for skills acquisition, their effectiveness in delivering these skills has to be determined. To address the issue of optimal use of technology, "we must consider the confluence of technology, subject matter, learner characteristics and pedagogical principles" (Cannon-Bowers & Bowers, 2007, p. 318).

In this chapter a review of literature is conducted to develop a conceptual framework that models how students learn in a virtual lab. In addition, literature related to empirical evidence of effectiveness, historical overview, skills acquisition, expertise, and transfer will be reviewed. In culmination, a research model based on the literature will be proposed.

History of the Debate on the Effectiveness of Technology in Teaching

The debate over the effectiveness of virtual labs in the training of skills is embedded in a more general debate of the usefulness of technology in teaching. The issue is whether computer aided instruction assist students to learn or are they mere popular distractions. At the core of the argument is whether the medium of instruction or the method of instruction is a key factor in student learning (Naidu, 2007).

There has been a long standing tradition of utilizing new media technology in teaching (Naidu, 1999). However questions have arisen of the real pedagogical value of these technologies (Clark, 1994). The modern debate on the effectiveness of media in learning was sparked off by Clark (1983), who argued that media does not influence learning achievement. He likened media to vehicles that deliver instruction and cannot in themselves influence learning. Clark (1983) explains:

The best current evidence is that media are mere vehicles that deliver instruction but do not influence student achievement any more than the truck that delivers our groceries causes changes in our nutrition. Basically, the choice of vehicle might influence the cost or extent of distributing instruction, but only the content of the vehicle can influence achievement. (p. 445)

Meta-analysis of the litany of media comparison studies, which pitted teaching using new media and traditional methods, either found no significant differences or favored the new media

(Lee, 1999). Clark's (1983) argument was that most of these studies ignored many confounding variables that could explain differences. Most common among these were the effects of teaching methods, content differences, and novelty effects. Poorly designed and executed experimental studies tended to produce positive effects for new media but this effect disappeared when the same instructor, content and teaching method were applied across the groups (Kulik, Kulik, & Cohen, 1980).

Failure to make a distinction between method, media and mode of content delivery is considered to be responsible for the extensive research on technology, that has yielded no significant differences or erroneously attributed media effects to learning achievement (Head, Lockee, & Oliver, 2002). It has been argued that attributes specific to a particular technology may make a classroom activity more efficient or interesting, but these do not in themselves produce better learning outcomes. For example, it has been found that computer interventions tend to produce reduction in time to complete lessons (Kulik, Banger, & Williams, 1983). The thrust of the argument is that the most important variable in the fostering of learning is the instructional methods and not media (Clark, 1994; Lockee, Burton, & Cross, 1999). In other words the instruments of delivery of instruction are limited in their effectiveness by the method of instruction.

Proponent of the effectiveness of media in learning contend that attributes of media make learning activities either more efficient or engaging and hence are more effective. Therefore, the example put forward by Clark that computer attributes do not in themselves affect learning but rather affects efficiency of students to complete tasks, is countered with the assertion that if this efficiency eventually leads to effectiveness in learning then it is an attribute that has an effect on learning. If a media attribute helps student to cognitively access concepts that may be too

complex in another format, through a form of scaffolding, then that attribute can be thought of as effective in the learning (Pea, 1985). Differences in student learning styles mean that carefully designed instruction that utilizes different methods of delivery can best be achieved by the most appropriate media. Different teaching strategies can best be delivered by leveraging attributes of media that supports the chosen method of delivery (Levie & Dickie, 1973).

The fundamental criteria of media's effectiveness in student learning, is whether it possess attributes that are relevant to learning outcomes (Dwyer & Lanverski, 1983). Rieber (1982) asserted that intrinsic media attributes that can reduce a student's cognitive distance in acquiring complex theories contribute to learning. In addition, media can allow for the representation of information in symbols such as images, graphics or sound which may be difficult to achieve otherwise (Salomon, 1990). Functional attributes of media such as the ability for students to assess their progress or pause video to assess the state of objects can enhance students' propensity to actively influence their own learning (Sinha, Khreisat, & Sharma, 2009). In essence the debate boils down to whether the emphasis of instructional design should be strategies of instruction or instruments of instruction. The coupling of the two factors with a view of achieving the most optimal outcome of the instruction is considered the best. Conventional wisdom seems to suggest that the framework of instruction design should begin with outcome objectives, which dictate the method of delivery and in turn will dictate choice of media to best achieve the chosen teaching strategy (Naidu, 2007). The appropriate use of media increases the possible delivery methods by giving the teacher options of different stimulus and learning avenues for the particular content being taught.

A study of effectiveness of media using comparison must use the same content delivery method and statistically equivalent groups in their aptitude and ability in the content area.

Therefore, it is important to isolate only those differences in achievement that are due only to using virtual labs.

Echoes of the media debate have resurfaced in the effectiveness of computer-based instructional tools, such as virtual labs, as predicted by Lockee, Moore and Burton (2001). Although this seems to be a rehashing of the debate there is room to ask whether the issues are identical in nature. Salomon (1990) makes the argument that two attributes of computer-based teaching tools are a game changer in the debate. The first of these, is the ability for student to interact with the software. The software is not a passive agent but actively responds to user action which could lead to cognitive skills. As opposed to other media, like television, computer interaction is bidirectional between the user and the computer software.

The second game changer is the concept of feedback. Salomon (1990) evokes a variation of Vygotsky's (1978) internalization theory, which states that learning involves the replication of external social interactions by internal psychological processes. Learning takes place as a result of social interaction with other people. Salomon (1990) extends this idea by asserting that this interaction does not have to be only social but with anything that gives feedback. In this vision, feedback of actions by the individual with computer software leads to internalization of the external models programmed in a computer into a student's cognitive model. Experiences with an external environment that feeds back the effect of a learners action forms the basis of experiential learning (Kolb, 1984).

Previous Research Studies on The Effectiveness Of Virtual Labs in Learning

The unresolved debate on the effectiveness of virtual labs in helping students learn can be attributed to several reasons. Ma and Nickerson (2006) in a comparative literature review, tried to determine the reasons behind the perpetuation of the debate. After reviewing the literature

they came up with several reasons. Firstly, there have been conflicting or ambiguous findings on the effectiveness of virtual labs. Secondly, there is no agreed upon definition of the virtual lab. This is attributed to the fact that the literature on virtual labs is spread across many different disciplines. Thirdly, they observed that there are no standard criteria in evaluating effectiveness. Fourthly, there are different methodological approaches in determining effectiveness. “Different approaches have been adopted for associating laboratory aims and outcomes” (Ma & Nickerson, 2006, p. 5). Lastly, the advocates and detractors have become entrenched in their views on virtual lab effectiveness.

Ambiguity of Research Findings

There have been a number of research studies that have attempted to demonstrate the pedagogical effectiveness of virtual labs in helping students learn. These studies vary in research methodology, objectives, achievement criteria, level of education, subject areas, and focus. Research methods used in these studies include both quantitative and qualitative methods. Research design using experimental, quasi-experimental, surveys, case studies, meta-analysis, and interviews are also utilized. Since this study is primarily a quantitative study using experimental methods it was important to find articles with similar research design. For the most part experimental studies are rare and even when they are available they are either quasi-experimental or infused with other methods (Ma & Nickerson, 2006).

The majority of the studies that quantitatively compared virtual labs and hands-on labs in the attainment of theoretical and practical knowledge produced no significant difference. Table 1 presents is a summary of some results.

Table 1

Quantitative Comparative Studies on Virtual Labs

Article	Field	Theoretical/Practical Knowledge	Results
Edward, (1996).	Mechanical Engineering	Practical	No significant difference
Nickerson et al. (2007).	Mechanical Engineering	Theoretical	No significant difference
Cavin, (1978)	Chemistry/Physics	Theoretical	No significant difference
Javidi and Giti (2005).	Electronics	Theoretical	No significant difference
Tanyildizi and Orhan (2009).	Electrical engineering	Theoretical	No significant difference
Akpan and Strayer (2010).	Biology	Theoretical	No significant difference
Finkelstein, Adams, Keller, & Kohl (2005).	Physics	Theory and Practical	Significant difference favoring virtual labs both on theory and practical test.
Kun-Yuan Yang and Jia-Sheng Heh (2007)	Physics	Theory and Practical	Significant difference favoring virtual labs both on theory and practical test.

Results of no significant difference are ambiguous in that they only inform us that there is no evidence of effectiveness, one way or the other. It could be that that both the virtual lab and the hands-on lab were ineffective, or they were equally effective. Favorable results for virtual labs could be attributed to variation in treatment as these studies were conducted in a classroom setting.

A number of qualitative studies using surveys or case studies have also been conducted. Karetky, Kelly and Gummer (2011) conducted a survey in which students in a mechanical engineering course were asked about their preferences between virtual labs and hands-on labs. The study concentrated on the acquisition of theoretical understanding, experimental skills and ambiguities in their knowledge. It was found that students reported gains in their theoretical understanding of the subject using both virtual and hands-on labs. Another finding was that students were able to suspend disbelief when dealing with objects in the virtual lab. Wolf (2010) using a case study found that students viewed practice in a virtual lab to have equal effectiveness in conveying content theory as the lectures. Another study that trained firemen using virtual labs found that even though there was some gains using virtual labs they were minimal over time (Elliott, Welsh, Ibeck, & Mills, 2007).

Some studies on virtual labs in skills training in computer networking have also been conducted. Anisetti et al.. (2007) conducted 2 case studies in which they used virtual labs to teach networking security, one in Italy and the other in Benin. Through direct observation, they found evidence that students using virtual labs “acquired the same or better practical skills than the ones attending traditional laboratory courses, which require access to real network equipment.” (Anisetti et al., 2007, p. 307). It was also observed that students had access to administrative privileges that they would not normally have using real labs. In addition, students collaborated on their work by sharing experiences online.

Jinhua, Weidong, and Shengquan, (2007) investigated the use of virtual lab they had developed to teach students about network traffic patterns. The study found that students had a better understanding of the intricate details of actual networking protocols after using the virtual lab. Hilmi and Jack (2010) surveyed networking students with different backgrounds to

determine their preferences between real labs and virtual labs. The survey found that learners with experiences in networking through work preferred the traditional lab, while student new to the field preferred the virtual lab.

Frezzo (2009), in a classroom based case study, using Cisco's computer network virtual lab (Packet Tracer[®]), found learners acquiring planning, implementing, and troubleshooting skills when taught in an activity-based style. In addition, students were able to develop elaborate network models in self-directed inquiry sessions. However, Frezzo (2009) also found that sometimes the effort of learning how to use the software could hinder the clarity of the objective of using virtual labs.

What is apparent in these studies is the absence of empirically measured skills acquisition and transfer. It must also be pointed out that sometimes the researchers that perform the assessments often are the same ones that developed the virtual labs, thus bringing out the issue of bias.

Non Standardized Definitions

It has been observed that part of the confusion in the evaluation of the effectiveness of virtual labs in education has been the ambiguity of its definition in different studies (Ma & Nickerson, 2006). Depending on the tradition of the discipline in which the investigation is being carried out, virtual labs have sometimes been referred to as simulations (Cavin, 1978), micro-worlds (Rieber, 1992), and synthetic learning environments (Cannon-Bowers & Bowers, 2007). Most of these terms are used interchangeably. To add to the confusion the virtual lab has to be distinguished from hands-on, remote, and computer mediated labs. It is important to have a clear and unambiguous definition of the virtual lab for this study.

A virtual laboratory is an interactive computer simulation of a real or hands-on laboratory (Ma & Nickerson, 2006). A virtual lab allows students to interact with a simulation of a dynamic and complex representation of a natural or engineered system. Virtual labs are imitations of real labs. “All the infrastructure required for laboratories is not real, but simulated on computers” (Ma & Nickerson, 2006, p. 4). At the core of this definition is the concept of simulation. Some of the literature uses the term simulation instead of virtual labs. Simulation is more of a generic term that can be interchangeably used to refer to other forms of mimicry of reality. For the purpose of this investigation, simulation is a computational rendering of a real system based on a model of the system. The behavior of the simulation is dependent on the execution of a computer program associated with an algorithm of a mathematical or logical model of the real system (Canon-Bowers & Bowers, 2007). Experts in a particular field of study develop the mathematical or logical model, design an algorithm for its implementation, and produce a computer program to execute the model. Users interact with the virtual lab through a graphical user interface that allow for manipulation of system variables. Graphics and animation are often included to allow for students to control and observe experiments conducted in the virtual labs.

Virtual environments differ from virtual labs in that they refer to simulations of environments rather than a laboratory. Laboratories, whether virtual or real by their very nature are controlled environments in which some of the variables affecting the phenomena under investigation are controlled or eliminated. Virtual environments on the other hand usually refer to situations where many interacting objects and variables are at play. For instance a virtual environment may include other people, weather and natural settings. A virtual lab is often restricted to a setting that is more confined to a controlled environment.

Micro-worlds are simulations based on “a simplified or constrained representation system making it easier for learners to focus on the most important principles and processes to be learned”(Dabbagh & Beattie, 2010, p. 3). Micro-worlds are similar to virtual labs in that both are simulations with the difference probably being that they come from the different disciplines of education and engineering respectively. In this study literature that uses micro-worlds, simulations, simulated learning environments, virtual environments, and web labs will be treated as virtual labs if they meet the criteria of the virtual lab definition.

Virtual labs differ from hands-on labs in that hands-on labs entail a real physical investigation process (Ma & Nickerson, 2006). All the equipment used in a hands-on lab is physically setup and students are physically present in the lab.

Unclear Outcomes

It has been previously stated that there is a variability of the targeted outcomes of the different research studies. Most of the studies reviewed measured students’ theoretical understanding of the content after performing on virtual labs. This somehow defeats the purpose of the lab which is to give students practical skills. In science-based disciplines, practical skills refer to conducting experiments to test or verify theory (Cavin, 1978). For engineers practical skills involve experimentation as well as equipment operator skills (Edward, 1996).

When determining the effectiveness of virtual lab training on technical skills it is necessary to consider the performance objectives of the training. When used in training in career and technical education programs, virtual labs are primarily used to develop student proficiency in the execution of practical skills (Anisetti et al., 2007) The training must equip students with the ability to perform career related tasks that students may encounter in a real work environment. For example, when training a computer network technician, the training must equip

the trainee with the skills that will enable them to configure, manage, troubleshoot, and monitor a real computer network (Anisetti et al., 2007). Understanding the conceptual and theoretical functionality of computer networks is necessary but not sufficient (Frezzo, 2009). Students must be able to perform hands-on tasks (Frezzo, 2009). Therefore, any research that tries to empirically prove the effectiveness of virtual labs on skills acquisition must measure transfer of skills from the virtual labs to the targeted real lab. Students must demonstrate that they can perform hands-on tasks correctly and efficiently on real equipment after they have performed in the virtual lab. In the case of computer networking, students trained in virtual laboratories must show that they are capable of configuring and troubleshooting computer networks on real equipment to a targeted level of proficiency.

How Virtual Labs Function

Before delving into how virtual labs affect learning, a brief description of how virtual labs function is useful. At the core of a virtual lab is a computer simulation, which is a computer program executing an algorithm of a dynamic model of a natural or engineered system (Canon-Bowers & Bowers, 2007). A model is a mental representation of a real system in terms of variables or concepts and their relations that can be used for predicting system behavior (Jong & Van Jong, 2008). Most scientific models of a dynamic system are represented in mathematical formulae in the form of differential equations (Rieber, 1992). The more complex a system is, in terms of its dynamic behavior, the more complex the associated differential equations become. Mathematical representation becomes difficult to mentally process when the number of variables and the number of interacting objects in the system become too many. In addition, some systems can only be represented using non-linear differential equations which are notoriously difficult to analyze due their chaotic nature. Therefore, mathematical modeling of systems such as the

weather, financial, biological, social, or engineered machines is difficult using mathematical models. These systems are messy and their models are difficult to understand by experts and even more difficult to learn by a novice. Other representation methods such as pictorial, graphical or video allow for a visualization of system behavior but they tend to be one dimensional, static, and uni-directional. Simulations on the other hand are dynamic systems that make the subject matter come alive (Lee, 1999). A simulation therefore can be thought of as an externalization of a mental model to a dynamic computer model of a system. Experts in a domain of knowledge develop a working algorithm of the model. The algorithm is coded into a program, packaged into software, and executed (Sinha et al., 2009). If the simulation output is an elaborate visual animation it may give the user the experience of a synthetic sense of reality (Rieber, 1990).

Simulations differ from other modeling mediums in four ways. Firstly, simulations are dynamic (Rieber, 2005). Simulation allows the user to observe a system over time and sometime in real time. Secondly, simulations are lived environments (Corter, et al., 2004). An observer does not usually see the underlying model of the system but rather the effects of the interactions of the system in forms of observable outputs. If the outputs are a form of moving images and sound, such as in games, the individual may feel that they are in a synthetic or virtual world. It is this experiential and immersive component of simulations that makes them attractive for teaching scientific and engineering disciplines. Thirdly, simulations are interactive (Rieber, 2005). For most education simulations, the user is not passive but can directly manipulate and interrogate objects and variables of the simulation. Fourthly, simulations produce feedback. Action by the user allow for changes in the system that can be observed (Rieber, Smith, Al-Ghafry, Strickland, Chu, & Spahi, 1996). The simulated environment reacts to user actions by

changing system state, which is converted into observable feedback that a user can sense. The user can then use this feedback to infer how the system functions and therefore making their own mental model of the system.

How Do Virtual Labs Help Students Learn?

From an education perspective, these four features create an opportunity for using simulations in an experiential mode. Some have suggested that for virtual labs to effectively spur learning students must undergo an authentic learning experience (Canon-Bowers & Bowers, 2007, p. 322). An authentic learning experience allows students to make a meaningful connection with their previous experiences. The authenticity of the learning experience in a virtual lab is dependent on the extent to which the interaction within that environment causes learners to engage in cognitive processes that are similar to those evoked by interaction with the real environment (Jonassen, 2000). According to Canon-Bowers and Bowers (2007, p. 322), the perceived authenticity of the virtual laboratory directly impacts its effectiveness. Authentic instruction does not necessarily have to be developed around real world tasks such as those in a real lab, but can be developed in a virtual lab as long as the cognitive processes that the learner engages allow for a meaningful connection to real experiences (Petraglia, 1998). The virtual lab therefore, can be effective if it gives students access to learning situations that provide challenges that are similar to those encountered by experts.

The authenticity of a virtual lab is contingent on the degree of simulation fidelity (Cannon--Bowers & Bowers, 2007). Fidelity is the extent to which the underlying model of the simulation faithfully represents the actual phenomenon it is representing (Andrews & Bell, 2000). If the virtual lab is simulating an aircraft, for instance, the fidelity of the simulation is the extent to which the underlying model produces virtual flying behavior similar to that of a real

aircraft. Of interest here is the virtual learning activity to spur the transfer of skills and knowledge attained in the training based on the virtual lab to actual operational skills of the real lab (Andrews & Bell, 2000). Acquisition of skills to operate real equipment is dependent on the virtual lab providing accurate feedback through fidelity of function (Jacobs, 1975). The feedback has to provide action cues that are similar to those who would be encountered in real situations (Issenberg, et al., 1999). Incorrect feedback from the virtual lab could lead to negative transfer, a situation in which the training actually does more harm than good in skills transfer. Transfer is therefore dependent on contextual learning. The virtual environment must be of sufficient situational detail to allow learners to make an imaginative leap to the real situation with minimal cognitive effort (Schwartz, Bransford, & Sears, 2005).

Theoretical Framework

The utilization of laboratories for learning is based on the underlying principle that learning is best attained through experience. Experiential learning asserts that active involvement enhances student learning (Oregon Technology in Education Council, 2007). Kolb (1984, p. 38) defined learning as “the process whereby knowledge is created through the transformation of experience”. According to experiential theory, learning occurs when concrete experiences, through direct sensory observation of the environment, are connected to previous experiences through reflection.

Experiential learning in its modern form is firmly rooted in constructivist theories of learning (Kolb, 1984). However, this is not a new idea as there has been a long tradition for advocacy of learning through experience in educational philosophy. Experience as a basis for learning about the nature of things can be traced back to the ideas of Locke, Lewin, Dewey, and Piaget (Kolb, 1984). Locke asserted that the only knowledge that humans can have is based on

experience (Locke, 1690). The resulting philosophy of empiricism asserted that science is a process of making physical sensory observation of the natural world through experiments, to test hypothesis and theories.

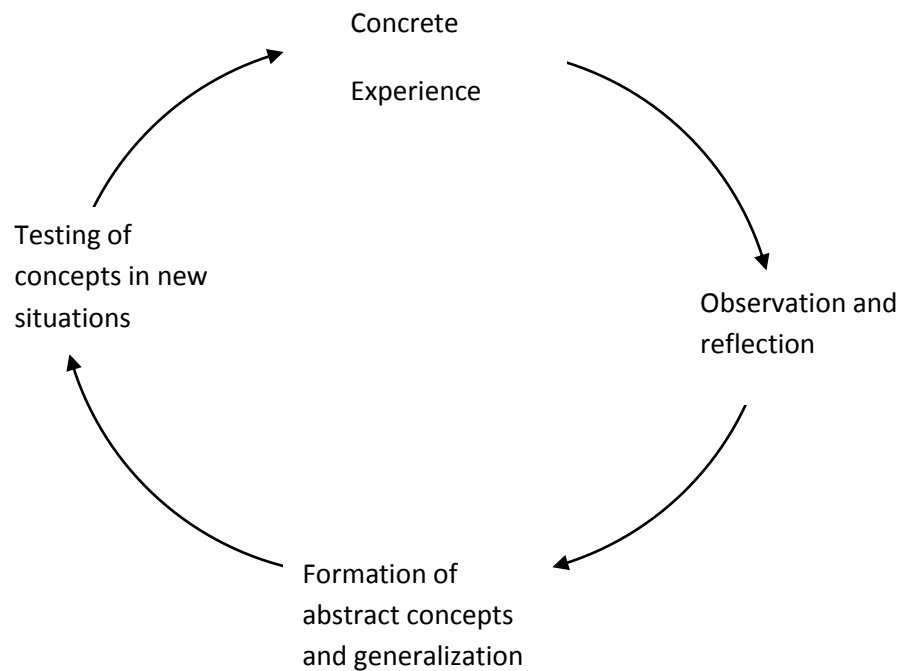


Figure 1. Lewinian experiential learning model. Adapted from “Experiential learning: Experience as the source of learning and development” by Kolb, 1984, Prentice Hall. p 21.

Lewin used the concept of feedback to develop a theory of social learning and problem solving (Kolb, 1984). Figure 1 graphically represents the model. In his model, learning is a continuous process of goal directed action and evaluation (Kolb, 1984). Concrete experiences are gained through sensory observations, which are reflected upon to form abstract concepts and generalizations. The generalizations are then tested in new situations by comparison of observed and predicted sensory outcomes. In this paradigm, action is evaluated through observation and the results are used to make corrective adjustments for future action. Lewin believed that an

imbalance between observation and action leads to ineffectiveness of the learning process (Kolb, 1984). Action without observation and reflection is unproductive as it leads to errors. On the other hand, too much observation and conceptualization without action, to test the concept, is also counterproductive. The aim of the laboratory method is to integrate these two processes for optimal learning.

John Dewey (1938) developed a similar but more detailed learning model to Lewin's (Kolb, 1984) model. His model explicitly mentions the developmental transformative nature of feedback. Sensory feedback in his model changes the learner's impulses, feelings, and desires of concrete experience. Dewey explains:

The formation of purposes, is a rather complex intellectual operation. It involves (1) observation of surrounding conditions; (2) knowledge of what has happened in similar situations in the past, a knowledge obtained partly by recollection and partly from the information, advice, and warning of those who have had a wider experience; and (3) judgment which puts together what is observed and what is recalled to see what they signify. A purpose differs from an original impulse and desire through its translation into a plan and method of action based upon foresight of the consequences of acting under given observed conditions in a certain way (Dewey, 1938, p. 69).

