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Building Cloud-Based Information Systems Lab Architecture: Deriving Design Principles that Facilitate the Effective Construction and Evaluation of a Cloud-Based Lab Environment

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Building Cloud-Based Information Systems Lab Architecture: Deriving
Design Principles that Facilitate the Effective Construction and Evaluation
of a Cloud-Based Lab Environment

by

Thomas J. Trevethan

A dissertation report submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in
Computer Information Systems

Graduate School of Computer and Information Sciences

Nova Southeastern University

2015

We hereby certify that this dissertation, submitted by Thomas Trevethan, conforms to acceptable standards and is fully adequate in scope and quality to fulfill the dissertation requirements for the degree of Doctor of Philosophy.

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An Abstract of a Dissertation Report Submitted to Nova Southeastern University in
Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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The problem explored in this dissertation report was that at the time of this study, there were no design principles or methodologies based on design science research (DSR) available to use for artifact construction, implementation, and effective evaluation of cloud-based networking lab environments that can be used to foster hands-on technology skills in students. Primarily based on Hevner's 7 guidelines of DSR, Peffer's design science research methodology (DSRM), and Gregor's IS design theory, this study forms the groundwork for the development of procedures and specifications derived from DSR literature to facilitate the construction, implementation, and evaluation of a comprehensive cloud-based computer and information systems (CIS) laboratory artifact that is globally accessible 24 hours a day and 7 days a week. Secondly, this study guided the construction and implementation of a prototype cloud-based lab environment using the procedures and specifications derived from DSR. The cloud-based lab environment was then evaluated based on the skill level attained by students enrolled in courses that leveraged the proposed system. Results of this study showed that the overwhelming majority of the students who participated in the experiment using the cloud-based lab environment showed statistically significant gains in pretest and posttest scores compared to the students who participated in the experiment using the classroom-based physical equipment. These results fully supported the first hypothesis for this study, that participation in the cloud-based lab environment would promote positive student outcomes. The second hypothesis also was supported. The majority of the experimental group students completed most of the labs and significantly spent more time on the system compared to the control group students using the traditional classroom-based physical lab equipment, which indicated the specifications derived from DSR positively influenced the use of the cloud-based system. An argument was made that the proposed study advances IS and education research through artifact construction and evaluation by correlating Hevner's 7 steps of effective DSR theory, Peffer's DSRM, and Gregor's IS design theory to the problem statement, research questions, and hypothesis in order to develop guiding principles and specifications for building and assessing a cloud-based lab environment.

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Chapter 1

Introduction

Background

Through the use of highly advanced technical resources, computer system technologies are changing the way students experience education from traditional one-dimensional (physical) to multi-dimensional (physical and virtual) learning. These resources include cloud-based web platforms, tablets, video conferences, eBooks, e-learning, iPads, and innovative delivery methods such as virtual reality, mobile, and immersive technologies. Pena-Rios, Callaghan, Gardner, and Alhaddad (2012) considered this paradigm shift a great opportunity for universities and educational institutions to collaborate with partners around the world to be part of technologically advanced education- and knowledge-driven economies. This cloud-based computer system technology phenomenon also enables greater opportunities to experience online distance learning and modifies one's experience of both space and time, changing specific spatial locations to ubiquitous locations and changing time to asynchronous or synchronous based on demanding schedules and classroom flexibility requirements (Pena-Rios et al., 2012). According to Masud and Huang (2012), cloud computing has recently materialized as a fascinating prototype for delivering services over the Internet, and based on the findings in their research, education is certainly no exception.

Potentially, a large number of world class skill-based laboratories running on advanced equipment can now be offered to teachers and students through cloud-based services that can be accessed anytime, anywhere, and from any fixed or mobile device. This, in turn, facilitates the preparation of students to compete for the highly technical information systems (IS) jobs that exist now and will exist into the future. After all, the pursuit of better employment is one of the primary reasons students choose education in the first place. This is a very good reason to leverage technology in order to enhance students' knowledge and skill sets and to prepare them to compete for highly technical positions throughout the industry.

According to Yan (2011), cloud-based educational labs differ from traditional educational labs primarily based on the differences in equipment access, scalability, and performance. In the cloud environment, systems are available on a 24/7 basis and equipment can be scaled on demand with built-in performance enhancement features depending on the number of users and labs accessed simultaneously. Traditional educational lab systems on the other hand are often difficult to access outside school hours and may require long lead time to scale up based on physical resources and personnel available. The potential value in using cloud-based lab environment is realized by preparing students to become proficient in networking administration and security skills because of full time high performance access along with the opportunity to experience continuous reinforcement of complex lab activities.