Meaning of new information is dependent on the interaction of the new information with previously retained experience. The cycle of learning is a directed process in which the next cycle is dependent on the learner's impulse after the previous cycle.

Piaget's model of learning is based on a developmental process from childhood to adulthood. Piaget (1952) makes the distinction between a child's view of the world, which is essentially a concrete view, to that of an adult which incorporates abstract conceptualization.

Piaget's learning model is also based on the interaction between the individual and their environment. When information is received from the external environment it can either be accommodated or assimilated into a person's existing schema. Accommodation is the process in which the existing schema (or model) is altered to explain the new information, which does not fit in the existing schema. Assimilation is the process in which the new information is fit or assimilated to an already existing schema (or model). In laboratories, accommodation is when the results do not fit the hypothesis and an alteration to the hypothesis is made. Assimilation is the when the results fit expectations and therefore assimilated to the existing schema (or model).

External Feedback

External feedback can be distinguished by how it is utilized. Feedback can be used to inquire and explore natural or constructed environments. In this mode, the learner directs their own exploration of a particular environment or domain by trying out things and seeing what happens. This can be referred to as positive feedback as the action output is used to further explore the environment and construct a schemer. Negative feedback is used for reinforcement, validation or for attainment of precision (Ericsson, 1993). Reinforcement helps in the student getting an intuitive feel of an external objects behavior. Validation is the confirmation of internally held convictions by checking if they can predict external behavior. In scientific experiment, theories are tested by hypothesizing the outcome of action and checking the validity of the hypothesis through observation (Kolb, 1984). Galileo's famous experiment at the tower of Pisa is an example. The theory was that objects of different weights fall at the same rate of acceleration. Dropping the objects from the tower and measuring the time when they land is a form of feedback that validates the theory. Feedback for precision is used for attainment of a mental or physical skill. In this mode the learner deliberately repeats an action with the objective

of gaining precision (Ericsson, 1993). Physical control such as in sports often requires feedback that has an action, observation, evaluation and adjustment cycle. Continuous repetition through practice or rehearsal eventually leads to proficiency.

Internal Feedback

Internal feedback can be thought of as internal visualization of the external world or mental simulation. Neurological research in motor skill acquisition has shown that mental simulation of action tends to improve performance (Grèzes & Decety, 2001). Computer simulations can therefore be thought of as the externalization of mental simulations. Limitations of internal memory to sustain and incorporate a multi object dynamic system using internal mental simulation make computer simulation attractive for research. The formulation of the algorithm for computer simulation requires continual referencing of the internal schema and simulation. In the case of instruction, students confronted with an abstract subject such as computer networking have trouble visualizing the interactions and processes of these systems simply from a theoretical lesson (Frezzo, 2009).

Educational Claims of Virtual Labs by Advocates

A number of attributes and instructional factors are considered to have beneficial impact for learning while using virtual labs.

Feedback

Feedback is considered to be the most important feature of the virtual lab (Issenberg & Scalese, 2008). Proponents of the utilization of virtual labs have pointed out that the experiential nature of virtual labs makes them useful in student centered instructional methods (Pappert, 1980). In student centered instruction, learners are encouraged to construct their own knowledge through interaction with their environment or society. In this method of learning the

learner performs most of the educational activity. Therefore, there is an emphasis on the external feedback in learning activities. The positive feedback is used for discovery and exploration, whilst the negative feedback for precision, reinforcement, mastering or zooming into a particular phenomena. Students who learn by performing tasks rather than overt instruction are believed to have a deeper and broader understanding of phenomena rather than superficial memorization of facts, formulas or rules (Papert, 1980).

Several studies in the teaching of science have shown that allowing students to “fool around” with their environment in the virtual lab led to gains in their theoretical understanding. In quantitative comparison studies students who performed their lab in a virtual lab tended to experiment with different configurations of the experimental objects in a lab and this eventually showed to have a beneficial outcome in written theory tests (Milo, Christine, & Edith, 2011; Javidi, 2005).

Student engagement is an essential objective of student centered instruction. Some studies have shown that students involved in a virtual lab tended to be more attentive to the task at hand than in hands-on labs (Finkelstein, Adams, Keller, & Kohl, 2005). Virtual labs can be used to promote learner centered instruction by allowing students to actively interact with the artificial system and experiment. Goals can be enshrined in the teaching by either including constraints on the virtual lab of possible outcomes or through activity instruction (Rieber, 1992). The learner through repeated interaction with the virtual lab eventually masters its behavior. However there has been some concern that students sometimes get tied up in learning how to interact with the simulator rather than exploring the subject matter (Frezzo, 2009).

Progressive Difficulty and Scaffolding

Advocates of virtual labs advance the idea that the virtual lab can be used to allow students to learn at the appropriate level of difficulty (Rieber, 1992). Learning has often been thought of being a continuum from novice to expert (Ausbel, 1968). Instruction has to be tailored to the level that learners can understand. In subject matter that involves a great deal of abstraction of complex environments such as computer networking this can be a challenge.

Virtual labs can be used to provide learners with simplified versions of reality in order for them to cognitively digest concepts or situations they are not familiar with (Rieber, 1992). Vygotsky's zone of proximal development refers to a situation in which a learner is on the verge of understanding a concept but cannot get there without external assistance or intervention (Vygotsky, 1978, Rieber, 1992). A virtual lab appropriately set to the level of the learner could be used to allow learners to visualize a concept in action and therefore make the leap of understanding easier. This is accomplished by reduction of complexity and fidelity of the virtual lab. The external feedback in this case would be more idealized, hence devoid of noise, interference or more complex situations. In this mode, the virtual lab is based on a simplified model of behavior in which learning tasks are designed for developing learner understanding of basic concepts. Critics have pointed out that simplification of external stimuli leads students to developing an incorrect view of reality (Barnard, 1985). Gagne (1962) put the concept in formula form:

$$\text{Simulation} = (\text{Reality}) - (\text{Task irrelevant elements})$$

Practice

In skills training, progression from novice to expert is achieved through deliberate and repetitive practice in different situations (Ericsson, 1993). Virtual lab gives learners the extra

opportunity to practice giving them the chance to repeatedly traverse over the same domain of knowledge. This eventually leads to their developing a more sophisticated cognitive schema of the domain (Milo et al., 2011; Cavin, 1978; Choi, 1987; Akpan, & Strayer, 2010). In the experiential model, this is an iterative looping between the internal and external feedback loops. If a physical technique is being learnt, repetitive adjustments of action and observation via the negative feedback path is conducted through practice. In between iterations of action, internal processes of visualizing of the action, using the deductive path is recursively performed. Iteration of action and observation allows for adjustment of the internal schema of the process. Eventually the action-observation cycle leads to the learner crystallizing their situation-action responses to a few rules that allow for faster and more accurate execution by the learner (Klein & Peio, 1989).

Virtual labs are thought to contribute to this progression if the feedback that they provide is equivalent to that offered by the actual lab (Jonassen, 2000). Transfer of learning literature of flight simulator training has repeatedly demonstrated that if the simulator produces the correct cues for action, skills acquired in the simulator will be transferred to the actual aircraft (Goettl, 1993). “There have been several researches of the transfer of training value of flight training simulations, the almost universal conclusion of which are that there is positive transfer of training associated with practice in a simulator” (Jacobs, 1975, p. 3).

Learning from Failure

Virtual labs have been touted for affording students the ability to make errors in a fail-safe environment (Duarte, Butz, Miller, & Mahalingam, 2008). Beginners in any type of skills training are prone to making errors in their execution of tasks. Training must provide learners opportunities to fail and correct themselves in order to learn (Feisel & Rosa, 2005). In sensitive systems such as computer networks, learners are not given a real system to practice and fail on as

it is being used by clients (Duarte et al., 2008). In the traditional hands-on lab it can be a challenge to include learning by failure in the training for several reasons. Firstly, in systems where failure can be hazardous to humans and equipment, failure cannot be allowed (Feisel & Rosa, 2005). Students can sometimes be timid to try out things as they are made well aware of the cost of failure. Secondly, in most lab courses students do not have the chance to repeat or access the lab with the equipment (Feisel & Rosa, 2005). Access to the laboratory is bound to specific time and place. Virtual labs allow students to fail without the consequences that this engenders. Learners can correct themselves as many times as possible until they get it right. In addition, the ability to quickly configure, tear down and reconfigure systems is seen to be a factor in improving error handling skills (Feisel & Rosa, 2005).

Students training in skills that involve monitoring and maintenance of systems that require high performance reliability must attain the ability to recognize, troubleshoot, and fix faults (Mayer & Johnson, 2010). These faults may be familiar or unfamiliar to them. Training and subsequent work experience should be designed to expose students to as many failure situations as possible (Kluge et al., 2010). This is referred to as routine or temporal transfer of skills (Arthur, Bennett, Stanush, & McNelly, 1998). Handling of unfamiliar situations due to prior exposure of similar ones in training is referred to as adaptive transfer (Kluge et al., 2010).

According to Kluge (2010):

In contrast to temporal transfer, adaptive transfer requires the invention of new procedures based on acquired knowledge and the mindful processing of learning experiences in order to build up a mindful abstraction and a deeper conceptual understanding of the target domain” (p. 329)

Computer networking technicians have to routinely correct system faults. Training therefore, must build learner capacity to troubleshoot both familiar and unfamiliar system failures. Access to real equipment and failure situations can be a bottle neck in this endeavor. Virtual labs have been shown to be a way out of this problem by providing an environment that is safe to fail in, accessible, and quick to reconfigure (Hutchinson, 2007).

Access to Internal State Variables

Positive learning outcomes have been reported when learners are allowed to visualize the internal process of dynamic system (Finkelstein, Adams, Keller, & Kohl, 2005). It is possible to include in the virtual lab, the ability to measure things that are not readily possible in a real experimental setup. For instance, the internal temperature at the core of an object may not be measurable in real life but available in a virtual lab. There is also the possibility of incorporating time and spatial instruments in a simulation such as slow motion or examination of internal structures of the objects under consideration. Pictorial and data manipulation is sometimes incorporated in a virtual lab..

The ability for students to see the inner workings of a system and be able to change or alter conditions, make virtual labs powerful tools for internal schema creation for students (Milo et al., 2011). The virtual lab can be paused, rewound, or stopped at any particular time to examine the state of the system. In engineering, it has become standard practice to design virtual systems of machines before creating the real ones (Hutchinson, 2007). To avoid overwhelming a beginner with too much information, a virtual lab can be designed to offer a simplified version of the system. More complex versions can be used to allow the student to cognitively build a more complex sense of the system behavior.

Support of Different Instruction Delivery Modes

Some researchers have advanced the idea that a good virtual lab can be used to teach in different training modes, to different learner types, and for varying instructional objectives (Rieber, 1992). Although it was earlier stated that virtual labs are useful for teaching in the constructivist mode, they can also be used in the behavioral mode. Rieber (1992) gave both a theoretical and empirical foundation of how this can be accomplished. In the behavioral mode, learning is conducted in an instructor lead fashion. The instructor articulates the objectives, activities, and the outcome expectations of a lesson. Often this is manifested in using the lecture method to convey information. The criticism of this mode of instruction is that the student is passive in this mode of instruction. Therefore, students find it hard to retain the information as they do not develop a deep understanding of the material. On the other hand, behaviorists have argued that self directed learning proposed by constructivists is inefficient and lacks clear goal definition and attainment.

In science, engineering, and vocational training, laboratory sessions have always been included to bridge the gap between theory and practice (Feisel & Rosa, 2005). However, there are still issues of how laboratories are conducted. In an instructor led mode typical labs usually require following strict procedures and directions, supported by prescribed theory to achieve predetermined objectives (Feisel & Rosa, 2005). Often this is important to attain prescribed standards of learning criteria. In the constructivist mode, learners are encouraged to set their own direction and pace of learning. It is felt that the one size fits all mentality of behavioral instruction leads to students going through the lab work in a routine ritualistic manner that in the end does not contribute to learning. In essence the issue boils down to preference for structured and flexible learning models. Rieber (1992) pointed out that the virtual lab can be used for

objective oriented learning whilst giving learners the opportunity to discover principles on their own. “The compromise is reached largely through a guided-discovery orientation to learning in which the nature of the learning activity and experience is naturally constrained by the parameters imposed by a particular microworld” (Rieber, 1992, p. 94). Depending on the performance objectives, virtual lab training should be flexible by including instructor led formats, small group tutorials and independent study.

Virtual labs can also be used as an intermediate strategy between pure theory and practice (Akpan & Strayer, 2010). During lecture sessions a simulation can be used to allow students to visualize a principle in action either as a demonstration or part of an activity. For example, students learning the function of a piston engine could go to a website view a simulation of the engine in action. An interactive simulation or virtual lab can allow students to change parameters such as the amount of fuel and air mixture and observe the effect immediately. This is difficult to do with real equipment.

Arguments Against the Use of Virtual Labs

One of the contentious issues in the debate over the effectiveness of using virtual labs in place of real lab has been how realistic the virtual lab should be (Javidi, 2005). Some have maintained that to learn practical skills any substitute to the actual physical system has the inherent problem of lack of physical and functional fidelity (Anisseti et al., 2007). For instance, real observation of real physical system involves measurement of physical parameters such as temperature, pressure and many other variables. The measurement process will always produce random and systematic errors. Learners, through interaction with real systems, eventually get an intuitive sense of these errors resulting in appropriate mental adjustments. Some researchers have asserted that students who train in virtual systems do not encounter the noise and

interference that accompanies real measurement (Wolf, 2010). Therefore, they may erroneously develop a schema or model of the system that is not realistic and their reaction to the real system may be inaccurate. Learners may therefore develop a false sense of reality.

Some studies have shown that after a few runs of some virtual labs, students begin to correctly guess results of inputs to a system as they become predictable (Javidi, 2005). Learners develop a superficial reaction that may be inadequate when unfamiliar situations arise. Real systems on the other hand often produce different results at different instances of an experimental run, even if the inputs are the same. Hence, students working on a real system will be exposed to a variety of situations that may not be replicated in a virtual system.

Virtual lab proponents have argued that the level of fidelity has often not shown differences in performance of conducting practical skills. A number of low fidelity virtual labs produced satisfactory results in the performance of learners in a number of studies (Gredler, 2004; Sherperee, 2005). The virtual lab enhances the theory by giving a dynamic feel of the idealized system (Akpan, & Strayer, 2010). The simplification of the possible outcomes can be used in a positive way by using them to clearly show the phenomena without the confusing effects of noise and interference (Gagne, 1962). Sometimes “because the system under investigation is constrained in particular ways, students are able to make progress they cannot in an unconstrained environment” (Finkelstein, Adams, Keller, & Kohl, 2005, p. 7).

Another issue associated with fidelity, is the argument that virtual labs lack all the necessary sensory cues encountered in the real environment. For example, if a person is using a flight simulator on a personal computer they do not encounter the sense of acceleration, angular acceleration or altitude of the real experience (Jacobs, 1975). Someone training on such a system may not recognize and react to situations that involve such psychomotor sensory signals.

In medical training, high fidelity virtual labs are used to train clinicians in skills such as surgery, laparoscopy, cardiology, and anesthetics (Issenberg et al., 1999). It has been shown that for the purpose of training of critical skills where errors are unacceptable, the virtual lab has to have a very high functional and physical fidelity (Issenberg & Scalese, 2008). For example, skills needed in laparoscopy surgery include proficiency in ambidextrous movements with unfamiliar instruments, requiring hand eye coordination and depth perception (Issenberg & Scalese, 2008). The simulator used in this type of training is run on a dummy with an embedded microprocessor and a monitor. The end result is that practice includes psychomotor sensory information in the simulator. Unfortunately, the cost of such a high fidelity virtual lab is over \$30, 000, countering the assertion that virtual labs are cheap (Issenberg & Scalese, 2008).

Another issue with virtual labs is related to the lack of context in which they are performed (Lawrence & Jacquelyn, 1999). In real life, tasks are performed in environments that have many interacting factors that cannot be included in a virtual lab. The effects of social interaction, different equipment, and contextualized problems are missing in the virtual lab. Unfortunately this is true of all lab work.

Virtual Labs in Skills Training

Virtual labs have traditionally been used in training of skills in fields that require a great deal of safety before learners are allowed to practice on the actual real equipment. Pilot training, medical training, military equipments training, and nuclear power plant training have a long documented history in the utilization of virtual labs (Gredler, 2004). Pilots have been trained in simulators since the 1940s, well before computers were even available (Jacobs, 1975). This fact alone gives an indication that there must be some education value associated with simulation for training of technical skills. Continuous progression in computing power, lower costs, and

sophistication of programming, have made simulations accessible to other fields of study such as in science and engineering at all level of education (Akpan & Strayer, 2010).

Despite the proliferation of virtual lab software, there have been a proportionally low number of publications seeking to measure skills attainment in virtual labs (Aggarwal et al., 2007). This can be attributed to the difficulty in measuring technical skills (Aggarwal et al., 2007). However a number of studies have been conducted to measure the attainment of technical skills using virtual labs. For instance, motor skills training for surgery training has been achieved in some fields like medicine (Issenberg, et al., 1999). In another field, Elliott et al. (2007) showed that firemen could learn decision making skills in a virtual lab and showed improvements in accuracy, speed, efficiency, and planning. Furthermore, students learning electrical engineering circuit building in a virtual lab, transferred their skills to the real lab (Finkelstein, Adams, Keller, & Kohl, 2005). In pilot training, students training on a PC showed transfer of skills to the actual plane (Ortiz, 1984). In computer networking there have been some studies that have shown gains in theoretical understanding but measured skills gains have not been found in this review (Anissetti et al., 2007).

Literature related to the utilization of virtual labs in teaching computer networking was also reviewed. It was found that the majority of journal articles reported the functional and technical nature of the virtual labs but did not test these labs with students. Of the 40 papers that fit the criteria of using virtual labs for student instruction, only four tested virtual labs for effectiveness. All four papers evaluated the effectiveness of the virtual labs through qualitative methods. The explanation for the low number of rigorous pedagogical evaluation can probably be due to the fact that almost all the articles were written by the engineers that developed the virtual labs, who may have been more interested in technical functionality rather than

pedagogical effectiveness of the virtual labs. However, some useful information was gained in this literature review.

Recognition Primed Decision Model

Troubleshooting of a network requires situational analysis to diagnose and facilitate decisions on the best course of action to solve faults. Traditionally, analytical strategies have been encouraged for troubleshooting (Klein, 1993). Although these methods have been found to be satisfactory for well defined situations, when dealing with ambiguous and time pressured situations they are ineffective (Klein, 1993). Prescriptive decision strategies derived from analytical methods have been found to be inadequate in ambiguous situations because of the amount of time required to sequentially analyze a very large number of permutations that arise in such situations. A recognition prime decision model (RPD) describes how decisions of ill defined, complex, and time pressured situations are made without excessive deliberations through experience (Klein, 1993). Experience gained by a person in a specific skill domain enables their understanding “of situations in terms of plausible goals, relevant cues, expectancies, and typical actions” (Klein, 1989, p. 147). In this model, interaction with a system over time allows for a person to recognize the relevant patterns or cues signifying critical information of the state of the system (Elliott, Welsh, Ibeck, & Mills, 2007). These in turn are used to generate actions based on a repertoire of responses built up over time. When the situation is not readily recognizable or the course of action is not clear, decisions are determined by the evaluation of the system using mental simulations (Klein, 1993).

Research with chess players found that experienced players made decisions faster and more accurately than novice players. This was attributed to either expert players being better at analyzing the outcomes of different alternatives or having the ability to accurately and quickly

recognize situational characteristics (Schwartz, Bransford & Sears, 2005). With experience the novice players gained the capacity to recognize situations by comparing them to past instances of similar situations. This is analogous to how we immediately recognize faces (Klein, 1993).

Chase and Simon, (1973) studied chess and physics experts, and found that they could distinguish up to 50,000 different patterns through thousands of hours of practice.

Interest in recognition decision strategy paradigm with respect to virtual labs is spawned by the following inquiry interests;

1. Can the interaction with a virtual lab contribute to the building up of relevant cues necessary for situational recognition in real situations?
2. What is the level of functional and spatial fidelity that a virtual lab must have to adequately contribute to a learner's capacity to recognize familiar situations in the real environment?
3. Can decisions and resulting actions performed in a virtual lab contribute to the repertoire of past experiences that can later be utilized in a real environment?
4. Can failure and subsequent self corrections performed in the virtual lab contribute to proficiency in fault diagnosis and remediation strategies in the real lab?
5. What are the dangers of misrepresentation of the real system in the virtual lab on student performance in troubleshooting?
6. Do virtual labs contribute to learners developing mental simulations capabilities that can help them solve faults of unfamiliar situations?

Reviewing the literature, there is a distinct lack of empirical investigations of these issues in computer network troubleshooting. Although the research questions in this study do not specifically deal with these issues, it is hoped that this can be a baseline study for future

investigation. In this study, it is hypothesized that practice in a virtual lab has an additive experiential contribution to a learner's troubleshooting capabilities. The assumption is that if the virtual lab sufficiently presents patterns that are of relevance in the real environment students will transfer these situational experiences. Relevance does not mean that all the functional realities have to be reproduced in the virtual lab, but those who patterns most commonly encountered in troubleshooting situations should be reproduced. Learners can eventually make distinctions between departures in the virtual lab model to that of the real lab.

Transfer of Training

Transfer of training is the extent of retention and application of the knowledge, skills and attitudes from the training environment to the workplace environment (Kluge et al., 2010). Evidence of transfer from training has been recorded in several studies related to skills training (Morrison & Hammon, 2000). Clark and Vogel (1985) found that the criterion for transfer to occur was dependent on the similarity of the training to the work environment.

In career and technical education the primary function of training is that it prepares the student for the world of work. Therefore, skills acquired in training need to be specific to the requirements of real jobs in the real world. In skills transfer, theoretical knowledge is not enough for transfer to occur. Trainees must also be able to recognize situations that their acquired knowledge is applicable to (Klein, 1993). Some researchers have argued that situational awareness is probably the most important factor distinguishing a novice from an expert (Benner, 1982). Experts tend to spend less of their cognitive effort on situational awareness than novices.

Some of the literature on expertise and transfer asserts that a distinction has to be made between transfer of routine skills and adaptive skills. Schwartz, Bransford and Sears (2005) believe that routine skills strive to achieve efficiency by preparing the student to make intuitive

procedural action for tasks that are repetitive. On the other hand adaptive skills transfer, prepare students to use innovation in novel situations to complete tasks. The primary factor affecting the acquisition of routine skills is the length of time that the trainee practices (Bransford, 1999). In addition, the acquisition of routine skills is domain specific. On the other hand, the transfer of adaptive skills is dependent on a deep understanding of the main concepts of a particular domain of knowledge (Bransford, 1999).

How virtual labs are used in teaching may therefore differ depending on the aim of the training. Access and repetition of procedural routines that lead to situational awareness and intuitive action are needed when trying to achieve routine skills transfer (Ericsson, 1993). With respect to adaptive skills, the virtual lab lends itself for experimentation of many different configurations that could lead to reinforcement of the fundamental conceptual structure of the domain of knowledge. A study conducted by the department of defense found that training that engages a learner through embedding their experience in a real-world context enhanced transfer (Morrison & Hammon, 2000).

In this study, there is a slight departure in the type of transfer that is intended to be measure. Of interest in this study, is the transfer of skills from virtual equipment to real equipment. This is traditionally measured using the transfer effective evaluation method (TEE). A TEE includes a learning experiment and a transfer experiment (Morrison & Hammon, 2000). “The simplest way to evaluate the amount of learning that has taken place is to measure performance prior to training and compare it with performance measures after training has taken place” (Morrison & Hammon, 2000). Deciding whether to train students using a virtual network lab is dependent on whether training on the virtual lab equipment would reduce the amount of time needed to train on the real equipment. The learner in this scenario goes from one controlled

environment to another controlled environment. This conveniently reduces the amount of confounding factors that have to be considered in the determination of whether transfer has actually occurred.

Transfer of training in pilot training is measured by the equation:

$$T = \frac{E-C}{C} \times 100 \quad (\text{Morrison \& Hammon, 2000, p. IV 11})$$

In this equation, C is the average performance score of the control group while E is the average score of the experimental group. The experimental group performs in the virtual lab before training on the real equipment. The control group does not perform any virtual lab training before training in the real lab.

The equation will produce positive transfer if the experimental group has a mean score higher than the control group. In other words, if the experimental group's average score is greater than the control group's average score then positive transfer has occurred. Otherwise, if the reverse happens then there is negative transfer.

To fit this equation with the intended research method it is transposed. All the participants perform the same number of trials but we measure variance of their performance.

Research Model

The effectiveness of any teaching transaction in the attainment of specific performance objective is dependent on a number of factors. In this case the performance objectives are the ability to configure and troubleshoot a real computer network accurately and quickly. The intervention is the use of virtual labs as a training technology. According to Naidu (2007) other factors that often impact media related instruction include; instructional method, instructional delivery, learner types, learner prior exposure, course content and media attributes. It is often

difficult to isolate the contribution of each of these factors and sometimes the interaction between each of them is not independent or linear. For instance, learners' prior exposure to virtual labs may have a prejudicial impact on their attitude towards using them. In addition, there may be mutual dependencies in the relationships of each of these factors. For this reason it is important to use a control group and random sampling to try and reduce effects of factors that cannot be controlled for. The two groups in this study were exposed to equivalent instructional content, method and delivery. The schematic below shows the research model that will be used in this study.

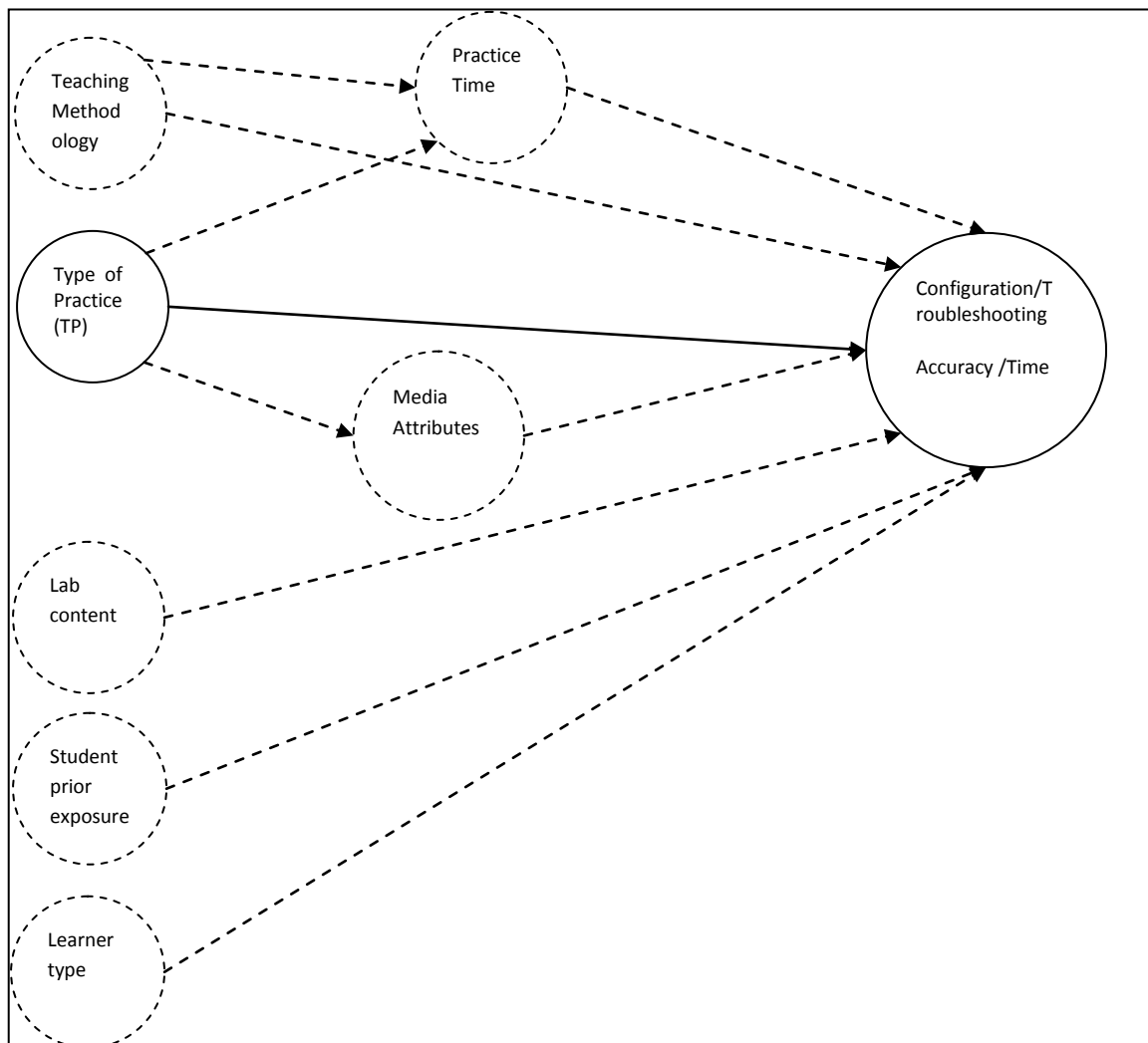


Figure 2. Research Model.

To measure transfer, the research method used in aircraft pilot training was used (Morrison, & Hammon, 2000). In this method two groups consisting of an experimental group and a control group were used. The experimental group was subjected to practice in virtual labs before practice on the real lab. The control group did not perform any practice before practicing in the real lab. Transfer was determined by the difference in the measured performance after the real lab training.

Computer Networking Content

The subject area for this research is in the field of computer networking. Computer networking is an engineering discipline that studies the communication between computers or other network devices, using wires or wirelessly, for the purpose of exchanging digital information (Kurose & Ross, 2005). A computer network (or network) consists of the interconnection of two or more computers through a communication media. The media can be wired using cables or wireless using radio transmitter and receivers. For networks that have multiple computers, routers are needed to connect the various computers. The Internet is a network of networks.

Information in computer networks is digitized. In a digitized communication system, information is encoded in binary states of either a one or a zero. During transmission, information is encoded into strings of these binary digits, grouped into packets, addressed, and eventually sent to the destination computer. For example, sending a picture on a network goes through, digital encoding, chopping the encoded picture data into packet data, putting the address information on the packets, sending it out the computer interface, switching the packets through a network, receiving the packets, putting the packets back together in the correct sequence, decoding, and lastly displaying the picture. The engineering challenge of sending data using this

sequence is to make sure that all the devices in the network talk the same language and follow the same rules. This has led to the creation of computer networking protocols to standardize communication between devices on the network. Standardization insures interoperability of networking devices and software.

Since the first computer networks were made in the 1960s there have been thousands of these protocols created. However the TCP/IP (Transmission control protocol and internet protocol) protocol has emerged as the protocol that all devices that operate on the Internet must follow. The TCP/IP protocol is a set of rules that control how devices on the Internet communicate. TCP/IP uses a division of labor system in a hierarchical 4 layer structure (Kurose & Ross, 2005). Each layer is responsible for different tasks in the communication process. When a layer completes processing a packet it passes the data over to the next layer.

Table 2

TCP/IP Protocol Hierarchy

Layer	Example Protocols
Application	Email, HTML, Telnet etc
Transport	TCP, UDP
Internet	IP
Network Interface	NIC, signaling protocols wires, connectors,

TCP determines:

1. how end to end connectivity is setup,
2. how communication is initiated and terminated,
3. the size and syntax of packets,

4. assignment of unique port numbers for different payloads of packets (e.g. email, html, file)
5. flow rate of packets

IP determines

1. addressing scheme, i.e. IP address
2. routing - navigation of packets to the correct address
3. switching of packets between routers
4. subnetting – creation of smaller networks within the Internet

Each end device on the Internet must have software to execute the TCP/IP protocol. For example, on a personal computer (PC) the Windows operating system includes programs to run TCP/IP.

Routers are devices on the Internet that relay information from one network to another use the IP protocol. Each router has some interfaces that are used to send and receive data. The router must decide where to send the packets it receives depending on the destination IP address that the original sender put on it. A router determines the correct route by routing information it has been given. A router gets its routing information in two ways; direct configuration by a network administrator, or automated scripts initiated by a network administrator. Either way routers at some point have to be configured by a human operator in order to perform the automatic function of routing and switching packets around the Internet.

The network administrators who configure routers must be trained to perform configurations and troubleshoot faults. The training must make sure that they understand the engineering design of the Internet as well as being able to configure specific routers. Therefore,

there is a theoretical and a hands-on component to computer networking. Training must equip the student with;

1. understanding of the TCP/IP protocol and other related protocols such as the OSI model.
2. a detailed knowledge of how networks function
3. a mastery of the nomenclature of networking language
4. how to connect, configure and troubleshoot specific routers.

(Kurose & Ross, 2005)

Students in a networking course must learn the complexity and abstract nature of the engineered environment of the computer network. However for student to be able to configure routers they must have direct hands on practice. Theoretical understanding of how routers are configured is necessary but is not sufficient. Students must also;

1. know how to connect to a router,
2. know how to initiate the configuration process,
3. know the command line interface,
4. know the commands and the command syntax,
5. know how to navigate through the CLI
6. know how to verify and save their configuration
7. know how to check and troubleshoot connectivity.

Computer network configuration skills are routine skills. A student must be able to remember the procedural steps needed to perform the configurations. Rote memorization will not be useful in this situation. Learning by doing through drill and practice is the most effective method in teaching this skill (Ericsson, 1993). Students must have access to equipment so that

they can practice the procedures, syntax and navigation. At the beginning of training all this new knowledge will be difficult to remember and the process can be rather frustrating. As student repeat the configurations each time, on a slight variation of the network topology, they will start to gain speed and accuracy. Anderson and Pearson (1984) showed that such practice regimes follow an inverse power law:

$$T = BN^{-k} ,$$

where T is the time to perform task, k is the learning rate parameter, B is the initial performance on task before training, and N is the number of learning trials. Although this particular form of the power law is stated in terms of speed of performance, similar relationships hold for other aspects of performance, such as accuracy.

Computer network troubleshooting is an adaptive skill. Troubleshooting involves problem solving. The student must recognize situations from prior experience and use their knowledge schema to determine the best course of action. If the situation is immediately recognizable and the correct reaction is known, immediate action is taken. If on the other hand the situation is unfamiliar, the learner must use both their internal model of the network and their problem solving skills acquired during training to solve and fix the fault. Practice of problems that exposes the student to as many possible situations builds both the schema and the repertoire of familiar configurations. Drill and practice is not useful in this case but rather using the recognition primed model is beneficial. In this model exposure to different situations through experience tends to build an experiential repertoire. This is often takes years of experience. For this research we are interested in seeing evidence of the beginning of this process.

As mentioned before practice requires access. The virtual lab can be used as a proxy to the actual equipment. This is similar to practice chess on a computer when you do not have a real

opponent. Dalgarno and Lee (2010) showed that virtual labs can be used to facilitate learning tasks that lead to improved transfer of knowledge and skills to real situations through contextualization of learning. At the risk of repetition the aim of the study is to determine the extent of routine and adaptive skills transfer from the virtual to the real lab.

Summary

This chapter provided that reader with: (a) a historical perspective of technology pedagogical studies; (b) literature review of similar studies; (c) a conceptual framework; (d) arguments for and against using virtual labs; and (e) a research design.

CHAPTER 3 - RESEARCH METHODOLOGY

The objective of this study was to determine the effectiveness of using virtual labs in student attainment of practical computer networking skills. Effectiveness was determined by the transfer of skills students learned in a virtual lab to a real lab. The skills consisted of configuring and troubleshooting of local area networks in a physical lab. Proficiency was measured by how quickly and accurately students configured and troubleshot a computer network. Transfer was determined by the difference in the level of proficiency between the experimental (virtual-lab) and control (no-virtual-lab) groups.

A description of the research design that was used in the study follows. The study was primarily a quantitative study using a two stage true experiment design. True experiment was used because it controlled for confounding variables and isolated variables of interest to the study (Ross and Morrison, 2004). The rest of the chapter describes the research hypotheses, research design, participants, instrumentation, data collection procedures, and data analysis.

Research Questions and Null Hypotheses

Before embarking on a description of the methodology, it is important to reiterate the research questions and their associated null hypotheses that the study sought to address.

Answers to the following research questions were sought:

1. Is there a significant difference in the accuracy of configuring real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and students who did not practice in a virtual lab prior to practicing in a real lab?
2. Is there a significant difference in the time taken to configure real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and students who did not practice in a virtual lab prior to practicing in a real lab?

3. Is there a significant difference in the troubleshooting accuracy of real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and students who did not practice in a virtual lab prior to practicing in a real lab?
4. Is there a significant difference in the time taken to troubleshoot real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and students who did not practice in a virtual lab prior to practicing in a real lab?

The following null hypotheses were made:

1. There is no significant difference in the accuracy of configuring real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and those who did not practice in a virtual lab prior to practicing in a real lab.
2. There is no significant difference in the time taken to configure real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and those who did not practice in a virtual lab prior to practicing in a real lab.
3. There is no significant difference in the troubleshooting accuracy of real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and those who did not practice in a virtual lab prior to practicing in a real lab.
4. There is no significant difference in the time taken to troubleshoot real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and those who did not practice in a virtual lab prior to practicing in a real lab.

Research Design

In this study, a two stage true experimental design using two randomly assigned groups was utilized. The experimental (virtual-lab) group practiced in the virtual lab before training on real equipment and the control (no-virtual-lab) group did not do any practice before training on

real equipment. Both groups were subjected to identical pre-tests, post-test 1, and post-test 2. The experimental design adopted is shown in figure 3.

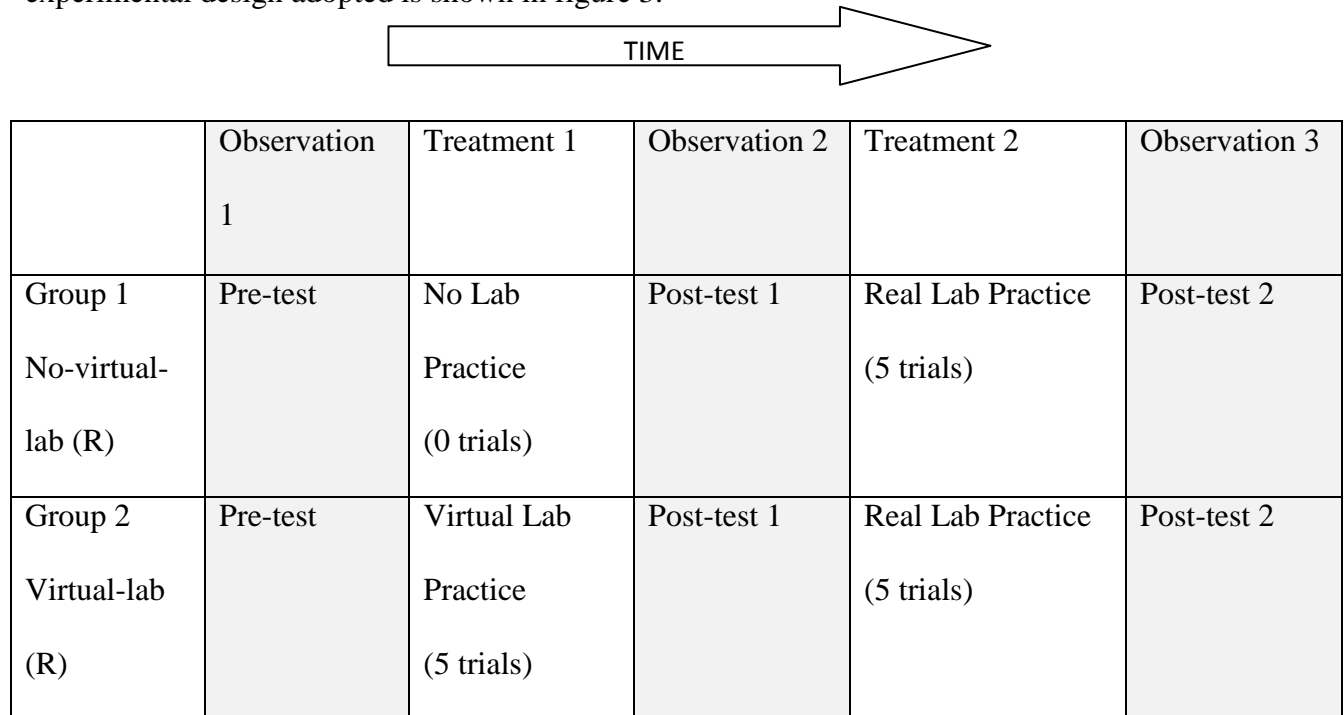


Figure 3. Experimental design. Group 1, No-virtual-lab (NVL). Group 2, Virtual-lab, R, Random Assignment.

Experimental Variables

The research design had one independent variable and four dependent variables. The independent variable was the type of practice (TP) students undergo. The four dependent variables are configuration accuracy (CA), configuration time (CT), troubleshooting accuracy (TA), and troubleshooting time (TT).

Independent Variable

- *Type of practice (TP)* - was a discrete variable with two possible values: 1 = VLB (virtual lab practice) and 0 = NLP (no virtual lab practice). The value for each student was dependent on which of the two practice modes they were randomly assigned to.

Dependent Variables

- *Configuration time (CT)*– measured the amount of time a student took to configure a network. This was measured by recording the time it took to complete a network design as specified in a lab test. Time was measured in minutes.
- *Configuration accuracy (CA)* - was measured by the score a student obtained in a lab test on configuring a network design. The instrument was based on the objective performance measure (Lewis, 1993). It consisted of a check list of items of tasks that had to be completed to determine the eventual score. Correct configuration of an item scored a value of 1 and an incorrect scored a value of 0.
- *Troubleshooting time (TT)* – measured the amount of time a student took to troubleshooting a network that had a number of faults. This was measured by recording the time it took to complete troubleshooting a network specified in a lab test based on a CCNA[®] certification test. Time was measured in minutes.
- *Troubleshooting accuracy (AC)*- was measured by the score a student obtained in lab test on troubleshooting a network that had a number of faults. The instrument was an objective performance measure (Lewis, 1993), with a check list of tasks that had to be completed to determine the eventual score.

Confounding Variables

A number of variables that could confound the results of the experiment had to be controlled during implementation. Based on the research models illustrated in the figure 4 and 5, it was determined that teaching methods, practice time, content, learner type and student prior exposure to the subject matter could affect the result of the study (Clark, 1983; Levie & Dickie 1973).

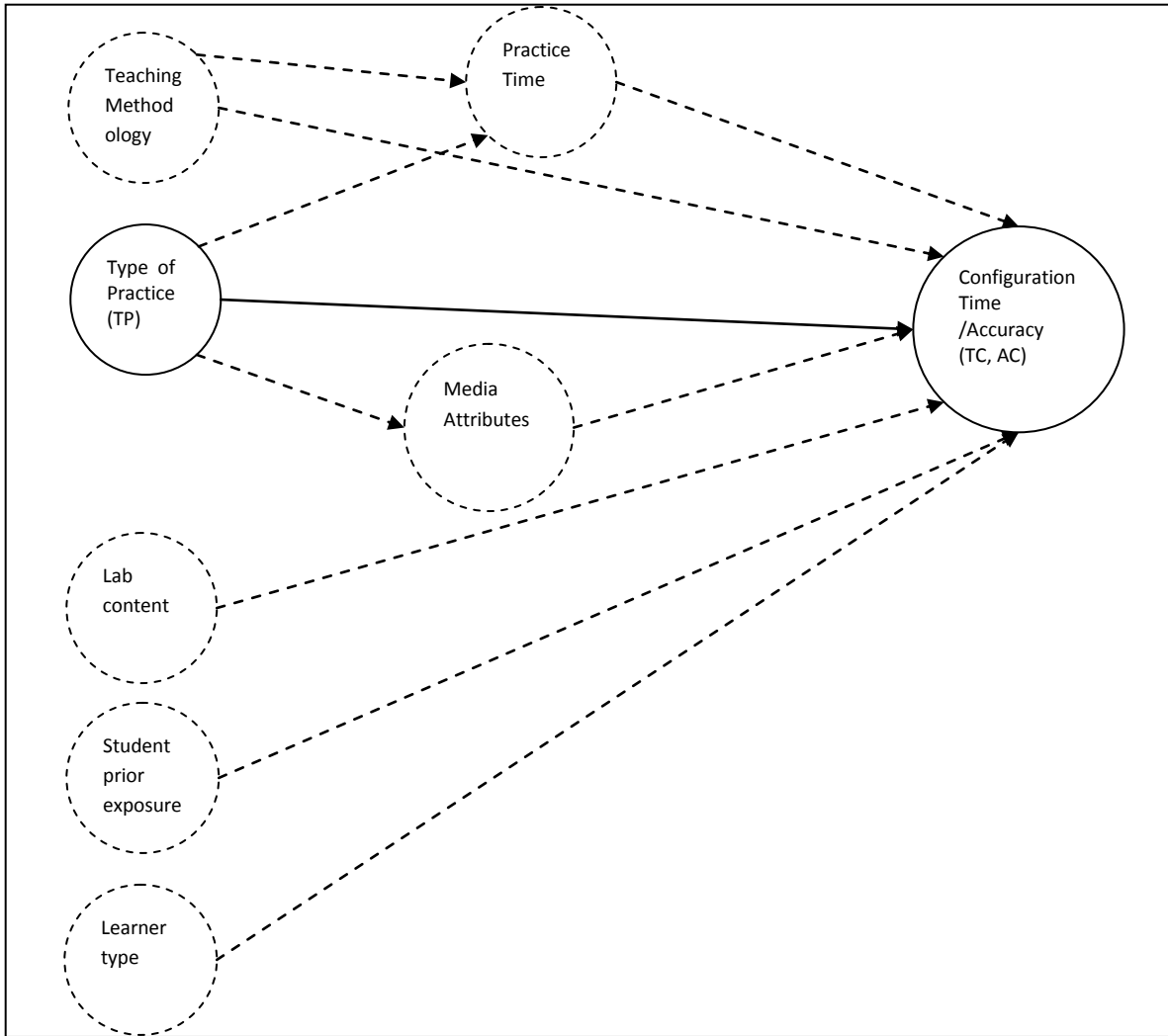


Figure 4. Research model for configuration skills.