According to Simon and Jackson (2013), universities should ultimately be responsible for graduating IS students with the skills necessary to be successful in rapidly changing technological environments. Because advanced technology skilled employees enhance

the quality and performance of enterprise-wide IS within an organization, communicating and understanding the skills required for IS work is of the utmost importance. Therefore, the need for graduates with current skill requirements should be a primary concern for educational institutions.

The demand for IS skills has experienced resurgence over the past several years and forecasts for positions with IS skill sets are currently strong as the roles of IS workers are expected to grow into the future. As a result, academic institutions should be aware of the various opportunities for career advancement in IS and design educational programs with technological access that provide skill development in these critical fields.

Janicki, Cummings, and Kline (2013) believe the demand for information technology (IT) professionals continues to be one of the highest in the United States. According to the U.S. News & World Report (2014), IT occupations comprise three of the Top Ten Best Jobs for 2014, with healthcare workers the other major occupation group in the top 10. Additionally, the US Bureau of Labor Statistics estimates an expected growth of 36.5% for information security analysts between 2010 and 2020 (US Bureau of Labor Statistics, 2014).

According to the Wall Street Journal (2015), a barrage of recent online attacks against companies such as Home Depot, Target, Sony, and Anthem set a precedence for cyber security hiring that is estimated to grow at 3.5 times the pace of the overall IT job market in the coming years. In January of 2015, President Obama discussed cyber security in his State of the Union address along with signing an executive order that creates guidelines on how the government and U.S. corporations should cooperate to protect critical U.S. infrastructure. Additionally, a report by Burning Glass International (2014) indicated the

demand for cyber security experts is growing at 2 times the rate of the overall IT job market, making it one of the most highly sought-after fields in the country. CEO Matthew Sigelman of Burning Glass reported that cyber security engineers command an average salary of \$100,000 and the average cyber security manager earns around \$107,000 annually. These are just a few of the recent reports that point out the continued need and demand for IT professionals with skill in cyber security technologies.

The good news is that in parallel with the demand for skilled IT workers commanding high wages, online course enrollments for technology based programs have increased exponentially when compared to traditional brick and mortar classroom enrollments. According to Duck and Parente (2014), it is clear that advancements in technology are entering the educational environment at an extremely accelerated pace. Instead of the traditional physical classroom in the school building, virtual classrooms now exist in coffee shops, living rooms, airports, and other remote locations across the globe. Instead of the traditional lecture halls, we now hold virtual discussion forums that engage groups of students through collaboration, virtual meetings, and digital communication sessions. Although online education and distance learning is still basically evolving, statistics show support for an overall increased enrollment in both of these platforms. The number of students enrolled in distance programs is rapidly rising in colleges and universities throughout the United States, so there is little doubt that life in the traditional classroom setting as we know it is rapidly changing.

Pund and Deshmukh (2012) found that e-learning environments are viable areas of interest for researching remote education delivery platforms. According to their study, cloud computing is rising rapidly as there is an abundant amount of research available in

virtualization, grid computing, utility computing, software defined networks, as well as cloud and application software services that will serve to advance these globally accessible technologies both in educational and business environments. However, there is no research that has been accomplished on how to effectively design a cloud-based lab architecture based on design science that will provide an always accessible environment for students to practice and master the hands-on skills they are lacking in the IS field. This means that remote connection cloud-based lab platform design using advanced technologies are ripe for research. The popular cloud computing transformation has recently emerged to potentially become available in education since it was built upon decades of research in virtualization, utility, and grid computing. In other words, researchers are only now scratching the surface of the potential capability and promise that cloud-based lab platform design will provide as a result of advanced research, artifact design, implementation, and deployment of these technologies.

In order to provide standardization and clarity of thought moving forward, the rest of this dissertation report will be organized into 5 chapters. Chapter 1 includes the problem statement that addresses the research-worthy problem; the dissertation goal that summarizes what the work will accomplish; the research questions and hypothesis that steer the literature review; the relevance and significance section that supports the problem statement and goal; the barriers and issues section that identifies how to overcome any known and potential problems related to the completion of the study; the assumptions, limitations, and delimitations section used to outline factors accepted as true, factors that are beyond the control of the researcher, and intentionally imposed constraints on the scope of the study. Chapter 2 includes the expansion and development

of the dissertation idea paper review including criteria justification; identification of the strengths and weaknesses of selected studies as well as gaps in the literature; analysis of methodologies that are used in existing studies; and an overall synthesis of the literature. Chapter 3 provides details of how the investigation was conducted; the research methodology; instrument identification as well as construct measurement techniques; instrument development and validation; sample population and data analysis that are used to answer the research questions and hypothesis. Chapter 4 includes an objective description and analysis of the findings, results or outcomes of the research including sections on data analysis, findings, and a summary of results. Chapter 5 provides conclusions based on the study analysis performed and results achieved; implications based on the study impact and contributions to the knowledge base and professional practice; recommendations for study expansion and future research; and a summary of the entire study.