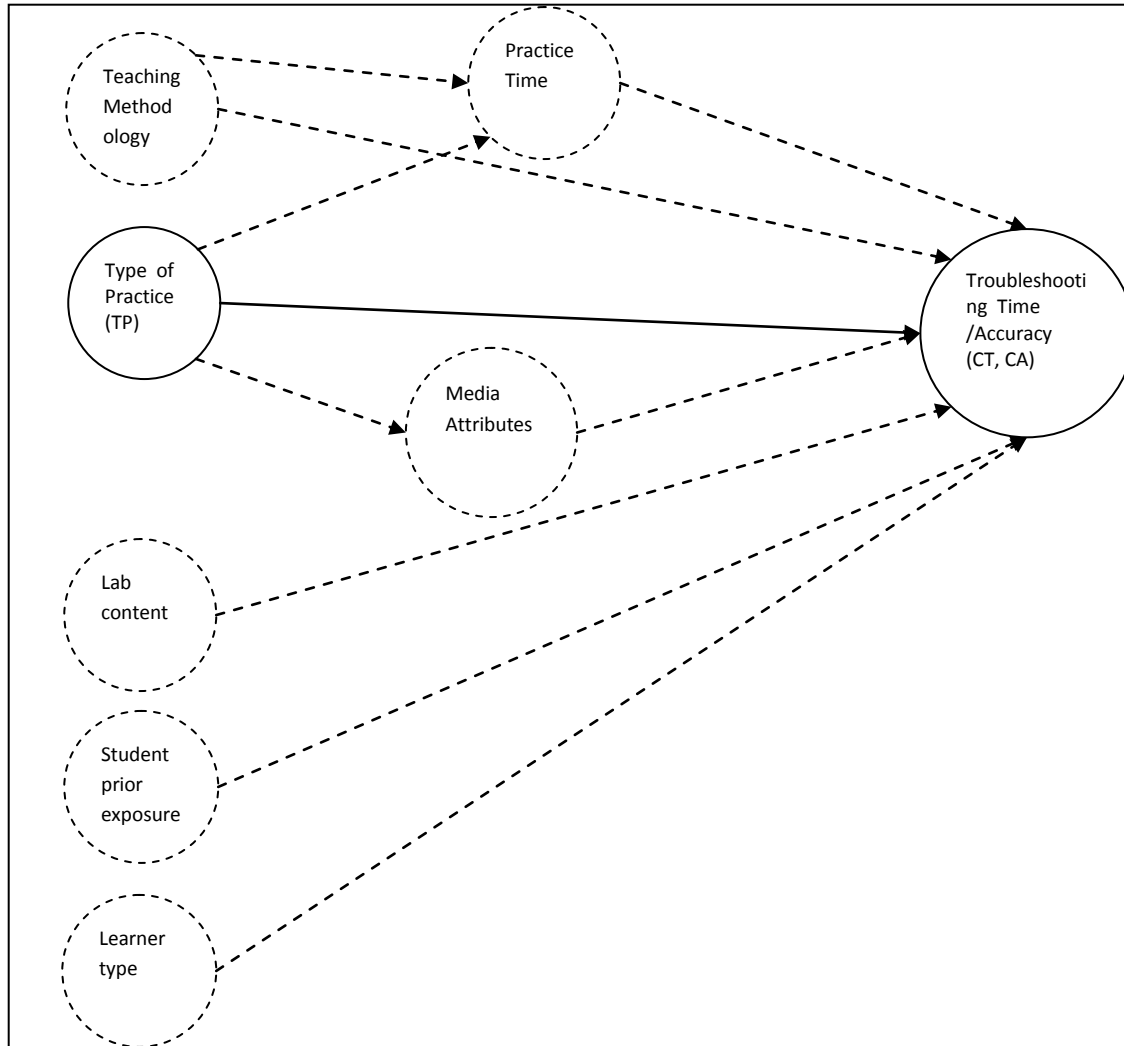


Figure 5. Research model for troubleshooting skills. Solid line, relationship of interest. Dashed line, confounding effects.

Teaching methods and lab content effects were controlled by ensuring that participants were exposed to the same treatment with regards to these variables. This is further elaborated in the procedure. Practice time in the real lab was the same for both groups. Practice in the virtual labs was varied as this was the independent variable. Participants in this course had no prior exposure to the content area. Random assignment to the groups removed bias of learner types, prior exposure or any other unknown confounding variable.

Participants

Third year students enrolled in a computer networking course at the University of Zambia participated in the study. The number of participants was 56, consisting of 50 males and 6 females. The students were randomly assigned to two groups of 28. All the participants completed the study.

Procedure

Implementation of the research study was carried out at the University of Zambia's Department of Computer Studies. The content was part of an already existing course in Computer Networking taught to 3rd year computer networking students. The researcher has a master's degree (MSc) in electronic engineering and is a registered Cisco[®] network instructor.

At the beginning of the study, participants were randomly assigned to the two groups. Both groups were taught theoretical knowledge from a unit of the course on configuration and troubleshooting. Participants in both groups took a pre-test that consisted of a configuration and troubleshooting lab test. Participants in the virtual-lab group then went on to practice configuration of local area networks using virtual labs, while the no-virtual-lab group participants did not perform any practice. Both sets of participants were then tested on configuration and troubleshooting on real lab equipment. The participants in both groups then took part in lab training, using real equipment. After the training both groups took a lab test using real equipment. Time to complete tasks and accuracy of the execution were measured in all the tests.

Instruction

A unit on the configuration and troubleshooting of routers in a network implementing transmission control protocol and internet protocol (TCP/IP) was taught in a classroom to both

groups. Lab training consisted of students practicing how to configure a router given network design specifications. Lab objectives, instructions, procedures and grading were given to the students during lab activities. The first two labs allowed students to practice the basics of router configuration and the last three concentrated on troubleshooting. Participants, who worked individually, had to complete predetermined tasks so that the network was functionally complete. In the configuration labs, a gradual drill and practice method was used until students were confident to perform their own configuration given only design specifications. Then participants were given incomplete network configurations, which they had to troubleshoot. Each student was assigned a workstation and a router. Due to limitation in equipment three sessions were done per day for the students. The virtual laboratory used in this study was the Packet Tracer[®], which is a network simulation software for the Cisco Certified Network Associate[®] (CCNA). The real lab was conducted on Cisco[®] routers. After completion of the training, students were tested on real equipment. Figure 6, 7 and 8 contain screen shots of the virtual lab user interfaces.

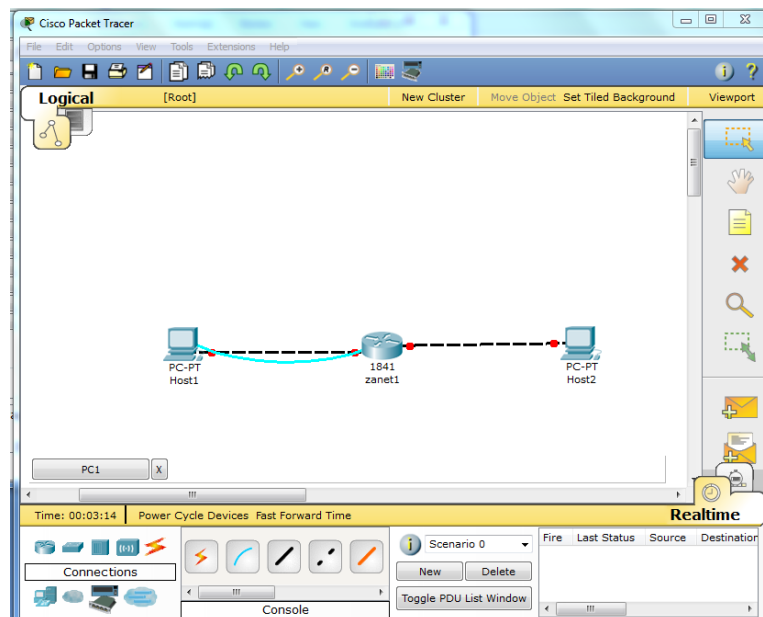


Figure 6. Packet Tracer[®] logical design area screen shot. Captured on computer running licensed “Packet Tracer” software by Cisco, 2011. Available from <http://community.netacad.net/web/packet-tracer/files>

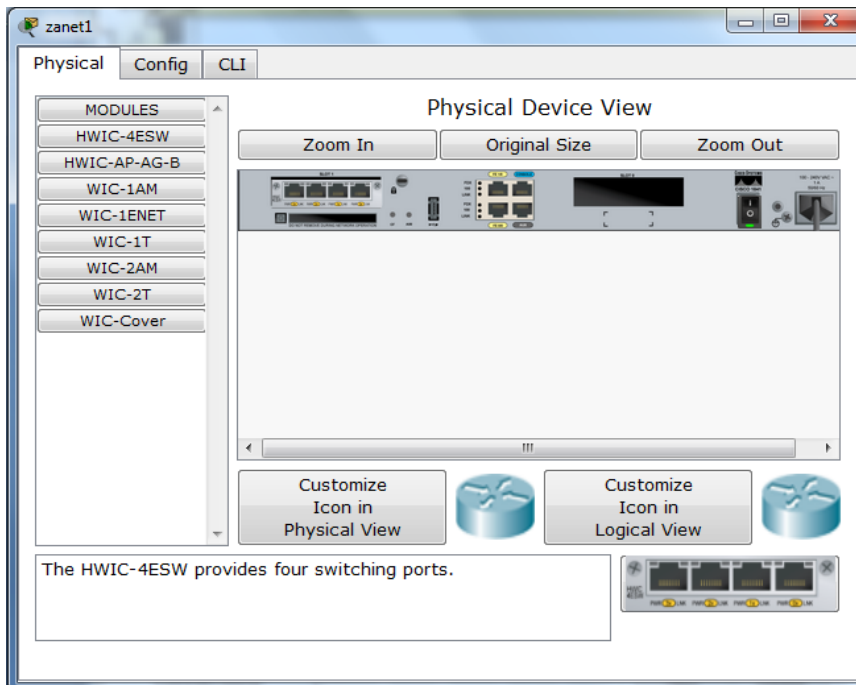


Figure 7. Packet Tracer® physical view of a router. Captured on computer running licensed “Packet Tracer” software by Cisco, 2011. Available from <http://community.netacad.net/web/packet-tracer/files>

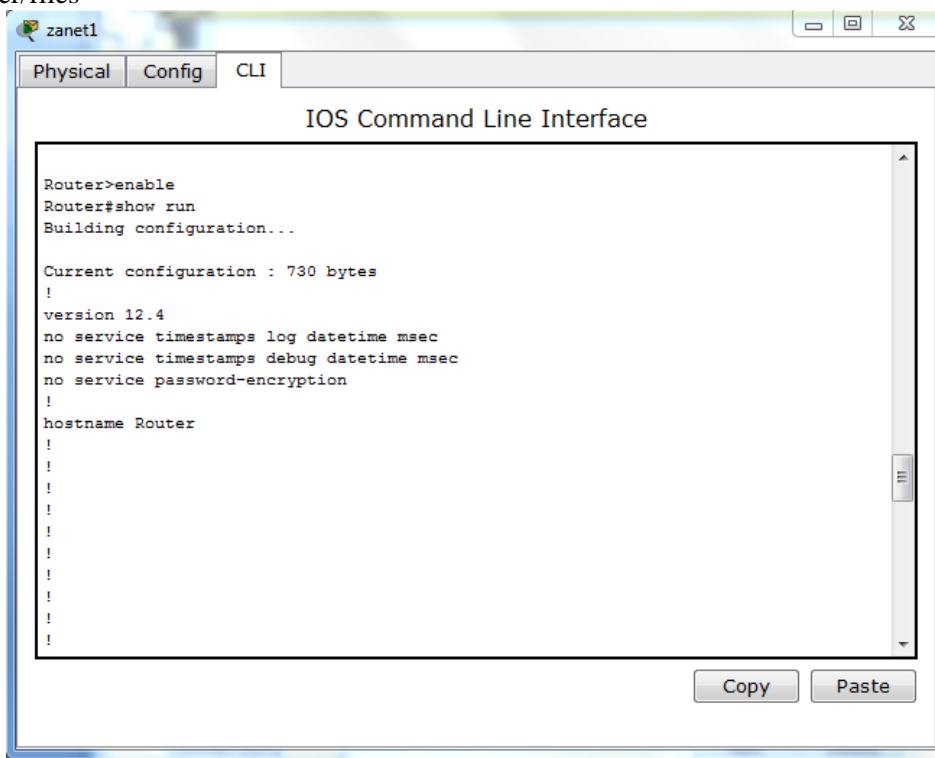


Figure 8. Packet Tracer® command line interface (CLI). Captured on computer running licensed “Packet Tracer” software by Cisco, 2011. Available from <http://community.netacad.net/web/packet-tracer/files>

The real labs were implemented using desktop computers and Cisco® routers as shown in figure 9.



Figure 9. Picture of Cisco® routers connected to computer. Picture taken at the University of Zambia

Data Collection

Data was collected in July of 2012 at the University of Zambia. Students signed an informed consent form to participate in the study. The data collection process was conducted during the course of the study. Data was collected in the form of six lab tests taken by the participants. The lab tests were part of pre-test and post-tests of the training program.

During the lab test, each student was given real equipment and tasks needed to connect a small network. A timer on the computer started when a student began the process of configuring the equipment. When the student completed the configuration, it was saved on the computer and the student logged out. The resulting accuracy score was determined by how many items on a checklist were completed in the configuration. Evidence of task completion was determined by examining the saved configuration file. Time when the exercise was completed was also

recorded. For the troubleshooting test, students were given a network with faults deliberately included. Students had to diagnose and fix the faults until end-to-end connectivity was restored. Time and accuracy of the final configuration was recorded. The maximum score on the accuracy test was 22 and the students score was dependent on how many of the items each student had configured correctly.

Table 3

Summary of Data Collection Activities

Activities	
Session 1	<ol style="list-style-type: none"> 1. Participants were instructed on the objectives of the activities 2. Participants filled in consent forms 3. Participants in both groups jointly learned the theory of configuration and troubleshooting routers and computers in a network. 4. Both groups of students undertook two pre-test lab test on real equipment. Time and accuracy of configuration and troubleshooting were measured and recorded.
Session 2	<ol style="list-style-type: none"> 1. Participants were assigned to virtual-lab and no-virtual-lab group. All subsequent activities were in separate times and places. 2. Participants in the virtual-lab group performed 5 rounds of practice on configuration and troubleshooting using the virtual lab. These were conducted on two different days. Participants in the no-virtual-lab group did not do any lab activity. 3. Both groups undertook the two first post-test lab on real equipment.
Session 3	<ol style="list-style-type: none"> 1. Participants in both groups performed 5 trials of practice on configurations and troubleshooting using real equipment. 2. Participants in both groups undertook the two post-test 2 lab on real equipment. 3. The no-virtual-lab group practiced on the virtual lab.

Instruments

Instruments in this study measured participants' configuration and troubleshooting skills by testing how long and accurately tasks were completed. The instruments (Appendix A) were developed by the researcher based on industrial certification skills objectives of the CCNA

program (Cisco, 2012). The objectives are publicly available for Cisco[®] certified network instructors to use for instruction in the program (Appendix B). Participants were given a network diagram (figure 10) and design specifications as shown in tables 4 and 5. The instrument was pilot tested and checked for reliability by the researcher before being used in the study.

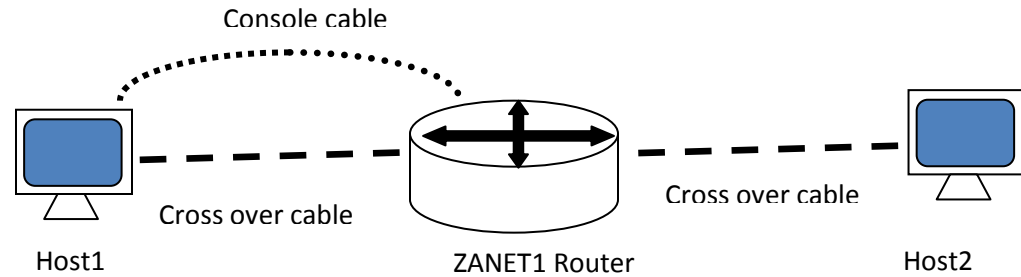


Figure 10. Network configuration.

Table 4

Network Design Specifications

Interface	IP address	Subnet mask
Fa0/0	192.168.0.1	255.255.255.240
Fa0/1	192.168.1.1	255.255.255.240
Host1		
Ethernet port	192.168.0.2	255.255.255.240
Host2		
Ethernet port	192.168.1.2	255.255.255.240

Table 5

Router Specifications

Specification	Value
Router Name	ZANET1
Console password	wiz789KID
Enable password	kid123WISE
Virtual terminal password	wise456MAN

Participants had to complete a real configuration that fully implemented the design specification. After completion, participants saved the configuration file of the router. The

configuration accuracy score was determined by comparing each participant's completed configuration file with a master configuration key. One point was awarded for each item on a checklist (table 6). Zero points were awarded for incorrect configuration of an item. The configuration time score was determined by checking the login and logout time stamps.

Table 6

Task Checklist

Task	Evidence in configuration file or prompt
Router name set correctly	hostname UNZA
Encrypted password set for EXEC mode	enable secret 5 \$1\$mERr\$5Qi10mHKg3LmVOQWWOjG8.
Console line password protection set	line con 0 password Lusaka123
Login password protection set	line vty 0 4 password Ndola789 login
Router Ethernet interface (Fa0/0) IP address set	interface FastEthernet0/0 ip address 10.0.0.1 255.255.255.0
Subnet mask for Fa0/0 configured correctly.	interface FastEthernet0/0 ip address 10.0.0.1 255.255.255.0
Router Ethernet interface (Fa0/0) switched on	protocol up
Router Ethernet interface (Fa0/1) IP address set	interface FastEthernet0/0 ip address 10.0.1.1 255.255.255.0
Correct subnet mask for Fa0/1 configured correctly	interface FastEthernet0/0 ip address 10.0.1.1 255.255.255.0
Router Ethernet interface (Fa0/1) switched on	protocol up
Static route to network connected to Fa0/0 configured correctly	ip route 10.0.0.0 255.255.255.0 FastEthernet0/0
Static route to network connected to Fa0/1 configured correctly	ip route 10.0.1.0 255.255.255.0 FastEthernet0/1
PC Host1 IP address set correctly	IP Address.....: 10.0.0.2
PC Host1 subnet mask set correctly	Subnet Mask.....: 255.255.255.0
PC Host1 default gateway set correctly	Default Gateway.....: 10.0.0.1
PC Host2 IP address set correctly	IP Address.....: 10.0.0.1
PC Host2 subnet mask set correctly	Subnet Mask.....: 255.255.255.0
PC Host2 default gateway set correctly	Default Gateway.....: 10.0.1.1
Connectivity	
PC Host1 to Router connectivity established	Ping statistics for 10.0.0.1: Packets: Sent = 4, Received = 4, Lost = 0 (0% loss)
PC Host2 to Router connectivity established	Ping statistics for 10.0.0.2: Packets: Sent = 4, Received = 4, Lost = 0 (0% loss)
PC Host1 to PC Host 2 connectivity established	Ping statistics for 10.0.1.2:Packets: Sent = 4, Received = 3, Lost = 1 (25% loss)

In the troubleshooting test, the participants were given a configured network that had faults deliberately introduced. Participants had to test, diagnose, repair and re-test the network until it became functional. Time and the final configuration file were recorded and evaluated. Accuracy was measured by determining how many of the faults had been cleared without introducing new ones. The score was reflected on a checklist in table 6.

Validity and Reliability

The instrument was pilot tested for validity and reliability using a different set of students from the ones in the main study at the University of Zambia. The students used in the pilot were 4th year computer science students, who had already completed a course in computer networking. To ensure that the various measurement instruments utilized in the research were equivalent, it was necessary to perform the alternate form reliability test. Pearson's correlation was calculated between the pre-test, post-test 1, and post-test 2.

Validity of the instruments involved checking that instructions were understandable, answers were adequate, questions were unambiguous, the length was appropriate, and there were no unintended errors. In addition, procedural error and internal consistency of items and definitions were corrected using the pilot test of the instrument. Since the participants who took the pilot test were not the same individuals as those in the main study, there was less chance of pre-test-post-test errors. Construct validity issues did not arise in this study as the variables of time, accuracy and treatment are not abstract psychological constructs. Time was measured in minutes and accuracy was the number of items the student scored.

During implementation of the study care was taken to avoid a number of possible validity threats that could arise during implementation. The first of these was to make sure that effects of the result was dependent on the lab practice environment rather than of the confounding

variables which included; teaching methodology, content, practice time and prior student exposure. It was imperative therefore, that both groups were given identical teaching methods, content and practice time when required. This was accomplished by using the same instructor, using the same content and allowing for the same practice time in the real lab for the two groups. Prior experience did not arise as none of the participants had performed configuration and troubleshooting of computer networks prior to this study.

Validity threats associated with implementation of the study included;

- i. Students from one group trying out the treatment from the other group,
- ii. Resentful demoralization,
- iii. Compensatory rivalry,
- iv. Mortality - students quitting the study before completion

Students were not allowed to switch groups during the experiment period and were informed that they would eventually perform both lab methods as they would switch over in the next unit. Hopefully this reduced the first three validity threats. All the participants completed the study hence there was no mortality validity issue.

Data Analysis

After all the data were collected a two-tailed, independent t-test, was conducted to test each of the four hypotheses of the study. The statistical calculations were conducted using the statistical package for the social sciences (SPSS 16.0). Each of the null hypotheses was accepted or rejected depending on a critical α value of 0.05. In addition, independent t-tests were conducted for the pre-test and post-test 1. The pre-test t-test determined the statistical equivalence of the groups with respect to the variable being measured. Post-test 1 t-test comparison was useful in measuring the training transfer ratio between virtual labs and real labs.

For each of null hypotheses, distribution graphs comparing the two groups were made to give a visual comparison of the performance of the two groups as well as verifying normality of the distribution. In addition a trend graph showing the mean scores for each group with error bars was made to show the progression after each training session.

The gains attained by using virtual labs were obtained by calculating the effect size of the pre-test and the post-test 1 for the virtual-lab group. The gains of using real labs were calculated by calculating the effect size of the post-test 1 and post-test-2 of the no-virtual-lab group. In both cases a paired t-test verified whether there was a significant difference between pre and post training scores.

Summary

In this chapter a detailed description of the research design, participants, procedure, data collection, instrumentation, and data analysis were presented. The next chapter presents the results of the study.

CHAPTER 4 - RESULTS

In this chapter, the results of the study are presented. This study investigated the effect of students' practice of computer networking skills using virtual labs on the following dependent variables; a) configuration accuracy, b) configuration time, c) troubleshooting accuracy, and d) troubleshooting time.

The results are separated in to the four sections: a) reliability tests, b) results for each null hypothesis c) transfer percentages d) performance gains, and e) summary of results. The Statistical Package for the Social Sciences (SPSS 16.0) was used for statistical calculations.

Reliability Tests

To ensure that the various measurement instruments utilized in the research were equivalent it was necessary to perform the alternate form reliability test. Pearson's correlation was calculated between the pre-test, post-test 1 and post-test 2. Tables 7 and 8 show a cross tabulation of the Pearson's correlations between the three sets of configuration and troubleshooting tests.

Table 7

Pearson's Correlation between Configuration Tests

	Configuration accuracy pre-test	Configuration accuracy post-test 1	Configuration accuracy post-test 2
Configuration accuracy pre-test		0.94*	0.95*
Configuration accuracy post-test 1	0.94*		0.97*
Configuration accuracy post-test 2	0.95*	0.97*	

Note. * $p < 0.05$, (N =30)

The high Pearson's coefficient between all the configuration accuracy tests with significance of $*p < 0.05$, shows a high reliability of the equivalence of the tests. Pearson's coefficient between all the troubleshooting accuracy tests was above 0.95 with significance of $*p < 0.05$. Therefore, it is concluded that there was a high reliability of the equivalence of the tests.

Table 8

Pearson's Correlation between Troubleshooting Tests

	Troubleshooting accuracy pre-test	Troubleshooting accuracy post-test 1	Troubleshooting accuracy post-test 2
Troubleshooting accuracy pre-test		0.98*	0.99*
Troubleshooting accuracy post-test 1	0.98*		0.96*
Troubleshooting accuracy post-test 2	0.99*	0.96*	

Note. $*p < 0.05$, (N =30)

Results for Each Null Hypothesis

To determine the transfer of computer networking skills learned in a virtual lab to a real lab, four null hypotheses were tested. For each of the hypotheses, a pre-test and 2 post-tests were conducted. The two-tailed independent t-test, using a critical value $\alpha = 0.05$, was used to test significance of differences between the two groups. The pre-test determined the equivalence of the two randomly assigned groups for each dependent variable. The first post-test compared the performance effect of the virtual lab training with no training. The second post-test was used to test the hypothesis and determined the transfer of skills from the virtual lab to the real lab.

All the t-tests had to meet the independence of observation, equivalence of variance, and normality of the distributions criteria. Independence of observation was assured in the execution of the methodology by insuring that participants did not share information. Homogeneity of the two samples was tested using Levene's F-test. In instances when this criteria was not met readjusted degrees of freedom were used to calculate the p-value in SPSS[®]. Normality of the distributions was tested for each of the independent variables using graphical methods.

Results for Null Hypothesis 1

Null Hypothesis 1. There is no significant difference in the accuracy of configuring real network equipment, between students who practiced on a virtual lab prior to practicing on a real lab and those who did not practice on a virtual lab prior to practicing on a real lab.

The independent variable for this null hypothesis is the type of training of the two groups and the dependent variable is the configuration accuracy.

Pre-test. The distribution of the configuration accuracy for the two groups in the pre-test is given in figure 11. The score attained was out of a maximum of 22. The two distributions met all the criteria of the independent t-test.

The results of the two-tailed independent t-test for the pre-test are given in Table 9. The two groups yielded mean scores of 16.11 and 15.64, which translated into a $p = 0.527$. Since $p > \alpha (0.05)$, then there was no significant difference between the two groups with respect to configuration accuracy. Therefore, the two groups were statistically equivalent with respect to configuration accuracy.

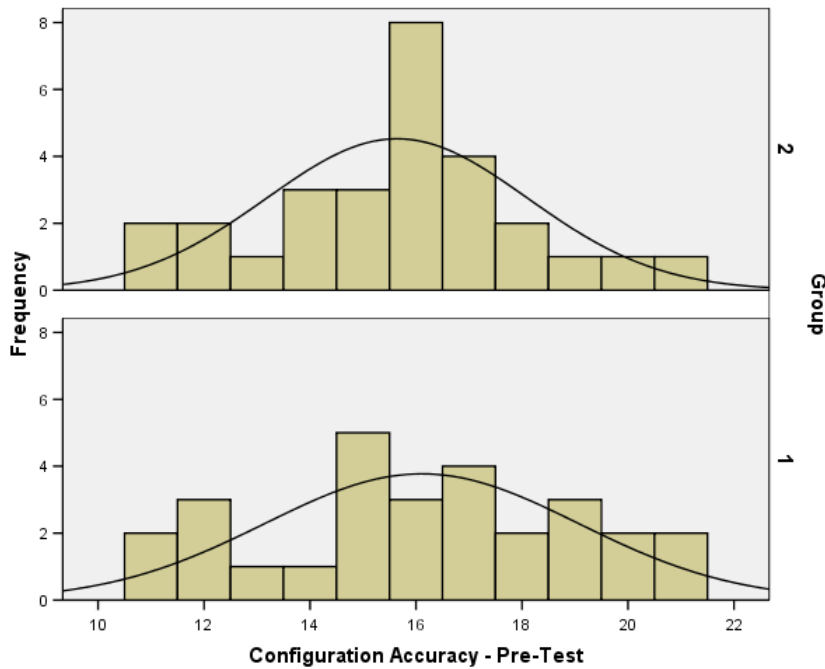


Figure 11. Distribution of configuration accuracy pre-test scores. Group 1 = No-virtual-lab group. Group 2 = Virtual-lab group.

Table 9

Result of Independent t-test of Pre-Test for Configuration Accuracy

	N	Mean	Std. Deviation	<i>p</i>
Group 1 No Virtual Lab	28	16.11	2.961	0.527
Group 2 Virtual Lab	28	15.64	2.468	

Note. Significance * $p < 0.05$

Post-test 1. The distribution of the configuration accuracy for the two groups in post-test 1 is given in figure 12. The two distributions met all the criteria of the independent t-test.

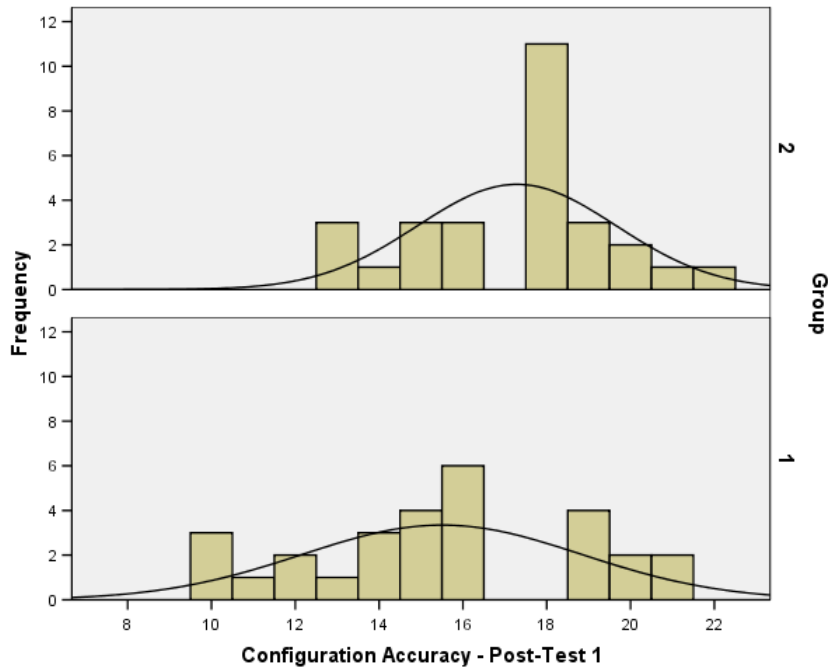


Figure 12. Distribution of configuration accuracy post-test 1 scores. Group 1 = No-virtual-lab group. = Virtual-lab group.

Table 10 shows the result of the two-tailed independent t-test for post-test 1. Even though there is no null hypothesis associated with this test, it is worth noting that there is a significant difference between the two groups with respect to configuration accuracy since the p -value (0.025) is less than α (0.05). The group who practiced on the virtual labs scored significantly higher than the group who did not practice on virtual labs with respect to configuration accuracy.

Table 10

Result of Independent t-test of Post-Test 1 for Configuration Accuracy

	N	Mean	Std. Deviation	p
Group 1				
No Virtual Lab Practice	28	15.50	3.339	0.025*
Group 2				
Virtual Lab Practice	28	17.29	2.380	

Note. Significance * $p < 0.05$

Post-test 2. The distribution of the configuration accuracy for the two groups in post-test 2 is given in figure 13. The two distributions met all the criteria of the independent t-test.

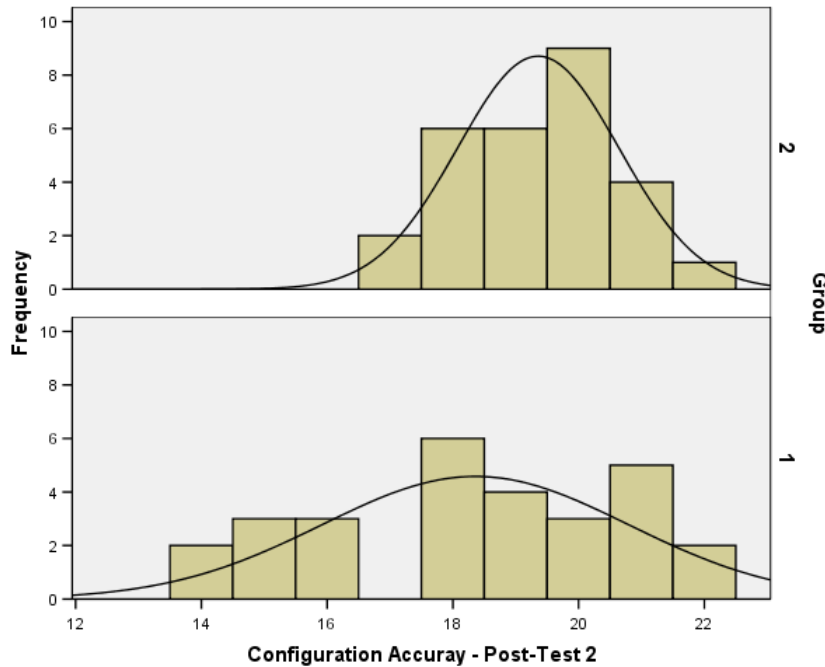


Figure 13. Distribution of configuration accuracy post-test 2 scores. Group 1 = No-virtual-lab group. Group 2 = Virtual-lab group.

Table 11 shows the result of the two-tailed independent t-test for the post-test 2.

The null hypothesis is retained at $\alpha = 0.05$ significance level because there is insufficient evidence to reject the null hypothesis according to the p -value calculated. The two-tailed p -value (0.06) is greater than α (0.05). Therefore, it is concluded that there was no significant difference in the means of the configuration accuracy scores between the Virtual-lab group and the no-virtual-lab group, although the Virtual-lab group (19.36) scored higher than the no-virtual-lab group (18.36). The Cohen's value ($d = 0.51$) represents a moderate effect size, indicating that a test of more statistical power may yield a significant difference.

Table 11

Result of Independent t-test of Post-Test 2 for Configuration Accuracy

	N	Mean	Std. Deviation	<i>p</i>
Group 1				
No Virtual Lab Practice	28	18.36	2.438	0.06
Group 2				
Virtual Lab Practice	28	19.36	1.283	

Note. Significance $*p < 0.05$

The graph in figure 14 shows the progression of the means of the participants' scores over successive tests. It can be inferred that the general trend for both groups is that there was an overall increase of the participants' configuration accuracy over the entire training period.

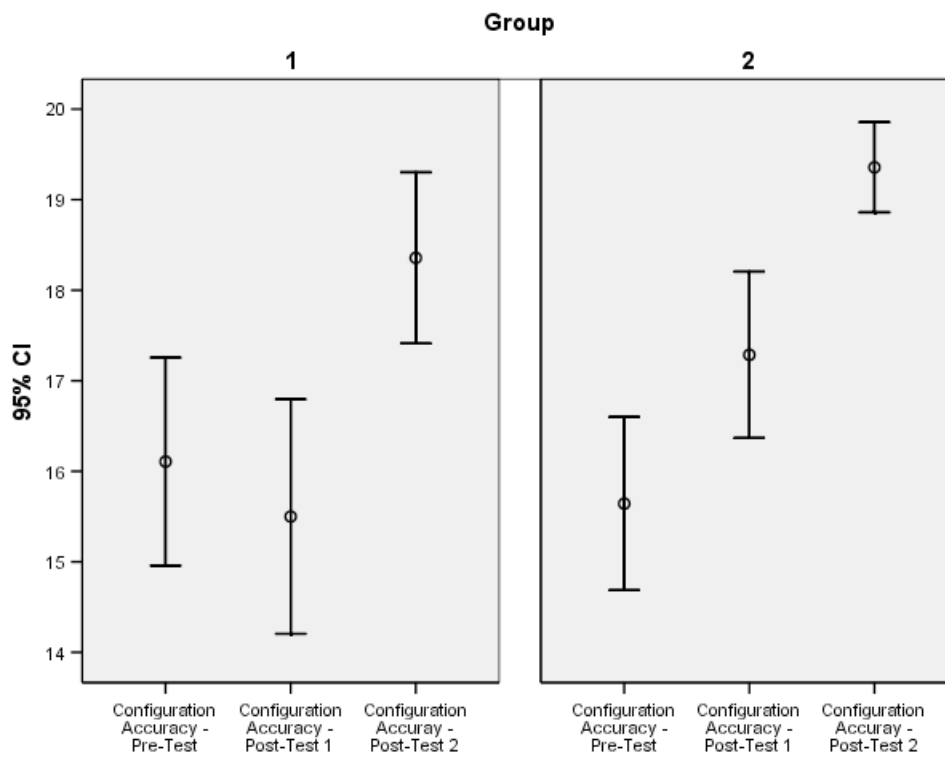


Figure 14. Graph of configuration accuracy scores trends. 95% confidence. Group 1 = No-virtual-lab group. Group 2 = Virtual-lab group.

Results for Null Hypothesis 2

Null Hypothesis 2. There is no significant difference in the time taken to configure real network equipment between students who practiced on a virtual lab prior to practicing on a real lab and those who did not practice on a virtual lab prior to practicing on a real lab.

The independent variable is the training of the two groups and the dependent variable is the configuration time.

Pre-test. The distribution of the configuration time for the two groups in the pre-test is given in figure 15. Time was measured in minutes. The two distributions met all the criteria of the independent t-test.

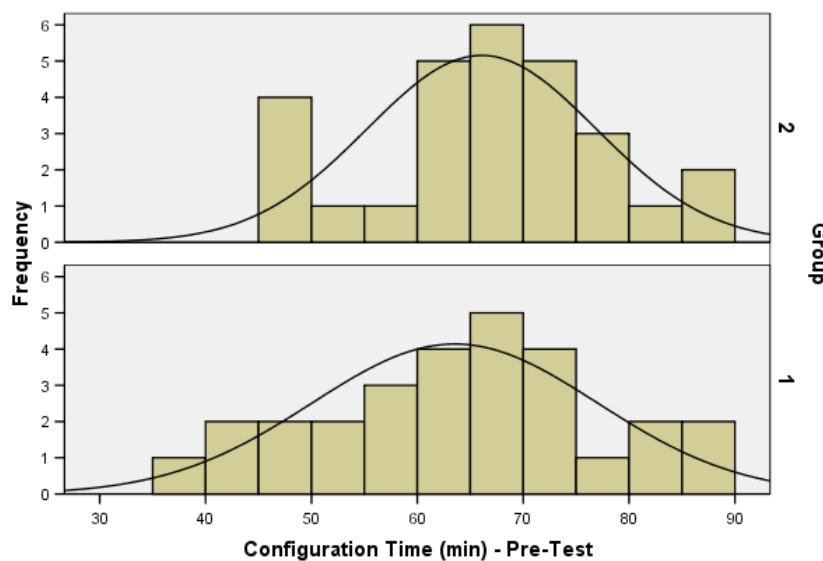


Figure 15. Distribution of configuration time for the pre-test in minutes. Group 1 = No-virtual-lab group. Group 2 = Virtual-lab group.

Table 12 shows the result of the two-tailed independent t-test for the pre-test. The mean time taken for No-virtual-lab and group 2 were 63.54 and 66.07 minutes respectively. There is no significant difference between the two groups with respect to configuration time, since p (0.441)

$> \alpha$ (0.05). Therefore, the two groups were statistically equivalent with respect to configuration time.

Table 12

Result of Independent t-test of Pre-Test's Configuration Time.

	N	Mean	Std. Deviation	<i>p</i>
Group 1 No Virtual Lab Practice	28	63.54	13.49	0.441
Group 2 Virtual Lab Practice	28	66.07	10.83	

Note. Significance ($*p < 0.05$)

Post-test 1. The distribution of the configuration time for the two groups in post-test 1 is given in figure 16. The two distributions met all the criteria of the independent t-test.

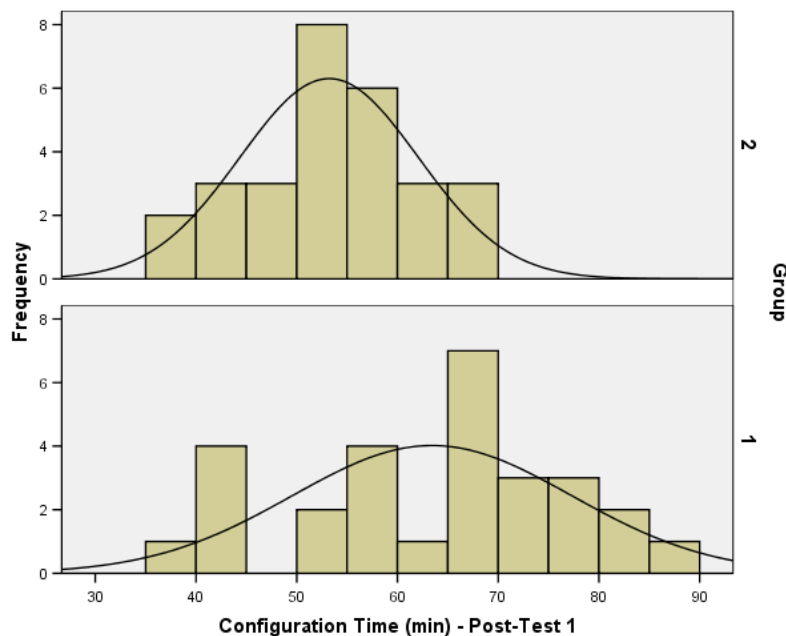


Figure 16. Distribution of configuration time post-test 1 in minutes. Group 1 = No-virtual-lab group. Group 2 = Virtual-lab group.

Table 13 shows the result of the two-tailed independent t-test for the post-test 1. There is a significant difference between the two groups with respect to configuration time, since p

(0.002) < α (0.05). The group who practiced on the virtual labs took significantly less time to configure equipment than the group who did not practice on virtual labs.

Table 13

Result of Independent t-test of Post-Test 1 for Configuration Time

	N	Mean	Std. Deviation	<i>p</i>
Group 1 No Virtual Lab Practice	28	63.43	13.89	0.002*
Group 2 Virtual Lab Practice	28	53.21	8.863	

Note. Significance (* $p < 0.05$)

Post-test 2. The distribution of the configuration time for the two groups in post-test 2 is given in figure 17. The two distributions met all the criteria of the independent T-test. Table 14 outlines the result of the two-tailed independent t-test for the post-test 2.

The null hypothesis is rejected, at $\alpha = 0.05$ significance level, because there is sufficient evidence to reject the null hypothesis according to the *p*-value calculated. The two-tailed *p*-value (0.011) is less than α (0.05). Therefore, it is concluded that there was a significant difference in the means of the configuration time between the virtual-lab group and the no-virtual-lab group. The group who practiced on virtual labs prior to practicing on real labs took significantly less time to configure real network equipment than the group who did not. The Cohen's value ($d = 0.70$) represents a large effect size, indicating that the mean difference between the two groups is substantive.

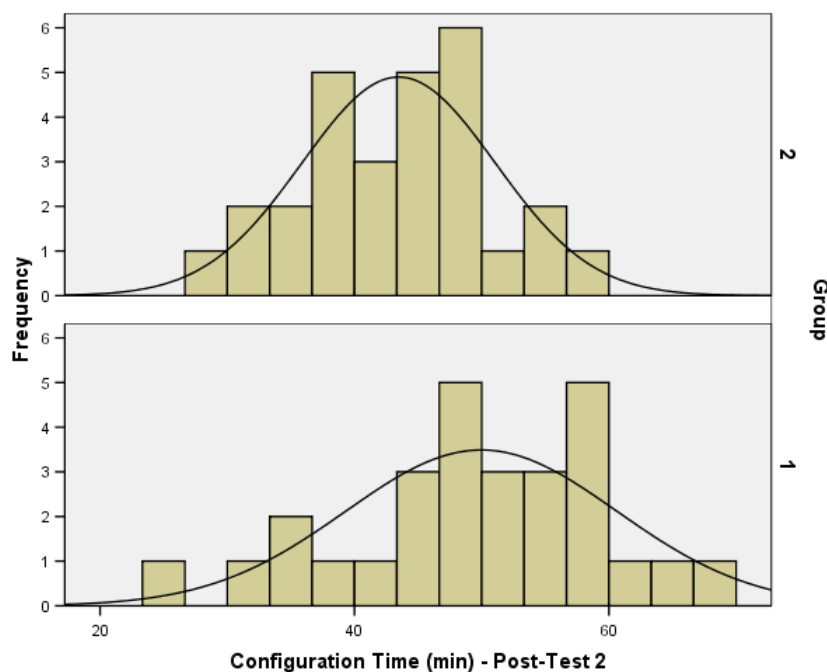


Figure 17. Distribution of configuration time post-test 2 in minutes. Group 1 = No-virtual-lab group. Group 2 = Virtual-lab group.

Table 14

Result of Independent t-test of Post-Test 2 for Configuration Time

	N	Mean	Std. Deviation	<i>p</i>
Group 1 No Virtual Lab Practice	28	49.96	10.67	0.011
Group 2 Virtual Lab Practice	28	43.46	7.60	

Note. Significance ($*p < 0.05$)

Progression of time to configure is given in figure 18 with a confidence of 95%. A trend of faster configuration times was observed during the course of the training.

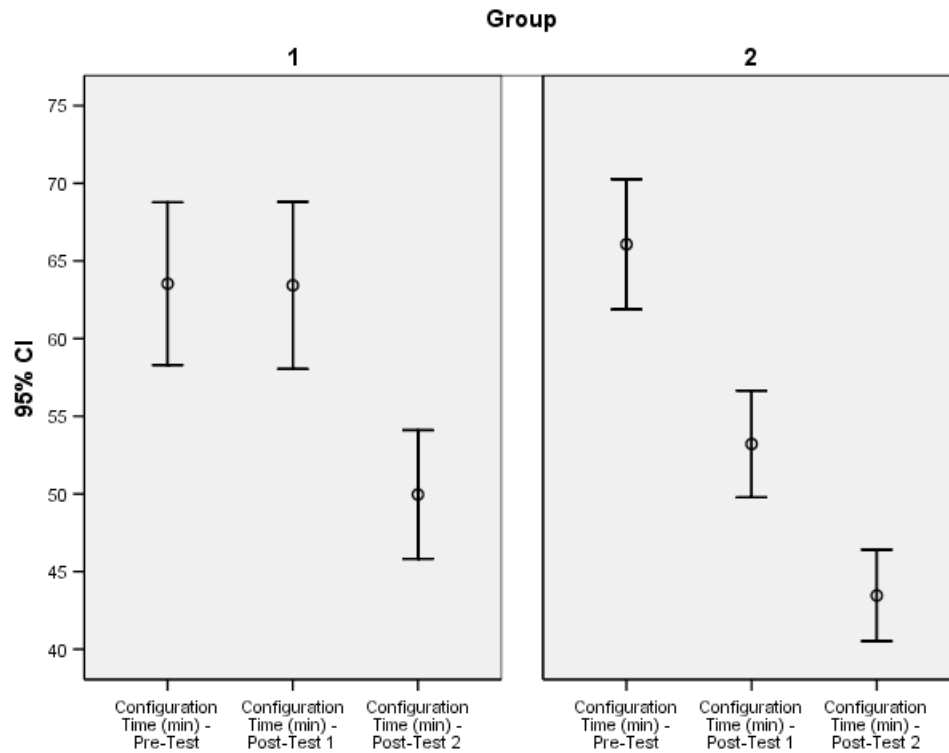


Figure 18. Graph of configuration time trends. 95% confidence. Group 1 = no virtual lab. Group 2 = virtual lab.

Results for Null Hypothesis 3

Null Hypothesis 3: There is no significant difference in the accuracy of troubleshooting real network equipment between students who practiced on a virtual lab prior to practicing on a real lab and those who did not practice on a virtual lab prior to practicing on a real lab.

The independent variable is the training of the two groups and the dependent variable is the troubleshooting accuracy.

Pre-test. The distribution of the troubleshooting accuracy for the two groups in the pre-test is given in figure 19. The score attained was out of a maximum of 6. The two distributions met all the criteria of the independent t-test.