Problem Statement

The problem explored in this dissertation report is there are no design principles based on DSR that focus on artifact construction and effective evaluation of cloud-based lab environments that can be leveraged to foster technology skills in IS students. Consequently, this type of properly designed system is not readily accessible across educational environments nor do we know how to implement effective cloud-based labs using sound DSR based artifact construction methodologies. As a result, students may be deficient in applied hands-on computer and IS configuration skills necessary to enter and

maintain highly technical jobs in the workforce; this is most likely because they lack the 24/7 access to effectively designed high performance lab environment architecture.

The reason the problem exists is because there are no studies past or present that directly address cloud-based lab environment construction that include process and procedure for design, implementation and evaluation based on DSR principles. There are a number of studies such as Imboden and Strothmann (2010), Martin and Woodward (2013), and Beasley and Floyd (2014) that address networking lab design in some capacity, however, all of these studies focus primarily on traditional lab environments that are only accessible through physical interaction and do not provide scientifically proven methods to facilitate construction, implementation, and evaluation of the same.

Imboden and Strothmann (2010) provide details regarding their networking and Voice over IP (VOIP) lab design including technologies and equipment required to construct the educational environment in a cost effective manner. The main difference between their model and the cloud-based lab model highlighted in this dissertation report (DR) is that in their model, networking equipment such as routers, switches, storage, servers, and workstations are available to students only as long as they are physically in the lab during class hours compared to 24/7 access available in the cloud-based model presented in this dissertation report.

From an artifact construction perspective, the lab designed by Imboden and Strothmann (2010) essentially mimics how several corporate offices connect to each other across a Wide Area Network (WAN) but there are no other details such as bandwidth requirements, number of students supported, system accessibility, expected performance, step-by-step construction procedures, or system evaluation methodologies

that are based on design science that can be used to positively affect the outcome of construction and implementation.

Martin and Woodward (2013) emphasize the importance of hands-on learning and the growing need to build labs that will prepare the future cybersecurity workforce. They also warn that remote labs should not be confused with simulation software since the latter does not always process incorrect commands or configuration procedures thereby potentially frustrating students. Martin and Woodward (2013) think remote access to lab environments such as the cloud-based lab architecture outlined in this DR is the best solution to leverage equipment resources thereby reducing the cost between multiple schools, however, nothing is offered in the form of lab design, construction, implementation or evaluation of the same.

Beasley and Floyd (2014) assembled a group of senior capstone students in an information technology (IT) program to design, develop, and implement a hands-on networking and information assurance (IA) lab environment. According to their study, even though the initial design was carefully planned, the lab immediately started to evolve into what is now in the design phase of the 4th generation based on feedback from students and faculty using the lab. The 1st generation of the lab environment design was constructed with guidance from faculty in the school of Information Technology (IT) and the primary goal included student mastery of theoretical concepts based on skills demonstration. The 2nd generation of the lab design methodology included practices learned in class that can be applied to mimic small business networks typically used throughout the industry. The 3rd generation of the lab design leveraged CompTIA's learning domains along with standard industry practices used throughout the construction

and implementation phase including a plan to include remote access capability between servers across two campuses. The planned changes for the 4th generation lab includes firewalls, monitoring capability, and switches to simulate WAN technologies but there are no details provided such as design process, step-by-step construction procedures, bandwidth requirements, number of students supported, system accessibility, expected performance, or system evaluation methodologies that are based on design science that can be used to guide the construction, implementation, and evaluation of the same.

According to Chen, Song, and Zhang (2010), there are many existing and emerging technologies which have been used to develop remote access laboratories across academia such as in studies conducted by Pickard, Spence, and Lunsford (2012), and Cronin, Pauli, and Ham (2013), however, there are few if any papers that document the design, construction, implementation, and evaluation of remote access lab systems through the use of scientific methods. In other words, we simply don't know how to effectively design, implement, and evaluate cloud-based lab systems using proven scientific methods such as found in DSR.