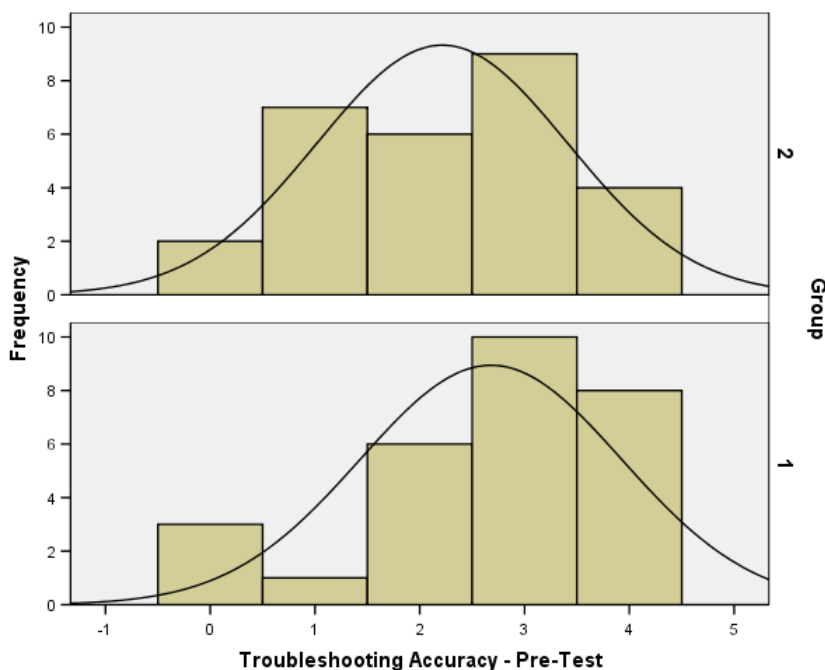


Figure 19. Distribution of troubleshooting accuracy pre-test scores.

Table 15

Result of Independent *t*-test of Pre-Test for Troubleshooting Accuracy.

	N	Mean	Std. Deviation	<i>p</i>
Group 1				
No Virtual Lab Practice	28	2.68	1.25	0.464
Group 2				
Virtual Lab Practice	28	2.21	1.20	

Note. Significance ($*p < 0.05$)

Table 15 gives the result of the two-tailed independent T-Test for the pre-test.

The two groups yielded mean scores of 2.68 and 2.21, which resulted into a $p = 0.464$. There is no significant difference between the two groups with respect to troubleshooting accuracy, since $p(0.464) > \alpha (0.05)$. Therefore, the two groups were statistically equivalent with respect to troubleshooting accuracy.

Post-test 1. The distribution of the troubleshooting accuracy for the two groups in post-test 1 is given in figure 20. The score attained was out of a maximum of 6. The two distributions met all the criteria of the independent t-test.

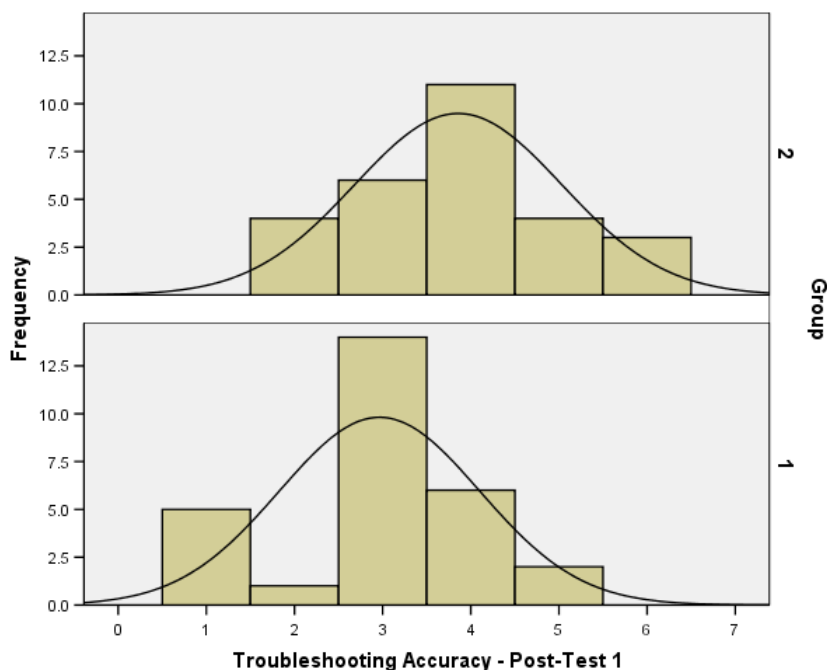


Figure 20. Distribution of troubleshooting accuracy post-test 1 scores. Group 1 = No-virtual-lab group. Group 2 = Virtual-lab group.

Table 16

Result of Independent t-test of Post-Test 1 for Troubleshooting Accuracy

	N	Mean	Std. Deviation	<i>p</i>
Group 1 No Virtual Lab Practice	28	2.96	1.14	0.006
Group 2 Virtual Lab Practice	28	3.86	1.18	

Note. Significance ($*p < 0.05$)

Table 16 gives the result of the two-tailed independent t-test for the post-test 1.

There is a significant difference between the two groups with respect to troubleshooting accuracy, since $p (0.006) < \alpha (0.05)$. The group who practiced on the virtual labs scored

significantly higher than the group who did not practice on virtual labs in troubleshooting accuracy.

Post-test 2. The distribution of the troubleshooting accuracy for the two groups in post-test 2 is given in figure 21. The score attained was out of a maximum of 6. The two distributions met all the criteria of the independent t-test.

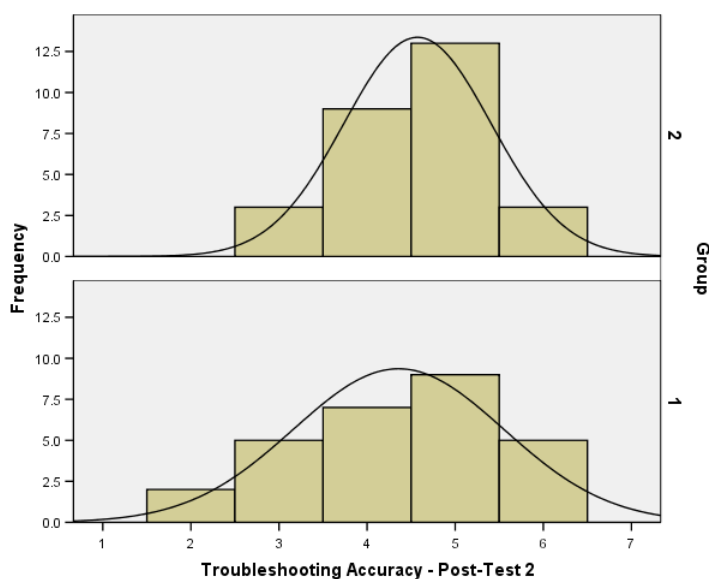


Figure 21. Distribution of troubleshooting accuracy post-test 2 scores. Group 1 = No-virtual-lab group. Group 2 = Virtual-lab group.

Table 17

Result of Independent t-test of Post-Test 2 for Troubleshooting Accuracy

	N	Mean	Std. Deviation	<i>p</i>
Group 1				
No Virtual Lab Practice	28	4.36	1.19	0.440
Group 2				
Virtual Lab Practice	28	4.57	0.84	

Note. Significance (* $p < 0.05$)

Table 17 gives the result of the two-tailed independent t-test for the post-test 2. The null hypothesis is retained at $\alpha = 0.05$ significance level because there is insufficient evidence to reject the null hypothesis according to the p -value calculated. The two-tailed p -value (0.440) is

greater than $\alpha = 0.05$. Therefore, it is concluded that there was no significant difference in the means of the troubleshooting accuracy scores between the virtual-lab group and the no-virtual-lab group, although the virtual-lab group (4.57) scored higher than the no-virtual-lab group (4.36). The Cohen's value ($d = 0.20$) represents a low effect size, indicating that the difference in the scores is trivial.

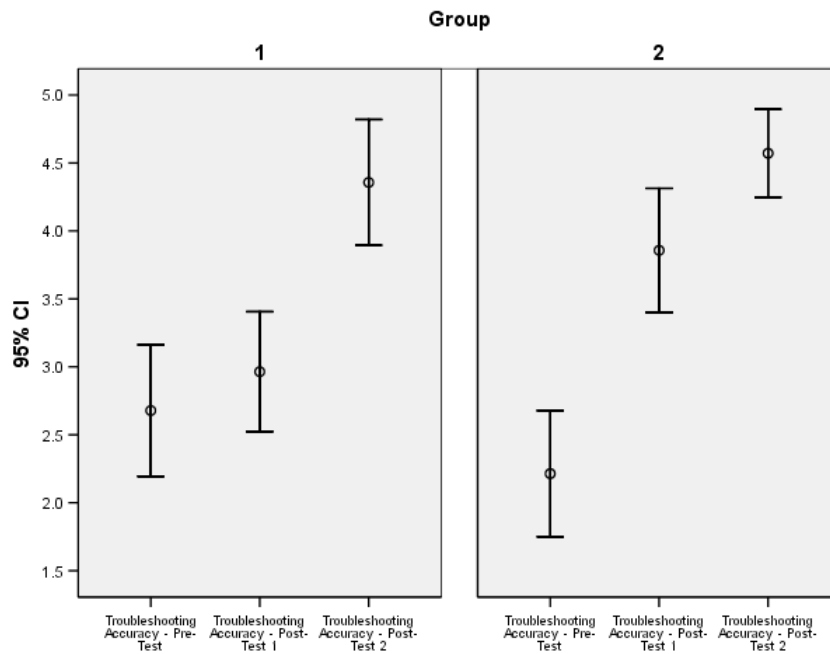


Figure 22. Graph of troubleshooting accuracy trends. 95% confidence. Group 1 = No-virtual-lab group. Group 2 = Virtual-lab group.

The graph in figure 22 shows the progression of the means of the participants' scores over time. It can be seen that the general trend for both groups was an overall increase of the participants' troubleshooting accuracy after the entire training period.

Results for Null Hypothesis 4

Null Hypothesis 4. There is no significant difference in the time taken to troubleshoot real network equipment between students who practiced on a virtual lab prior to practicing on a real lab and those who did not practice on a virtual lab prior to practicing on a real lab.

The independent variable is the type of training of the two groups and the dependent variable is the troubleshooting time in minutes.

Pre-test. The distribution of the troubleshooting time for the two groups in the pre-test is given in figure 23. The two distributions met all the criteria of the independent T-test.

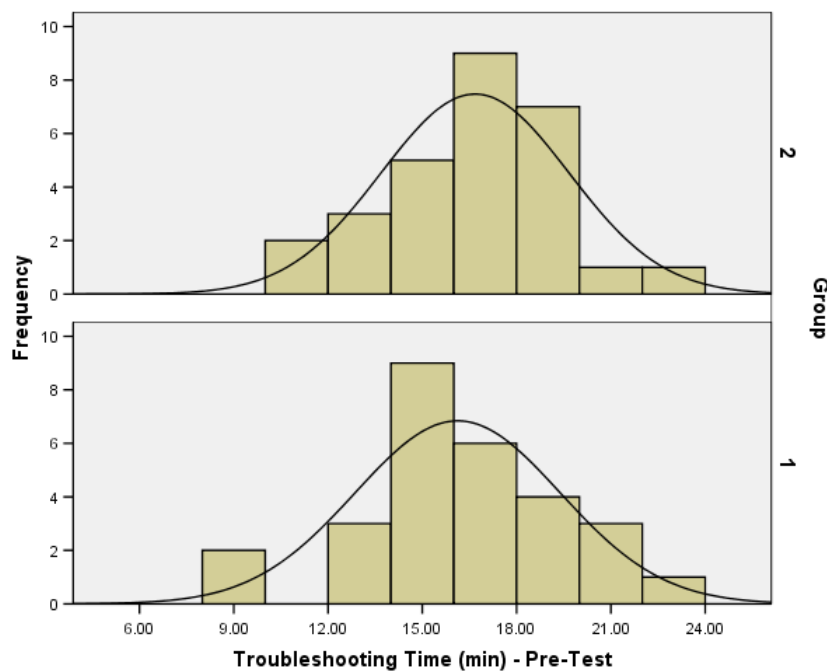


Figure 23. Distribution of troubleshooting time in pre-test. Group 1 = No-virtual-lab group. Group 2 = Virtual-lab group.

Table 18

Result of Independent t-test of Pre-Test for Troubleshooting Time.

	N	Mean	Std. Deviation	<i>p</i>
Group 1 No Virtual Lab Practice	28	16.12	3.27	0.512
Group 2 Virtual Lab Practice	28	16.67	2.99	

Note. Significance ($*p < 0.05$)

Table 18 shows the result of the two-tailed independent t-test for the pre-test.

The mean time taken for the no-virtual-lab group and group 2 were 16.12 and 16.67 minutes respectively. The translated into a $p = 0.512$. There is no significant difference between the two groups with respect to troubleshooting time since $p (0.512) > \alpha (0.05)$. Therefore, the two groups were statistically equivalent with respect to troubleshooting time.

Post-test 1. The distribution of the troubleshooting time for the two groups in post-test 1 is given in figure 24. The two distributions met all the criteria of the independent T-test.

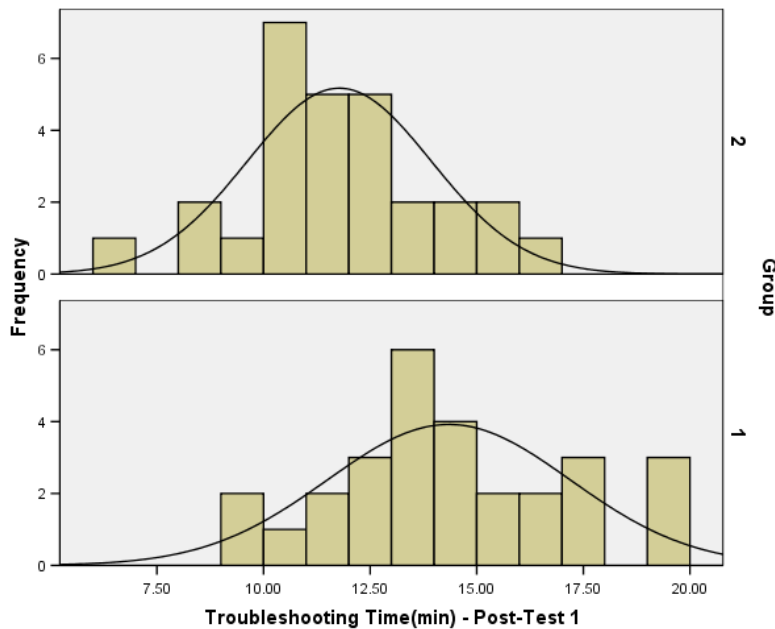


Figure 24. Distribution of troubleshooting time post-test 1. Group 1 = No-virtual-lab group. Group 2 = Virtual-lab group.

Table 19

Result of Independent t-test of Post-Test 1 for Troubleshooting Time

	N	Mean	Std. Deviation	<i>p</i>
Group 1 No Virtual Lab Practice	28	14.34	2.85	0.01
Group 2 Virtual Lab Practice	28	11.77	3.16	

Note. Significance ($p < 0.05$)

Table 19 gives the result of the two-tailed independent t-test for post-test 1.

There is a significant difference between the two groups with respect to configuration time, since $p (0.01) < \alpha = 0.05$. The group who practiced on the virtual labs took significantly less time to troubleshoot faults than the group who did not practice on virtual labs.

Post-test 2. The distribution of the troubleshooting time for the two groups in post-test 2 is given in figure 25. The two distributions met all the criteria of the independent T-test.

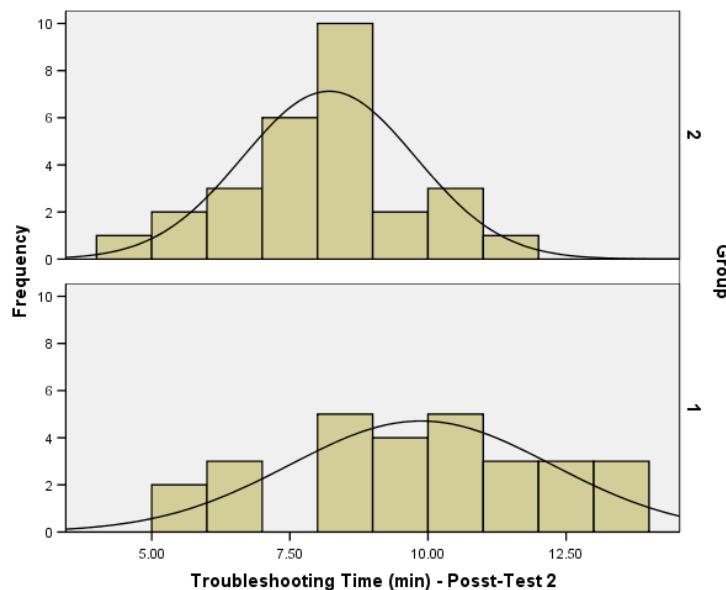


Figure 25. Distribution of troubleshooting time post-test 2. Group 1 = No-virtual-lab group. Group 2 = Virtual-lab group.

Table 20

Result of Independent t-test of Post-Test 2 for Troubleshooting Time

	N	Mean	Std. Deviation	<i>p</i>
Group 1 No Virtual Lab Practice	28	9.87	2.37	0.03*
Group 2 Virtual Lab Practice	28	8.21	1.87	

Note. Significance ($*p < 0.05$)

Table 20 gives the result of the two-tailed independent t-test for the post-test 2. The null hypothesis is rejected at $\alpha = 0.05$ significance level because there is sufficient evidence to reject the null hypothesis according to the *p*-value calculated. The two-tailed *p*-value (0.03) is less than $\alpha = 0.05$. Therefore, it is concluded that there was a significant difference in the means of the troubleshooting time between the virtual-lab group and the no-virtual-lab group. The group who practiced on virtual labs prior to practicing on real labs took significantly less time to troubleshoot real network equipment than the group who did not. The Cohen's value *d* (= 0.77) represents a large effect size, indicating that the mean difference (1.65) between the two groups is substantive.

Progression of time to troubleshoot for the two groups is given in the chart in figure 26 confidence of 95%. A trend of faster troubleshooting times is observable as the training progresses.

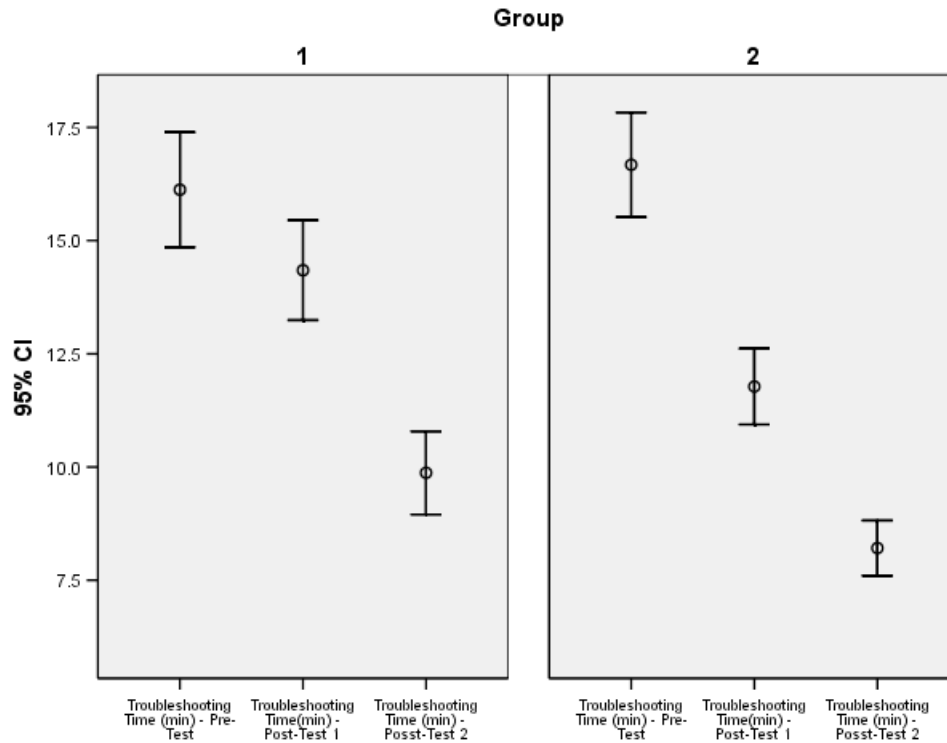


Figure 26. Graph of troubleshooting time trends. 95% confidence. Group 1 = No-virtual-lab group. Group 2 = Virtual-lab group.

Performance Gains

In this section, results of performance gains of the training are presented. These results measure the effectiveness of the virtual and real lab training on student performance of configuring and troubleshooting tasks. Performance gains compare the results of participants' scores prior to and after training interventions within the same groups. Paired sample t-tests were used to determine if there is a significant difference in the scores of the pre-test and post-test within groups.

Virtual Lab Performance Gains

In measuring the performance gains of the virtual lab training, a comparison of the pre-tests and post-tests 1 of the Virtual-lab-Group was conducted by calculating the paired difference in the paired t-test. Table 21 shows the results of the paired t-test for each variable.

Table 21

Performance Gains for Virtual Labs

Variable	Pre-test mean	Post-test 1 mean	<i>p</i>	Effect size (Cohen's <i>d</i>)
Configuration Accuracy	15.64	17.29	0.011*	2.25
Configuration Time (min)	66.07	53.21	0.021*	3.29
Troubleshooting accuracy	3.18	4.04	0.034*	0.97
Troubleshooting Time (min)	16.68	11.77	0.015*	3.07

Note. Significance * $p < 0.05$

The mean comparisons for all variables resulted in p -values less than $\alpha(0.05)$, therefore showing significant differences between all pre-tests and post-tests 1. In all the cases, participants who practiced on the virtual labs on average performed better in post-test 1 than in the pre-test. The effect size measured using Cohen's d , showed the extent of the gains. Cohen's d measures differences in the means normalized to the standard deviation. Therefore, an effect size of 2.25 indicates that the post-test was 2.25 standard deviations larger than pre-test. The calculated effect sizes of 2.25, 3.29, 0.97 and 3.07 for configuration accuracy, configuration time, troubleshooting accuracy and troubleshooting time respectively indicate large effects due to virtual lab practice.

Real Lab Performance Gains

In measuring the performance gains of the real lab training, a comparison of the post-tests 1 and post-tests 2 of the No-virtual-lab group (no virtual lab) was conducted by calculating the mean difference in the paired t-test. In this case the post-test 1 was used as the pre-test as it was conducted immediately before the training. Table 22 presents the results of the paired t-test results for each variable.

Table 22

Performance Gains for Real Labs

Variable	Post-test 1 mean	Post-test 2 mean	<i>p</i>	Effect size (Cohen's <i>d</i>)
Configuration Accuracy	15.50	18.36	0.015*	2.25
Configuration Time (min)	63.43	49.96	0.013*	2.44
Troubleshooting accuracy	3.61	4.18	0.022*	0.62
Troubleshooting Time (min)	14.35	9.87	0.017*	3.26

Note. Significance * $p < 0.05$

The mean comparisons for all variables resulted in $p < 0.05$, therefore showing significant differences between post-test 1 and post-test 2. In all the cases students performed better in post-test 2 than in post-test 1. Effect sizes of 2.25, 2.44 and 3.26 for configuration accuracy, configuration time and troubleshooting time respectively are large effects.

Troubleshooting accuracy had an effect size of $d = 0.62$ which is a modest gain.

Transfer Percentage

Transfer of training measured the extent to which training on the virtual equipment was transferred to the real equipment. The transfer percentage measures the percentage improvement between the virtual-lab and the no-virtual-lab group. This was calculated by the difference in the post-test 1 score between the virtual-lab and the no-virtual-lab group, divided by the no-virtual-lab group score, and all multiplied by 100. Table 23 gives the calculated transfer percentages

Table 23

Transfer Percentages

Variable	No-virtual-lab Group	Virtual-lab Group	Percent transfer
Configuration Accuracy	15.50	17.29	11.5%
Configuration Time (min)	63.43	53.21	-16.1%
Troubleshooting accuracy	3.61	4.04	11.9%
Troubleshooting Time (min)	14.35	11.77	-17.9%

From table 23 it can be inferred that 5 trials of practice on virtual labs increased accuracy of configuration and troubleshooting on real equipment by 11.5% and 11.9% respectively. In addition the same virtual lab training reduced time of configuration and troubleshooting by 16.1% and 17.9% respectively.

Summary of Results

After testing each of the four hypotheses two were rejected and two were retained. It was found that there was no significant difference in the final configuration accuracy and troubleshooting accuracy in the final test between the two groups. On the other hand, it was found that there was a significant difference in the configuration time and troubleshooting time. In both instances, the group who had prior training on the virtual labs performed faster than the group who did not have prior training on virtual labs. Table 24 shows a summary of the results.

Table 24

Summary of Results for Each Null Hypothesis

Null Hypothesis	Variable	No-virtual-lab	Virtual-lab	<i>p</i>	Accept/Reject Null Hypothesis
1	Configuration Accuracy	18.36	19.36	0.06	Retain
2	Configuration Time	49.96	43.46	0.011*	Reject
3	Troubleshooting Accuracy	4.36	4.57	0.440	Retain
4	Troubleshooting Time	9.87	8.21	0.03*	Reject

Note. Significance * $p < 0.05$

Calculating the performance gains by calculating the effect size revealed that both the virtual and real labs contributed to student improvements in configuration and troubleshooting accuracy and time. In all cases there was a significant difference between the pre-test scores and the post-test scores. The gains which differed between tasks were comparable in magnitude between treatments. Table 25 summarizes the findings on performance gains.

A calculation of transfer percentage revealed that there was positive transfer from the virtual lab to the real lab for all the tests. Participants who used virtual labs scored 11.5% and 11.9% better in configuration and troubleshooting real equipment respectively, than their counterparts who did not practice on virtual labs. Similarly there was a reduction of 16.1% and 17.9% in time to configure and troubleshoot due to the use of virtual labs. This is also positive transfer as reduction in time is the desired goal of the training.

Table 25

Comparison of Performance Gains of Virtual and Real Labs.

Variable	Virtual lab gains		Real lab gains (Cohen's d)	
	Effect size (d)	<i>p</i>	Effect size (d)	<i>p</i>
Configuration Accuracy	2.25	0.011*	2.25	0.015*
Configuration Time	3.29	0.021*	2.44	0.013*
Troubleshooting accuracy	0.97	0.034*	0.62	0.022*
Troubleshooting Time	3.07	0.015*	3.26	0.017*

Note. *Significance* * $p < 0.05$

Further discussion and conclusions based on the results reported in this chapter will be presented in the next chapter.

CHAPTER 5 - SUMMARY, CONCLUSIONS, DISCUSSION, AND RECOMMENDATIONS

In this chapter a summary, conclusions, discussion, and recommendations of the study are presented.

Summary

The purpose of this study was to determine the effectiveness of using virtual lab practice in the transfer of computer networking skills to real hands-on labs. The research was conducted to determine whether time spent training in a virtual laboratory had a positive additive contribution to the acquisition of practical skills needed in computer networking. The skills were broken into routine and adaptive skills which in this case were configuration and troubleshooting of computer networking equipment. Proficiency was measured by the accuracy and speed with which participants completed computer networking tasks.

Problem Statement

The effectiveness of using virtual labs to train students in computer networking skills when real equipment is limited is uncertain (Annisetti et al., 2007). Virtual labs have been found useful for teaching for a number of reasons including, remote access for distance education, low cost, reliability, security, flexibility, and convenience to the student (Auer, Pester, Ursutiu, & Samoila, 2004). However, there has been a lingering debate on their effectiveness in student learning of skills (Corter et al., 2007). In this study a direct comparison of the transfer of skills from the virtual lab to the real lab was conducted. This was accomplished using experimental comparison of two groups subjected to different treatments, using measurable variables of accuracy and time of configuration and troubleshooting.

Research Questions and Null Hypotheses

The study sought answers to the following research questions:

1. Is there a significant difference in the accuracy of configuring real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and students who did not practice in a virtual lab prior to practicing in a real lab?
2. Is there a significant difference in the time taken to configure real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and students who did not practice in a virtual lab prior to practicing in a real lab?
3. Is there a significant difference in the accuracy of troubleshooting real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and students who did not practice in a virtual lab prior to practicing in a real lab?
4. Is there a significant difference in the time taken to troubleshoot real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and students who did not practice in a virtual lab prior to practicing in a real lab?

The following are the null hypotheses associated with the research questions:

1. There is no significant difference in the accuracy of configuring real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and those who did not practice in a virtual lab prior to practicing in a real lab.

2. There is no significant difference in the time taken to configure real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and those who did not practice in a virtual lab prior to practicing in a real lab.
3. There is no significant difference in the accuracy of troubleshooting real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and those who did not practice in a virtual lab prior to practicing in a real lab.
4. There is no significant difference in the time taken to troubleshoot real network equipment between students who practiced in a virtual lab prior to practicing in a real lab and those who did not practice in a virtual lab prior to practicing in a real lab.

Findings

1. Null hypothesis 1 was retained as there was no significant difference ($p = 0.06$) in the means of the configuration accuracy scores between the virtual-lab group and the no-virtual-lab group. The virtual-lab group scored higher than the no-virtual-lab group with a moderate effect size (Cohen's $d = 0.51$).
2. Null hypothesis 2 was rejected as there was a significant difference ($p = 0.011$) in the means of the configuration time between the virtual-lab group and the no-virtual-lab group. The virtual-lab group completed faster than the no-virtual-lab group with a large effect size (Cohen's $d = 0.7$).
3. Null hypothesis 3 was retained as there was no significant difference ($p = 0.44$) in the means of the accuracy of troubleshooting scores between the virtual-lab group and the no-virtual-lab group. The virtual-lab group scored higher than the no-virtual-lab group with a small effect size (Cohen's $d = 0.2$).

4. Null hypothesis 4 was rejected as there was a significant difference ($p = 0.03$) in the means of the configuration time between the virtual-lab group and the no-virtual-lab group. The virtual-lab group completed faster than the no-virtual-lab group with a large effect size (Cohen's $d = 0.77$).
5. There were significant differences in the configuration accuracy ($p = 0.025$) and configuration time ($p = 0.002$) between the virtual-lab group and the no-virtual-lab group in post-tests 1, which compared virtual lab training to no lab training. These differences resulted in percent transfer gains of 11.5% and 16.1 % respectively.
6. There were significant differences in the troubleshooting accuracy ($p = 0.025$) and troubleshooting time ($p = 0.002$) between the virtual-lab group and the no-virtual-lab group in post-tests 1, which compared virtual lab training to no lab training. These differences resulted in percent transfer gains of 11.9% and 17.9 % respectively.
7. There were significant differences in the configuration accuracy, configuration time, accuracy of troubleshooting, and troubleshooting time after virtual lab practice compared to before virtual lab training for the virtual-lab group.

Conclusions

The following conclusions can be made based on the findings:

- 1. Practicing configuration of computer networks in a virtual lab positively improved students' ability to accurately configure real networking equipment.**

The combined results of the data suggested that even though the null hypothesis was

retained, students beneficially gained accuracy as a result of the practice in the virtual lab. Comparison of students' gains in accuracy after only using the virtual lab to those who did not use virtual labs, showed a significant difference in favor of the virtual-lab group. In addition, a comparison of the pre-test and post-test scores of virtual lab practice showed significant performance gains.

- 2. Practicing configuration of computer networks in a virtual lab reduced the amount of time students configured real networking equipment.** The data analysis showed a significant reduction in the amount of time it took students to complete network configurations on real networks after practicing in the virtual labs. In addition, after further training using the real lab, the students that had prior practice in the virtual lab performed their configuration tasks faster than their counterparts who had no prior virtual lab practice.
- 3. Practicing troubleshooting of computer networks in a virtual lab improved students' ability to accurately troubleshoot networking faults on real equipment.** Students who practiced in virtual labs were able to identify and fix more faults than their counterparts who did not perform any virtual labs. Both groups showed further improvements when they practiced on the real equipment.
- 4. Practicing troubleshooting of computer networks in a virtual lab reduced the amount of time students troubleshot networking faults on real equipment.** From the data analysis, it was evident that prior practice on the virtual lab significantly reduced troubleshooting time for the students who had prior practice in the virtual lab..Students were quicker in their ability to spot faults and find solutions with prior

practice in virtual labs. Comparison of troubleshooting times immediately after virtual lab practice showed a significant reduction in troubleshooting times.

5. **Computer networking configuration skills learned in a virtual lab were transferred to the real lab.** The combined effects of improved accuracy and increased speed of configuration of real networking equipment after virtual lab training, indicated that the skills learned were transferred between the lab environments. Positive transfer ratios were recorded in both configuration accuracy and configuration time.
6. **Computer networking troubleshooting skills learned in a virtual lab were transferred to the real lab.** The coupling of improved accuracy and increased execution speed of troubleshooting, supported the claim that troubleshooting skills were transferred from the virtual to the real lab. In addition, positive transfer ratios were recorded in both troubleshooting accuracy and time.

Discussion

From the findings, there is evidence that the use of virtual labs positively contributes to the transfer of practical computer networking skills from the virtual lab to the real lab environment. Practice in virtual labs improved students' rate of execution and increased accuracy of both configuration and troubleshooting on the real equipment. Similarly, DiCerbo, West, Frezzo, Behrens, and Cisco (2009), in a three group comparison of a virtual lab, real lab, and no-virtual-lab group, found no significant difference in the accuracy of configuration between the virtual, and real lab groups. However, the virtual and real lab groups performed significantly better than the no-virtual-lab group ($p < 0.001$). That study, commissioned by Cisco[®], concluded that “some skills that can be adequately simulated can be learned via simulation in such a way that

they can be transferred to real world scenarios” (DiCerbo et al., p.16). Therefore, at the very least, well designed virtual labs can do no harm and at the most, they can be used as surrogates to real labs for some networking skills. Frezzo (2009) in a qualitative study observed that students improved in their troubleshooting skills using Packet Tracer[®], the same virtual lab used in this study. However, both of these studies did not measure speed of execution,

Anisetti et al. (2007) found similar gains in the acquisition of network security skills using a virtual lab. These skills also involved the ability for students to configure computer security equipment and troubleshoot breaches to the system. Jinhua, Weidong, and Shengquan, (2007) investigated the use of virtual lab to teach students about network traffic patterns and found that students had a better understanding of the intricate details of actual networking protocols after using the virtual lab.

Performance gains of the virtual labs and the real lab treatments in this study were of comparable value across all the tests. There were statistically significant differences between the pre-test and the post-tests in the virtual and real lab scores for all the dependent variables. Comparison of the effect sizes of the virtual lab and the real lab practice, showed comparable gains between the two treatments. The effect size of the configuration accuracy was identical between the two treatments. Virtual lab practice was more efficient in improving configuration accuracy and troubleshooting time. Real lab practice was more efficient in improving time to troubleshoot than virtual labs. This result gives strong evidence that virtual lab practice was just as effective as the real lab in student’s acquisition of the target skills.

After the gains of the initial five trials of practice by the virtual lab practice group, the rate of improvement tapered off when students switched to the real lab environment. A possible explanation for this is that the rate of improvement reduces with the inverse power law proposed

by Newell and Rosenbloom (1981). The more students improved the harder it was to make further improvements. This may explain the reason why the real lab group tended to close the performance gap between the first post test and the second one.

After students trained on virtual labs, performance gains in configuration accuracy and troubleshooting accuracy slowed down when they continued with real lab training. It seems that the ceiling in the configuration and troubleshooting accuracy was transferred into improvements in the configuration and troubleshooting time. It is important to note that there may be issues of lack of independence of the two variables. For instance students who find that they are making more mistakes may slow down in their execution to improve accuracy.

Relevance

It is hoped that the findings in this study will contribute to the understanding of the feasibility of using virtual labs in programs, that require practical skills as a core component of training, but in which student access to equipment is limited. The positive transfer of skills from the virtual lab to the real lab in this study provide measured evidence of transfer of training in computer networking skills fashioned on established methods in pilot and military training. The findings indicate that appropriate pedagogical use of a well designed virtual lab is possible provided an environment for authentic learning of routine and adaptive skills relevant in real environments.

Transfer of skills from the virtual lab to the real lab provided evidence of experiential equivalence between the real and virtual environments. Substitution of real interaction with virtual interaction at a basic functional level seemed to provide similar cognitive schema building in the student with respect to the two environments. It is as if the student suspends belief long enough to build an internal functional model of the behavior of the system. Ma and

Nickerson (2006, p. 1) observed “that the boundaries among the three labs (remote, simulated and hands-on) are blurred in the sense that most laboratories are mediated by computers, and that the psychology of presence may be as important as technology”. Participants training in the virtual environment were able to form habitual reflexive routines in addition to developing the situational awareness necessary for quick and accurate configuration and troubleshooting needed in the real environment. This is in conformity with Ericsson (1993), who asserted that practice leads to an automatic execution of tasks. Feedback from the virtual lab seems to act as a source of reinforcement of students’ mental schema of the configuration environment. Students gained a sense of what is going on inside the virtual machine and through self correction, improved both accuracy and speed. Jacobs (1975) observed the same phenomena in pilot training. After practicing in virtual labs, students spent less time thinking of their actions but instead developed an automatic condition and action response after each trial. In this study, the acquired automaticity of action seems to have been transferred from the virtual to the real environment.

Relevance for Skills Training in Zambia

In developing countries such as Zambia, where the study was conducted, the acute shortage of networking equipment for training make teaching of computer networking skills difficult. The Zambian Ministry of Science Technology and Vocational Training (2003), in its strategic plan, observed that building Information Communication Technologies (ICT) lab infrastructure for training is key to building capacity for provision of technical, vocational and entrepreneurship skills. Appropriate and effective utilization of virtual labs should be promoted, from a policy and teaching standpoint, as a way to alleviate this capacity gap. The use of virtual labs in Technical Education Vocational and Entrepreneurship Training (TEVET) institutions could

be promoted as a way of reducing costs and increasing enrollment while making sure that quality is not compromised. Institutions can train faculty on the usage of virtual labs to maximize enrollment without compromising quality. Quality can be assured by making sure that the appropriate amount of virtual and real lab training time is used to teach students. Skepticism by faculty on the effectiveness of using virtual labs in skills training can be overcome by exposing them to virtual labs in their field. In some instances limitations of the use of virtual labs to replicate hands on performance should also be clearly pointed out.

From a teaching perspective, using virtual labs as a complementary part of the hands on training would increase the capacity to teach networking skills to larger groups. The amount of time students would require to practice, using scarce networking equipment, would be reduced if practicing in virtual labs contributed toward the acquisition of the target skills. The virtual lab could be installed on shared computers on which students would have more access time. This would enable students to actively practice procedures learned in theoretical sessions. The real lab can then be used by more students in a time-shared fashion.

Limitations

As encouraging as the findings of this study appear, caution must be taken on the scope and context in which such results are applicable. In this section, external validity and limitation of interpretation are discussed.

This study does not make any assumptions on students' gains in theoretical understanding, design capabilities, or management of computer networks. Findings are limited to gains in troubleshooting and configuration skills of computer networking using routers.

There could also be issues relating to confounding effects. An alternative explanation of the findings may be that the virtual-lab group performed better in the final post-test simply

because they spent more time thinking about the subject matter as opposed to the beneficial effects of virtual lab practice. After the theory training, the no-virtual-lab group had a period of time when they had no activities to complete. Hence, this may have led to students in the no-virtual-lab group forgetting some of the knowledge acquired. Motivational differences of the groups, due to two day lay off of the no-virtual-lab group could have also affected the result. However, this would further support the original assertion that time spent in virtual labs further enhances learning. The first post-tests showed that students who were idle performed worse than those who practiced in virtual labs. A way to improve the design may be to have a three group experiment with a virtual-lab group, a real-lab group, and a no-virtual-lab group. This requires more participants to reach the desired statistical power. Using more participants in the design could further increase the credibility of the findings as the statistical power would improve.

The applicability of the results of this study to other areas of training, both within and outside computer networking, should be approached with some caution. The choice of the skills and tasks in this study were made to maximize authenticity of the virtual lab experience to the real lab experience. Therefore, the choice of the virtual lab was dependent on interface and behavioral characteristics that were almost identical between the two environments. Hence, Packet Tracer[®] was used in this study as it was developed by the same company that developed the real machines. It is not clear the extent to which discrepancies of the user interface layout and functionality would affect the results between the virtual and real environment. In the execution of the study, care was taken to minimize the possible effects of such differences. The internet operating system of the virtual machines sometimes differed slightly from the actual equipment in syntax and supported protocols, but these differences were very minor.

Another issue of the portability of the results is the extent to which physical skill differences between the virtual and physical environments affect the results. When configuring the virtual and real computer networks, both groups of participants performed the majority of their actions on the command line interface. However, when using the real equipment, participants had to make real physical connections requiring some skills that are absent in the virtual environment. In this study, a deliberate attempt was made to reduce motor-related skills to connecting of cables in order to concentrate on the command line interface skills. Care must be taken in generalizing these results to environments that may have large differences in the amount of real physical motor skills that may not be encompassed in the virtual lab environment.

External validity of the results depends on the target population and settings of the study. Students in this study were full time students in a computer networking course on site at University of Zambia. These results may differ if they are to be used to enhance students' skills acquisition in distance learning for instance. Isolation, differences in computing equipment, and the lack of homogeneity of computer skills of the target population could have a great effect on the outcomes of the study. Further investigations using samples of different target population could shed facilitate exploration on the effectiveness of using virtual labs to learn computer networking skills in distance education.

Recommendations

As a result of the conclusions made, the following are recommendations for further study and teaching practices.

Recommendations from the Study

Based on the findings and conclusions of this study, the following recommendations are being made.

1. Investment in the development and usage of virtual labs in the training of students in computer networking is worthwhile provided it meets the pedagogical threshold of authenticity of learning. If the virtual lab training produces negative transfer of learning by the introduction of erroneous habits in the students, this could actually do more harm than good.
2. Educators should use virtual labs to allow students to practice asynchronously. Where access to real networking equipment is limited but access to computers or the Internet is possible, virtual labs can be used to afford students the opportunity to practice and experiment with the networking environment in their own time and place.
3. Distance education students can practice in virtual labs and later transfer the skills to the real lab when they attend on site training. Transfer of training from the virtual to the real lab could reduce the length of the residential training period.
4. Virtual labs could be used to promote self directed learning by giving students the opportunity to safely explore computer networking scenarios and possibilities. Students can experiment with different network configurations and discover for themselves different possibilities and limitations of the technology.
5. Practice in virtual labs to reduce troubleshooting time on computer networks is a useful activity in situations in which the real equipment is not available. This is in tandem with the theory that virtual labs gives students extra practice time which in turn allows them to try out different things not available in the real lab setup.
6. Transfer of skills between the virtual lab and the real lab implies that the virtual lab can be used to assess proficiency. In career and technical education the final objective of training is the acquisition of practical skills but often the equipment is not available to

assess students due financial limitations. Virtual labs can be used for practical skills assessment as long as they reliably and validly represent the real lab.

Recommendations for Further Study

Based on the findings and conclusions of this study, recommendations for further research are as followings:

1. Research-based standardized pedagogical measurement instruments should be developed. These would be used to measure effectiveness of a particular virtual lab for its intended use.
2. Conduct similar studies in other fields. This could further improve confidence in the pedagogical effectiveness of using virtual labs for teaching and training.
3. Conduct a longitudinal study into the effects of virtual lab training on real work performance.
4. Conduct more targeted studies related to:
 - a. limitations of using virtual labs in training.
 - b. amount of authenticity needed in virtual labs for them to be effective.
 - d. factors that most effect performance when using virtual labs-
 - e. dangers of misrepresentation of the real system in the virtual lab on student performance in troubleshooting-
 - f. contributions virtual labs may have toward the development of a learner's mental simulations capabilities
 - g. effectiveness of using virtual labs in a self-directed learning environment.
 - h. effectiveness of using virtual labs to design and manage computer networks.

Concluding Remarks

The findings of the study justify the use of virtual labs as a teaching tool in computer networking. The amount of time students spent in the virtual lab had a positive contribution to

their acquisition of the target skills. However it is important to bare in mind that teaching methods are the most important factor in attainment of skills and the virtual lab is a tool in that objective. The veracity of the findings depends on replication of the results using similar design methodologies. Educators can use virtual labs to allow students practice asynchronously with the intention of scheduling them to use the real equipment when it becomes available. In developing countries, such as Zambia, virtual labs can be used to increase capacity for computer networking labs. For distance education, students can practice in virtual labs and later transfer the skills to the real lab when they attend on site training. Transfer of training from the virtual to the real lab could reduce the length of the residential training period using the real equipment. In conclusion, the investment in the development and usage of virtual labs in the training of students in computer networking is worthwhile provided it meets the pedagogical threshold of authenticity of learning.

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APPENDIX A

Instruments

Instrument 1: Pre-test

Lab Test

Configuring a small network using a router on a virtual lab

Unit: Configuring Network Devices

Introduction

In this laboratory test, you will use the skills that you have learned in Packet Tracer® to configure a virtual small office network using a router.

Scenario

You have been assigned by your network manager at company ZANET to install a small office network which has already been designed. As a first task in the process you have to create a basic configuration of the Integrated Services Router (ISR) in a lab. The following router configuration specifications are given.

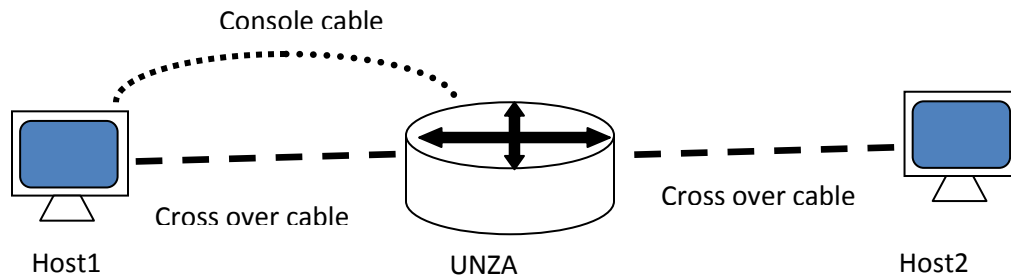
Interface	IP address	Subnet mask
Fa0/0	10.0.0.1	255.255.255.0
Fa0/1	10.0.1.1	255.255.255.0
Host computer		
Host1	10.0.0.2	255.255.255.0
Host2	10.0.1.2	255.255.255.0

Router name: UNZA

Console password: Lusaka123

Enable password: Kitwe456

Virtual Terminal: Password: Ndola789



Instructions

Your task is to make a basic configuration of the router to fulfill the specifications given above.

Hardware	Qty
Cisco Router	1
Computer host with Windows	2
Console cable	1
UTP crossover cable	2

Complete the following tasks as quickly and as accurately as you can:

1. Connect the devices based on the network diagram.
 - a. Connect the console cable to the Router. On the computer side use the DB9 adapter to connect to the serial interface.
 - b. Connect a crossover cable from the computer to the router's fa0/1 Ethernet connection.
2. Connect the host computer to the router using HyperTerminal.
3. **Login (Timer starts)**
4. Set the router global configuration name to ZANET1.
5. Set the router access passwords.
 - a. Configure the console password.
 - b. Configure the privileged executive password in encrypted format.
 - c. Configure the virtual line passwords.
6. Configure Router interfaces

- a. Set the router interface fa0/0 with IP address given in the specifications. Activate the interface.
 - b. Set the router interface fa0/1 with IP address given in the specifications. Activate the interface.
 - c. Configure the host computer with the IP address given in the specifications.
7. Set static routes to the two networks with host1 and host2.
 8. Verify network connectivity.
 - a. Ping from the computer to the routers two Ethernet ports. Troubleshoot and fix if the connection is not going through.
 9. Save your configuration to NVRAM. Copy the configuration file and paste it in notepad. Print out the configuration file and hand it in.
- 10. Logout**
- 11. DO NOT DISCONNECT OR SWITCH OFF THE DEVICES BEFORE THE INSTRUCTOR HAS HAD CHANCE TO EXAMINE AND GRADE THE TEST.**
12. Deliverables
 - a. A completed connected and configured router in the laboratory.
 - b. A router configuration file.