March and Smith (1995) found that design science is concerned with constructing artifacts to serve human purposes or attain organizational goals in general; they claim the two fundamental activities associated with design science are construction and evaluation. The construction phase of the artifact may be complicated by the incomplete understanding of the environment in which the system operates while the artifact evaluation phase may experience problems based on the fact that performance is related to intended use that may cover a wide range of specified tasks. In other words, the fast changing dynamics of artifact development matched with all possible end user

requirements in this study make it difficult to devise an effective strategy for construction and evaluation without effectively written and implemented design principles.

Additionally, Pena-Rios et al. (2012) has found that hands-on laboratory environments in distance learning is an area with many difficult challenges since it requires administration and management oversight to effectively orchestrate the constructivist approach to learning through large-scale deployment coupled with strong support mechanisms. This strengthens the argument that the cloud-based lab system at the center of this study is a research worthy project and the results will make a significant contribution to solving problems across Information Systems (IS) and education domains.

The problem continues to persist due to the assumptions that systems of this nature are inherently expensive and difficult to manage in dynamic educational environments. According to literature, this type of problem may be difficult to solve based on the complexities of designing, building, implementing, maintaining, and supporting large scale equipment architecture with 24/7 access that will prepare students to compete for advanced technical positions in the industry. Yan (2011) found that having anytime access to hardware and software is a very important and central factor in the computer and IS laboratory environment. According to his study, a successful computer and IS skills based course requires access to a plethora of computer network systems and services. Regrettably, it is difficult to achieve this objective due to restrictions Yan (2011) explains below:

- In many computer and information systems skills based labs; students need to reserve access to equipment or entire topologies to perform labs or various experiments. Therefore, a fully equipped computer and information systems

lab requires a number of devices such as servers, workstations, switches, routers, firewalls, virtual machines, and storage.

- The rapid proliferation of computer and information systems technology demands constant updating of curriculum including lab environments required to perform hands-on skill based exercises. However, it is in many cases difficult to provide the specific numbers of fully updated devices required in the classroom on demand. Not having enough devices will unavoidably apply adverse impact on the implementation of teaching pedagogy as well as affect the quality of content delivery both locally as well as from remote locations.
- When teaching computer and information systems practical courses, one method would be to render students to an open lab skills based architecture that will prepare them to examine labs through cooperative and exploratory learning. The students for the most part would need administrator access to extract the full functionality of the distinct machines or potentially to the complete network. Providing the students with this type of access would most certainly lead to security and privacy issues since students would have the ability to influence the behavior of the systems in any way, shape, or form. In a more controlled environment, faculty would need to enforce boundaries on experimental procedures in certain practical scenarios in order to minimize risk that may destroy the lab facility or worse the business production networks. This type of control and sandbox environment makes exploratory learning and open experiment lab environment impracticable to the point of affecting the quality of teaching as well as the student experience.

- After the student completes the skills based lab exercises, the condition of involved hardware and software typically remain in a persistent state.

Consequently, active maintenance may be required to restore the system ensuring the lab environment is reset to baseline configuration and available for future deployment. This type of maintenance is often times boring, repetitive and costly.

Additionally, Yan (2011) has found that once the laboratory environment is functional, any inattention to maintenance or support may turn a well-designed class and lab exercise into a major problem. His study focused on past efforts that have used many different methods of handling issues dealing with anytime lab access such as having equipment dedicated to specific courses or using software such as VMware virtualized workstation or Linux operating systems to provide virtual machines (VMs), however, the study mainly focused on small-scale environments and did not appear to use established design science principles to facilitate artifact construction and evaluation.

The cloud-based lab system reported in this study was constructed in a prototype environment to support education and training in a Computer and Information Systems (CIS) cyber-security course. The initial small-scale system incorporated built in functionality for scheduling that facilitates scalability and availability of labs providing step-by-step instructions across multiple networking and security devices as well as operating systems simultaneously.

On the basis of associating educational cloud-based lab architecture with graduate skill levels, there are several studies supporting the argument that advanced IT skill levels through effective training are absolutely relevant in education and the work force. As the

literature in proceeding paragraphs and chapters will reveal, cloud-base lab environments do in fact offer potential solutions to acknowledged problems in education. According to Prieto-Blázquez, Arnedo-Moreno, and Herrera-Joancomartí (2008), computer IS and related technology training are extremely important to organizations and the global economy. As these pervasive systems increase in size, complexity, and scale, the need for practitioners with hands-on experience is necessary to implement, maintain, and manage these devices as they interconnect systems and businesses alike across the globe.

Gallagher, Kaiser, Simon, Beath, and Goles (2010) found that hands-on experience in IS educational courses is an important skill to develop because it provides a fundamental starting point for students to enter technical areas of employment. Based on the findings in their research, networking, security, programming, testing, and various operating system skills establish the catalyst for future employees to develop more advanced skills such as analytical thinking, proposals, and project management. According to Gallagher et al. (2010), “it is important to have these skills to gain entry into the profession; their importance diminishes with the individual’s experience and tenure in the profession” (p.146).

To effectively prepare students for employment in the computer IS industry, which is part of the problem statement in this study, Lemke (2002) believes the solution is found in the acceptance that traditional education methodologies are insufficient for learners today. In order to prepare students to excel in this rapidly changing digital world, academic excellence must be acquired in the context of today’s technology driven economies. Hawk et al. (2012) found that having a keen understanding of basic, intermediate, and advanced technical skill sets required by employers is important

information to have when updating computer IS related curriculum coupled with skill building hands-on lab environment. For this reason, the continuing relationship between employers and education leaders is necessary to bridge the gap between the hands-on skills that are offered in educational program courses and the ever-changing requirements of the industry.

Lunt et al. (2008) strengthen the argument of needing advanced cloud-based lab environments to enhance skills by finding that four year college IS programs should provide their students with knowledge and skill experience that goes well beyond pure theory; this must be done in order to pursue and maintain highly competitive jobs in the technology industry. In addition to theory, IS professionals must stay up-to-date on the latest technical innovations. In order to do that, hands-on experience is required since these graduates will be responsible for integrating technology into the organizations where they work. However, Pundand and Deshmukh (2012) have found that the current models of e-learning platforms lack the support of foundational infrastructures upon which they are built. Since these systems are designed to run applications as services over the Internet, the architecture should seamlessly and dynamically adapt to storage and computational resource demands based on usage.

As a result, this is the primary reason why cloud computing and effectively designed cloud-based lab environment architecture can be leveraged as a solution for educational institutions that need to prepare their students with the hands-on skills required to compete for highly technical jobs in the industry.

Dissertation Goal

This section will present an argument that this study leverages DSR through artifact construction and evaluation by correlating Hevner et al.'s (2004) seven steps of effective DSR theory, Peffers, Tuunanen, Rothenberger, and Chatterjee's (2007) DSR Methodology (DSRM), and Gregor and Jones's (2007) IS Design Theory to the problem statement, research questions, and hypothesis in order to extrapolate guiding principles and specifications for the design, development, construction, and assessment of a cloud-based lab environment.

In support of the goal, this study reports on procedures, specifications, and emergent knowledge processes that advances the IS and education domain knowledge base used to design, build, and implement the cloud-based lab architecture. The IS artifact in this study was evaluated on how effectively it provides 24/7 access used to bridge skills gap among computer and IS graduates. In their study, Hevner, March, Park, and Ram (2004) indicate that researchers in the IS discipline should be compelled to advance the body of knowledge that facilitates the effective application of IS to organizations and their management.

The rationale for the research presented in this study is not necessarily to discover solutions for a completely unsolved problem since there are a number of studies that address the issue of lab architecture requirements in computer and IS education (Sivakumar, Robertson, Artimy, & Aslam, 2005). The overarching goal of this study is to discover more effective or efficient solutions that lead to the construction and evaluation of cloud-based lab environments based on design science principles that can be used to advance the IS and education domain body of knowledge (Hevner et al., 2004).

Ultimately, previous research was explored by thoroughly examining design science related to this domain and correlating the research to make recommendations for procedures and specifications that improve lab environment design, construction, implementation, and deployment in high schools, technical education centers, colleges, and universities for the overall benefit of education and the IS industry.

Research Questions and Hypothesis

The research questions identify the specific objectives this dissertation report addresses and helps shape the conceptual framework for the study.

1. Can procedures and specifications be derived from DSR to guide construction of a cloud-based information system's hands-on lab architecture artifact that provides educational utility?
2. Are the procedures and specifications derived from DSR, and used in the construction of a cloud-based information system's hands-on lab architecture effective based on artifact use?

The hypothesis in this study guides the explanation of and provides answers to the research questions through rigorous testing and evaluation methods.

- H1. The procedures and specifications derived from DSR and guiding the construction of cloud-based lab architecture artifact will empower positive student outcomes as measured by hands-on configuration skills assessment results.
- H2. The procedures and specifications derived from DSR will have a positive effect on the use of cloud-based lab architecture as measured by the number of labs completed and time spent on the system.