Solution

Task Checklist

Task	Evidence in configuration file or prompt
Router name set correctly	hostname UNZA
Encrypted password set for EXEC mode	enable secret 5 \$1\$mERr\$5Qi10mHKg3LmVOQWWOjG8.
Console line password protection set	line con 0 password Lusaka123
Login password protection set	line vty 0 4 password Ndola789 login
Router Ethernet interface (Fa0/0) IP address set	interface FastEthernet0/0 ip address 10.0.0.1 255.255.255.0
Subnet mask for Fa0/0 configured correctly.	interface FastEthernet0/0 ip address 10.0.0.1 255.255.255.0
Router Ethernet interface (Fa0/0) switched on	protocol up
Router Ethernet interface (Fa0/1) IP address set	interface FastEthernet0/0 ip address 10.0.1.1 255.255.255.0
Correct subnet mask for Fa0/1 configured correctly	interface FastEthernet0/0 ip address 10.0.1.1 255.255.255.0
Router Ethernet interface (Fa0/1) switched on	protocol up
Static route to network connected to Fa0/0 configured correctly	ip route 10.0.0.0 255.255.255.0 FastEthernet0/0
Static route to network connected to Fa0/1 configured correctly	ip route 10.0.1.0 255.255.255.0 FastEthernet0/1
PC Host1 IP address set correctly	IP Address.....: 10.0.0.2
PC Host1 subnet mask set correctly	Subnet Mask.....: 255.255.255.0
PC Host1 default gateway set correctly	Default Gateway.....: 10.0.0.1

PC Host2 IP address set correctly	IP Address.....: 10.0.0.1
PC Host2 subnet mask set correctly	Subnet Mask.....: 255.255.255.0
PC Host2 default gateway set correctly	Default Gateway.....: 10.0.1.1
Connectivity	
PC Host1 to Router connectivity established	Ping statistics for 10.0.0.1: Packets: Sent = 4, Received = 4, Lost = 0 (0% loss)
PC Host2 to Router connectivity established	Ping statistics for 10.0.0.2: Packets: Sent = 4, Received = 4, Lost = 0 (0% loss)
PC Host1 to PC Host 2 connectivity established	Ping statistics for 10.0.1.2:Packets: Sent = 4, Received = 3, Lost = 1 (25% loss)

Instrument 2: Post-test 1 Configurations

Lab Test

Configuring a small network using a router

Unit: Configuring Network Devices

Introduction

In this laboratory test, you will use the skills that you have learned and practiced to configure a router for a small office network.

Scenario

You have been assigned by your network manager at company ZANET to install a small office network which has already been designed. As a first task in the process you have to create a basic configuration of the Integrated Services Router (ISR) in a test lab. The following router configuration specifications are given.

Router name: ZANET1

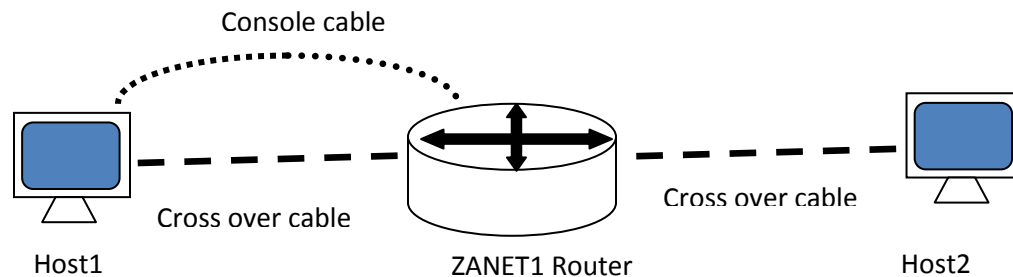
Console password: wiz789KID

Enable password: kid123WISE

Virtual Terminal: Password: wise456MAN

Interface	IP address	Subnet mask
-----------	------------	-------------

Fa0/0	192.168.0.1	255.255.255.240
Fa0/1	192.168.1.1	255.255.255.240
Host computer		
Host1	192.168.0.2	255.255.255.240
Host2	192.168.1.2	255.255.2



Instructions

Your task is to make a basic configuration of the router to fulfill the specifications given above. You have been provided with the following equipment.

Hardware	Qty
Cisco Router	1
Computer host with Windows	2
Console cable	1
UTP crossover cable	2

Complete the following tasks as quickly and as accurately as you can:

Physically connect the devices based on the network diagram.

- c. Connect the console cable to the Router. On the computer side use the DB9 adapter to connect to the serial interface.
 - d. Connect a crossover cable from the computer to the router's fa0/1 Ethernet connection.
1. Connect the host computer to the router using HyperTerminal.

- 2. Login (Timer starts)**
3. Set the router global configuration name to ZANET1.
4. Set the router access passwords.
 - a. Configure the console password.
 - b. Configure the privileged executive password in encrypted format.
 - c. Configure the virtual line passwords.
5. Configure Router interfaces
 - a. Set the router interface fa0/0 with IP address given in the specifications. Activate the interface.
 - b. Set the router interface fa0/1 with IP address given in the specifications. Activate the interface.
 - c. Configure the host computer with the IP address given in the specifications.
6. Set static routes to the two networks with host1 and host2.

7. Verify network connectivity.
 - a. Ping from the computer to the routers two Ethernet ports. Troubleshoot and fix if the connection is not going through.
8. Save your configuration to NVRAM. Copy the configuration file and paste it in notepad. Print out the configuration file and hand it in.
- 9. Logout**
10. **DO NOT DISCONNECT OR SWITCH OFF THE DEVICES BEFORE THE INSTRUCTOR HAS HAD CHANCE TO EXAMINE AND GRADE THE PROJECT.**
11. Deliverables
 - a. A completed connected and configured router in the laboratory.
 - b. A router configuration file.

Solution

Checklist. Same as in pretest with changes to evidence.

Instrument 3: Post-test 2 Configuration

Lab Test

Configuring a small network using a router

Unit: Configuring Network Devices

Introduction

In this laboratory test, you will use the skills that you have learned and practiced to configure a router for a small office network.

Scenario

You have been assigned by your network manager in the department of computer science to install a small office network which has already been designed. As a first task in the process you have to create a basic configuration of the Integrated Services Router (ISR) in a test lab. The following router configuration specifications are given.

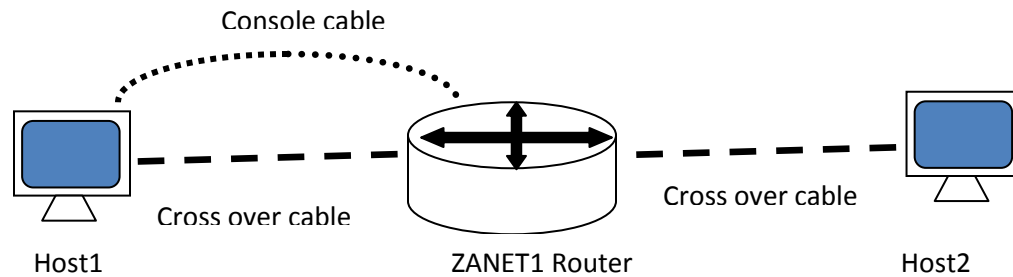
Interface	IP address	Subnet mask
Fa0/0	10.0.0.1	255.255.255.240
Fa0/1	10.0.1.1	255.255.255.240
Host computer		
Host1	10.0.0.2	255.255.255.240
Host2	10.0.1.2	255.255.255.240

Router name: COMSCI

Console password: com123SCI

Enable password: dig123SCI

Virtual Terminal: Password: sci456WIZ



Instructions

Your task is to make a basic configuration of the router to fulfill the specifications given above. You have been provided with the following equipment.

Hardware	Qty
Cisco Router	1
Computer host with Windows	2
Console cable	1
UTP crossover cable	2

Complete the following tasks as quickly and as accurately as you can:

1. Physically connect the devices based on the network diagram.
 - a. Connect the console cable to the Router. On the computer side use the DB9 adapter to connect to the serial interface.
 - b. Connect a crossover cable from the computer to the router's fa0/1 Ethernet connection.
2. Connect the host computer to the router using HyperTerminal.
3. Login (Timer starts)
4. Set the router global configuration name to ZANET1.
5. Set the router access passwords.
 - a. Configure the console password.
 - b. Configure the privileged executive password in encrypted format.
 - c. Configure the virtual line passwords.
6. Configure Router interfaces

- a. Set the router interface fa0/0 with IP address given in the specifications. Activate the interface.
 - b. Set the router interface fa0/1 with IP address given in the specifications. Activate the interface.
 - c. Configure the host computer with the IP address given in the specifications.
7. Set static routes to the two networks with host1 and host2.
 8. Verify network connectivity.
 - a. Ping from the computer to the routers two Ethernet ports. Troubleshoot and fix if the connection is not going through.
 9. Save your configuration to NVRAM. Copy the configuration file and paste it in notepad. Print out the configuration file and hand it in.
 10. Logout
 11. DO NOT DISCONNECT OR SWITCH OFF THE DEVICES BEFORE THE INSTRUCTOR HAS HAD CHANCE TO EXAMINE AND GRADE THE PROJECT.
 12. Deliverables
 - a. A completed connected and configured router in the laboratory.
 - b. A router configuration file.

Solution

Checklist. Same form as in pretest.

Instrument 4: Pre-test Troubleshooting

Lab Test

Troubleshooting a small network using a router

Unit: Configuring Network Devices

Introduction

In this laboratory test, you will use the skills that you have learned and practiced to troubleshoot a router for a small office network.

Scenario

Office clients of the local area network have reported that they cannot connect to each other's computers. You are tasked with the job of finding the faults and fixing them. You are

given the original network specifications as below. Troubleshoot and repair the network to restore it to full connectivity in the lab.

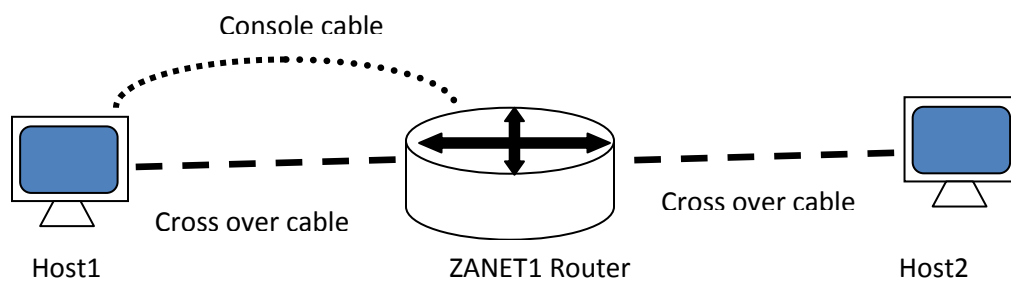
Interface	IP address	Subnet mask
Fa0/0	10.4.0.1	255.255.255.240
Fa0/1	10.4.1.1	255.255.255.240
Host computer		
Host1	10.4.0.2	255.255.255.240
Host2	10.4.1.2	255.255.255.240

Router name: ZANET1

Console password: wiz789KID

Enable password: kid123WISE

Virtual Terminal: Password: wise456MAN



Checklist. Same as in pretest.

Instrument 5: Post-test 1 Troubleshooting

Lab Test

Troubleshooting a small network using a router

Unit: Configuring Network Devices

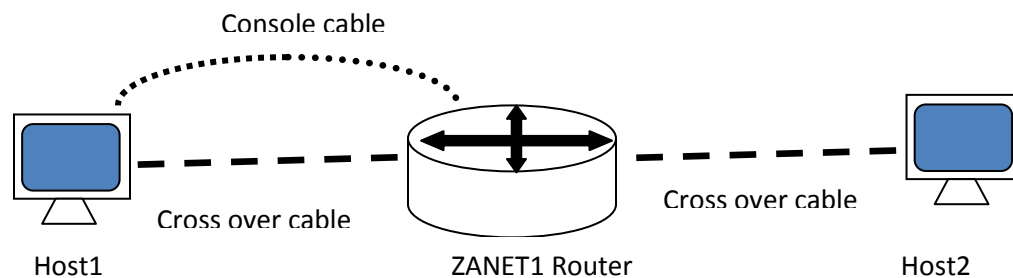
Introduction

In this laboratory test, you will use the skills that you have learned and practiced to troubleshoot a router for a small office network.

Scenario

Office clients of the local area network have reported that they cannot connect to each other's computers. You are tasked with the job of finding the faults and fixing them. You are given the original network specifications as below. Troubleshoot and repair the network to restore it to full connectivity.

Router name: ZANET1
Console password: wiz789KID
Enable password: kid123WISE
Virtual Terminal: Password: wise456MAN



Interface	IP address	Subnet mask
Fa0/0	171.16.0.1	255.255.255.240
Fa0/1	172.16.1.1	255.255.255.240
Host computer		
Host1	172.16.0.2	255.255.255.240
Host2	172.16.1.2	255.255.255.240

Instrument 6: Post-test 2 Troubleshooting

Lab Test

Troubleshooting a small network using a router

Unit: Configuring Network Devices

Introduction

In this laboratory test, you will use the skills that you have learned and practiced to troubleshoot a router for a small office network.

Scenario

Office clients of the local area network have reported that they cannot connect to each other's computers. You are tasked with the job of finding the faults and fixing them. You are given the original network specifications as below. Troubleshoot and repair the network to restore it to full connectivity.

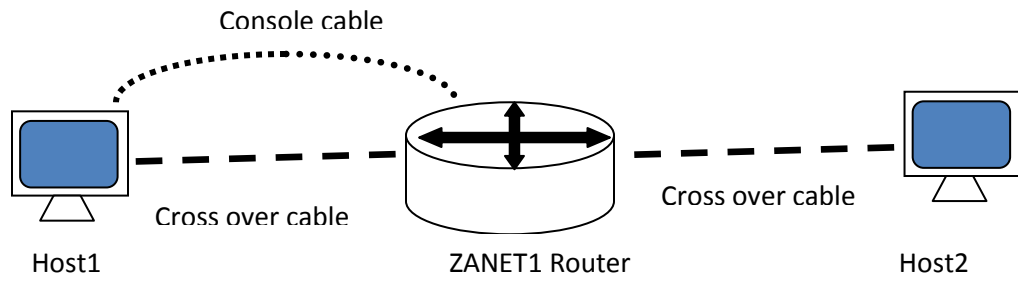
Interface	IP address	Subnet mask
Fa0/0	192.168.0.1	255.255.255.240
Fa0/1	192.168.1.1	255.255.255.240
Host computer		
Host1	192.168.0.2	255.255.255.240
Host2	192.1698.1.2	255.255.255.240

Router name: UNZA

Console password: camp456UNZA

Enable password: kid123WISE

Virtual Terminal: Password: wise456MAN



Appendix B.

CISCO CCNA Skills assessment objectives

Purpose:	The purpose of this Cisco Packet Tracer Practice Skills Based Assessment (PTSBA) is to support student success by providing additional student practice prior to taking the end of course hands-on Skills-Based Assessment (SBA).																								
PT Assessment Objectives:	<p>Using the Claims and Component Skills, design a PT assessment that will collect data about whether or not the student can demonstrate the following skills:</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: left;">Claim#</th> <th style="text-align: left;">Compound Observable/Assessment Objective Statements</th> <th style="text-align: left;">Point %</th> </tr> </thead> <tbody> <tr> <td></td> <td>IP Addressing Design</td> <td>38</td> </tr> <tr> <td>0.3.2</td> <td>The student can subnet a given address space based on given set of requirements.</td> <td></td> </tr> <tr> <td></td> <td>Basic Device Configuration</td> <td>50</td> </tr> <tr> <td>0.4.2;0.4.4;0.4.5; 0.4.6;0.5.2</td> <td>The student can perform basic router and switch configurations including naming, security (passwords and banner motd), interface addressing and activation, and default gateway configuration.</td> <td></td> </tr> <tr> <td>0.3.3;0.5.4</td> <td>From the subnetting scheme, the student can assign valid IP addresses to hosts and networking devices .</td> <td></td> </tr> <tr> <td></td> <td>Verification and Troubleshooting</td> <td>12</td> </tr> <tr> <td>0.3.5;0.5.3</td> <td>The student can identify and correct IP addressing problems, DNS address misconfiguration, and cabling problems.</td> <td></td> </tr> </tbody> </table>	Claim#	Compound Observable/Assessment Objective Statements	Point %		IP Addressing Design	38	0.3.2	The student can subnet a given address space based on given set of requirements.			Basic Device Configuration	50	0.4.2;0.4.4;0.4.5; 0.4.6;0.5.2	The student can perform basic router and switch configurations including naming, security (passwords and banner motd), interface addressing and activation, and default gateway configuration.		0.3.3;0.5.4	From the subnetting scheme, the student can assign valid IP addresses to hosts and networking devices .			Verification and Troubleshooting	12	0.3.5;0.5.3	The student can identify and correct IP addressing problems, DNS address misconfiguration, and cabling problems.	
Claim#	Compound Observable/Assessment Objective Statements	Point %																							
	IP Addressing Design	38																							
0.3.2	The student can subnet a given address space based on given set of requirements.																								
	Basic Device Configuration	50																							
0.4.2;0.4.4;0.4.5; 0.4.6;0.5.2	The student can perform basic router and switch configurations including naming, security (passwords and banner motd), interface addressing and activation, and default gateway configuration.																								
0.3.3;0.5.4	From the subnetting scheme, the student can assign valid IP addresses to hosts and networking devices .																								
	Verification and Troubleshooting	12																							
0.3.5;0.5.3	The student can identify and correct IP addressing problems, DNS address misconfiguration, and cabling problems.																								

Retrieved from <https://www.netacad.com/group/offerings/all-resources>
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Appendix C

Fair Use Evaluation for Cisco CCNA Skills assessment objectives

Fair Use Evaluation Documentation

Compiled using the Fair Use Evaluator [cc] 2008 Michael Brewer & the Office for Information Technology Policy,
<http://librarycopyright.net/fairuse/>

Name: Evans Lampi
 Job Title: PhD Student
 Institution: Virginia Tech
 Title of Work Used: The Effectiveness of Using Virtual Laboratories to Teach Computer Networking Skills
 In Zambia
 Copyright Holder: Cisco
 Publication Status: Published
 Publisher: Cisco
 Place of Publication: San Jose
 Publication Year: 2012
 Description of Work: Skills based assessment for students taking an online course
 Date of Evaluation: January 30, 2013
 Date of Intended Use: February 15, 2013

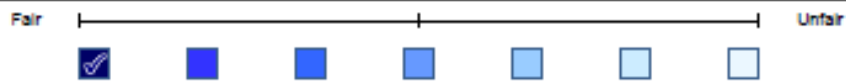
Describe the **Purpose** and Character of Your Intended Use:

[+] Use is for "criticism, comment, news reporting, teaching, (including multiple print copies for classroom use), scholarship or research"



Describe the **Nature** of Your Intended Use of the Copyrighted Work:

[+] Work to be used has been previously PUBLISHED



Describe the **Amount** of Your Intended Use in Relation to the Copyrighted Work as a Whole:

[+] Only limited and reasonable portions will be used



Describe the **Effect** of Your Intended Use on the Potential Market or Value of the Copyrighted Work:

[+] The work is NOT currently under commercial exploitation (out of print, no licensing available, etc.)



The Average **"Fairness Level,"** Based on Your Rating of Each of the 4

Factors, is:

[see tool disclaimer for important clarifying information]:



Based on the information and justification I have provided above, I, Evans Lampi, am asserting this use is **FAIR** under Section 107 of the U.S. Copyright Code.

Signature: _____

Date of Signature: _____

Evans Lampi
01/30/2013

***Disclaimer:** This document is intended to help you collect, organize & archive the information you might need to support your fair use evaluation. It is not a source of legal advice or assistance. The results are only as good as the input you have provided by are intended to suggest next steps, and not to provide a final judgment. It is recommended that you share this evaluation with a copyright specialist before proceeding with your intended use.

Appendix D

IRB Consent form and Approval Letter

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants in Research Projects Involving Human Subjects

Title of Project: The Effectiveness of Using Virtual Laboratories to Teach Computer Networking Skills in Zambia

Investigator(s): Bill Price and Evans Lampi

I. Purpose of this Research/Project

The purpose of this research is to determine whether using virtual labs is effective in students learning practical computer networking skills. 60 students will participate in the study. The students will be at least 18 years old.

II. Procedures

You will take part in a short 3 week course on computer network configuration and troubleshooting. You will be tested for how quickly and accurately you configure and troubleshoot local area networks before, during and after the course. Participants will be randomly assigned to two groups and will follow two different practice methods: practice on virtual labs and no practice. The activities that will be conducted in the computer studies department of the University of Zambia will include:

1. Theory session. 2 hours
2. Pretest. 1 Hour
3. 5 practice rounds. 2 sessions on 2 different days.
4. 1st posttest. 1 hour
5. 5 practice rounds. 2 sessions on 2 different days.
6. 2nd posttest – 1 hour

You will be tested for how quickly and accurately you can configure a local area network given the design specifications. Your saved configuration file will be used to grade your performance. You will be able to see your performance if you wish. No identifying information will be needed.

III. Risks

They are minimal risks associated with this study. You may suffer from opportunity cost due to committing time to the study, which you may have used on some other activity.

IV. Benefits

You may use the skills learned in this study to prepare for your industry certification exams or computer networking course.

No promises or guarantees of benefits have been made to encourage you to participate.

You may contact the researcher at a later time for a summary of the research results.

V. Extent of Anonymity and Confidentiality

Every effort will be made to hide your identity in any written work resulting from this study.

Within the statistical data file you will be identified by a number. Your test files will be labeled with the same number.

The configuration files will be stored in a password protected computer in the researcher's office.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

All data will be destroyed after the publication of any articles resulting from the study or presentations made related to the study.

VI. Compensation

There will be no money given to participants.

VII. Freedom to Withdraw

You are free stop participating in this study at any time.

VIII. Subject's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

- I agree to take practical test to the best of my ability Initial_____

- I agree to allow researchers to record and grade my performance on tests Initial _____

IX. Subject's Permission

I have read the Consent Form and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

_____ Date _____
Subject signature

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research-related injury to the subject, I may contact:

Evans Lampi
Investigator(s)

email: elampi@vt.edu
Telephone/e-mail

Bill Price
Faculty Advisor

+1-540-231-7390 / wprice@vt.edu
Telephone/e-mail

—
Departmental Reviewer/Department Head

Telephone/e-mail

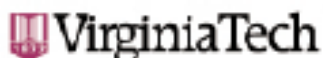
David M. Moore

540-231-4991/moored@vt.edu

Chair, Virginia Tech Institutional Review Board for the Protection of Human Subjects Office of Research Compliance

2000 Kraft Drive, Suite 2000 (0497)

Blacksburg, VA 24060



Office of Research Compliance
 Institutional Review Board
 2000 Kraft Drive, Suite 2000 (0497)
 Blacksburg, VA 24060
 540/231-4808 Fax 540/231-0959
 email irb@vt.edu
 website <http://www.irb.vt.edu>

MEMORANDUM

DATE: May 17, 2012
TO: Bill Price Jr, Evans Lampi
FROM: Virginia Tech Institutional Review Board (FWA00000572, expires May 31, 2014)
PROTOCOL TITLE: The Effectiveness of Using Virtual Laboratories to Teach Computer Networking Skills in Zambia
IRB NUMBER: 12-496

Effective May 17, 2012, the Virginia Tech Institutional Review Board (IRB) Chair, David M Moore, approved the New Application request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

<http://www.irb.vt.edu/pages/responsibilities.htm>

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As: Expedited, under 45 CFR 46.110 category(ies) 7
 Protocol Approval Date: May 17, 2012
 Protocol Expiration Date: May 16, 2013
 Continuing Review Due Date*: May 2, 2013

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Invent the Future

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 An equal opportunity, affirmative action institution