Relevance and Significance

The problem in this dissertation report is both meaningful and research worthy due to the number and quality of academic studies supporting the argument that advanced cloud-based laboratory architecture design supports education, improves IS graduates' job skills, and is important. According to Wang, Hembroff, and Yedica (2010), applications of virtualization techniques will be found in more fields in the near future when they are integrated in cloud computing systems and other computing infrastructures. The researchers also indicate the application of virtualization in education will most likely continue and further research is required to advance artifact design, implementation, and evaluation. Additionally, Yan (2011) indicates that skills based experience when performing labs is generally recognized as a vital component of the computer IS education. Successful technology based hands-on activities require access to larger scale systems having cloud-based remote access capability with built-in centralized management functionality. Furthermore, Prieto-Blázquez et al. (2008) indicate that in virtual or cloud-based systems, networking and security courses cannot always be delivered in a face-to-face environment; therefore, providing students with real-world labs to practice and master technical skills becomes a very complex challenge. Their research has found that new and adaptive virtual topologies such as the cloud-based lab artifact proposed in this study, will need to be designed and developed in order to facilitate the successful accomplishment of these types of skills based hands-on activities.

To strengthen the relevance of this problem, Madan, Pant, Kumar, and Arora (2012) found that cloud computing provides the capability to enable students across the globe to acquire the 21st-century skills and training they need to compete and succeed in the

global information systems work force. Their study indicates the information and physical space of e-learning cloud-based lab environments will be fully integrated in the near future because of omnipresent computing capability where students should be able to access these digital services anytime and from anywhere in the world. Furthermore, Pena-Rios et al. (2012) indicates the use of virtual and remote laboratory activities is an example of the application of educational delivery systems and provides a basic foundation for research based on the challenges associated with defining architecture, process, and standardization required for wide-spread implementation across academia. Consequently, the relevancy of remote educational lab access using cloud-based architecture design requirements is evident and supports the primary driver for advancing the research through this dissertation report.

Finally, Hevner (2007) “contends that design science research is essentially pragmatic in nature due to its emphasis on relevance; making a clear contribution into the application environment” (p. 91). Therefore, deriving artifact and process building to facilitate the construction and evaluation of the cloud-based lab architecture reported in this study based on DSR makes a clear contribution to problems that span IS and education domains.

Barriers and Issues

Even though the equipment, network, components, facilities, and experimental/control groups were available to design, build, and evaluate the effectiveness of the prototype production system, there were problems with immediately scaling the system in order to meet the potential demand of running multiple lab intensive courses simultaneously on a

large scale. The cloud-based lab artifact reported in this study was designed and developed based on DSR principles with the intention of addressing the study research questions based on the limited number of subjects in the control and experimental groups. Additionally, performance in a remote access virtual lab environment is paramount and this key indicator of success could not effectively be measured in a small scale prototype system compared to a system that could potentially be used to provide 24/7 availability across a large number of users.

In order to analyze and evaluate a large-scale production environment, the system will need to be scaled up by increasing the number of components, and the experimental/control groups will need to be expanded and tested against the dependent variables in order to successfully evaluate the artifact in a more meaningful way.

Assumptions, Limitations, and Delimitations

The initial assumption made in this study was that both the experimental and control group students would have the same level of motivation in improving their skill levels while using the cloud based lab architecture equipment or the fixed classroom equipment. Because the study utilized both pre and post skill level assessment measures, the delta or skills gap was one of the most important indicators that validate the dissertation report hypothesis. During the study and when formulating the dissertation report, an assumption was made that because the students were preparing themselves to compete for advanced technical positions in the industry after graduation, they would be fully engaged in the learning process that would help them to be successful both in school and in the work force.

There were limitations in this study beyond the researcher's control and that had the potential to impact the internal validity of the report overall. One such limitation was that the researcher could not necessarily control whether the student groups would apply their best effort skill set during the pre and post skills test evaluation. The researcher considered one possible way to minimize the impact of this potential limitation by applying weights in the form of grades to the skills assessment in order to capture standard and consistent results. That consideration was later ruled out based on the potential problem with incentivizing students to do well on the skills assessment thereby potentially creating an adverse effect of producing inconsistent results.

Another limitation discovered was the physical under or over performance of the system based on the design, construction, and implementation requirements. This limitation was mitigated by running performance analysis of the prototype during pilot stage and subsequent fine tuning of the system based on the results.

One of the delimitations intentionally imposed during the study was to design, build, and implement the system in a small scale prototype test environment to control manageability and scalability. The physical number of devices and footprint of the network was intentionally limited based on the number of participants that were available for the control and experimental groups. The reason for the delimitation was to validate the proof-of-concept prior to large scale implementation and deployment. This approach ultimately fed a cost/benefit analysis and subsequent justification for equipment acquisition based on ROI assumptions.

Definition of Terms

Artifact: something of value created by humans that can be used for a specific purpose or function (Chandrasekaran, 1990).

Centralized management: ability to manage and administer networking and control systems from a central location (Wang, Hembroff, & Yedica, 2010).

Cloud-based lab: lab system that is accessible through a web-based connection on the front-end and includes devices, servers, racks, machines, networking, and storage on the back end (Madan, Pant, Kumar, & Arora, 2012).

Educational delivery system: web-based platform that is used to organize educational content, lab access, presentations, assessments, communication tools, and course materials (Hill, 2014).

Grid computing: collection of distributed computing resources that can be used to perform large-scale computational tasks (Pund & Deshmukh, 2012).

Hands-on skill: the ability to perform specific device configuration tasks with your hands (Martin & Woodward, 2013).

Network component configuration: setting up individual components to communicate and function as designed in a network environment (Imboden & Strothmann, 2010).

Process building: set of modularized and modifiable instructions that can be used to perform a finite set of tasks to complete a project (Morita, James Flynn & Ochiai, 2011).

Prototype system: Trial system that can be analyzed, adjusted, and replicated before deployment in a production environment (Beck & Weber, 2013).

Remote access: connecting to a network device or system from a remote location outside the physical network such as through the Internet (Chen, Song, & Zhang, 2010).

Software defined networks: allow administrators to have central control of network traffic through the use of a controller that serves as a bridge between the physical layer and software (Monsanto, Reich, Foster, Rexford, & Walker, 2013).

Traditional physical lab: lab environment where the end users must have physical access to perform experiments and make device configuration changes (Anderson, Joines, & Daniels, 2009).

Utility computing: computer resources such as processing, memory, and storage that can be measured and charged back to the customer (Pund & Deshmukh, 2012).

Virtualization: specialized software used to separate the physical devices from the operating systems (Pund & Deshmukh, 2012).

Abbreviations

BLS	Bureau of Labor Statistics
CBAC	Content Based Access Control
CIS	Computer and Information Sciences
DR	Dissertation Report
DSRM	Design Science Research Methodology
DSR	Design Science Research
IA	Information Assurance
IS	Information System(s)
IT	Information Technology
LAN	Local Area Network
MANOVA	Multivariate Analysis of Variance

NDG	Network Development Group
PODS	Point of Delivery Systems
SPSS	Statistical Package for Social Sciences
VM	Virtual Machine
WAN	Wide Area Network

Summary

This first chapter of the dissertation report outlined the background for the study including the problem statement which explained the absence of procedures and specifications based on DSR that speak to artifact construction and effective evaluation of cloud-based lab environments that can be leveraged to foster technology skills in IS students. The dissertation goal section of the first chapter presented an argument that the study will advance IS and education domains through DSR principle derivation during artifact construction and evaluation by primarily correlating Hevner's seven steps of effective DSR theory, Peffer's DSRM, and Gregor's IS Design Theory. The research questions identified the specific objectives the dissertation report addresses and helped shape the proposed conceptual framework for the study. The hypotheses stated in this chapter are designed to guide the explanation of and provide answers to the research questions through rigorous assessment and evaluation methods. Chapter one also shaped the relevance and significance of the research report as well as the barriers and issues that were addressed in order to successfully complete the study. Finally, chapter one addressed the assumptions, limitations, and delimitations that had an overall impact on the dissertation report.

Chapter 2

Review of the Literature

Overview of Topics

In order to shape a foundation for the problem statement in this report, a number of studies have been reviewed to discover what is already known about the problem including potential solutions and how they align with the problem statement, research questions, and hypothesis. This chapter of the dissertation report is organized into four main topics as themes have emerged from the initial review of the literature. As a result, the literature review ultimately focuses on the justification for the study, identification of existing studies, strengths and weaknesses, gaps in literature, research methods in similar studies, and synthesis of the literature all related to the four main topics of (a) need for skilled IT workers, (b) lack of skill in IS graduates, (c) educational cloud based lab environments, and (d) DSR theory and principles. The overall goal of the literature review was to synthesize and guide the extrapolation of DSR principles and specifications that facilitate the artifact construction and assessment methodology of the cloud-based lab system that is central to this study. The emergent methodology was then used to direct the construction and evaluation of the cloud-based lab environment that holds the potential to foster student learning of advanced IT hands-on skill levels.

Justification

The rationalization used in determining the criteria for selecting studies that are included and excluded from this review stem from what was learned throughout the development of the idea paper and the initial review of literature in the dissertation proposal. The majority of the papers selected in this literature review were published no earlier than 2004 because anything written prior to that time would most likely not be relevant to the industry and ongoing academic practices. The papers were also selected mainly based on relevancy to design science, online or cloud based lab environments, IS graduates, and IT workers. In order to support the quality of the literature review, studies from IT and online lab environments from peer reviewed journals were included as long as they related to the problem statement, research questions, and hypothesis. The selected studies were also required to contain observed evidence so that the researcher of this study could be assured the results have been accepted by the scientific community.

Identification of Existing Studies

There are a number of existing studies that address the four main topics discussed in this literature review: (a) need for skilled IT workers, (b) lack of skill in IS graduates, (c) educational online or cloud based lab environments, and (d) DSR theory and principles related to IS and technology education through the use of online or cloud-based virtualized lab environments. This section will begin with a chronological summary of the studies in each of the four main topic areas and will help provide a foundation for synthesis and evolution of the literature at the end of the chapter. Summary tables of

the articles by topic are presented in Appendix A. The tables include author names, article titles, and the main point of each article.

Need for Skilled IT Workers

The literature review in this section will attempt to discover and support the organizational need and high demand for IT workers skilled in implementing, configuring, managing, and securing complex information system networks. The studies included in this section were chosen because they illustrate a convincing trend toward the need for skilled IT workers now and well into the future.

In order to build the groundwork for the summary of literature supporting the need for skilled IT workers over the past several years, Luftman and Kempaiah (2007) found that between 2006 and 2012, 25% of new jobs would be IT-related. Additionally, Luftman and Kempaiah stated in their study that as the baby boomers of the dot-com era retire over the next several years, the lack of abundance in the pool of IT professionals is expected to continue; this is an indication the trend toward the need for skilled IT workers is increasing and momentum is on the rise. Additionally, considering this ongoing movement and growing complexity of our information system networks, the need for IT workers to secure our national network infrastructure continues to grow as well. Abraham and Chengalur-Smith (2010) found that protection of cyber assets requires a large scale multipronged approach that requires the coordination of government, academia and industry across the globe. At the core of this issue is a critical shortage of cyber security professionals and there is an exigent need for a commitment to educating

the current and future workforce in this profession (Locasto, Ghosh, Jajodia, &Stavrou, 2011).

Rowe, Lunt, and Elkstrom (2011) indicated that even though IT security workers are some of the highest compensated in the industry, there is a strong indication of a shortage of tens of thousands of qualified cyber-security specialists in the United States. Rowe et al. also found the need to graduate students with the hands-on skills required to configure and defend our critical infrastructure is becoming a greater responsibility of academic institutions across the United States and beyond.

Consequently, it is crucial to recognize the importance of university education that builds IS and cyber security professionals with a hands-on perspective on how to secure important infrastructure since the current and future need for skilled IT workers may continue to become greater than the pool of trained resources available. As Locasto et al. (2011) noted, “Plans for training government cyber security workers should focus on educating a new work force rather than mass certification of existing workers” (p. 130).

In support of the need for skilled IT workers, Rowe et al. (2011), Awad, Banimelhem, Taqieddin, and Bani-Hani (2012) analyzed feedback collected in their study from the industry and concluded that although graduates were very competitive when seeking technology related positions and excelling in such positions, there was still a major requirement for more advanced courses with skills based hands-on training related to the information system networking and security fields. Awad et al. observed that as the market demand for skilled IT workers increases, the students’ demand for networking and security related courses also increases in parallel. The ultimate employability of the student is an important factor for high tech organizations because according to Khoo

(2012), there has been a consistent trend of increasing demand for IT professionals over the past several years and this may contribute to the reason why there is a shortage in the pool of available skilled IT workers.

Looking at the shortage of skilled IT workers problem from a slightly different perspective, Hawk et al. (2012) found that middle and upper IT management as well as educational institutions continue to view the IT workforce issues with apprehension and trepidation (Luftman, Kempaiah, & Rigoni, 2009). From the demand side of the issue, there is an increasing emphasis on IS business transformation coupled with exponential growth and complexity of global networks that are driving the demand for skilled IT workforce members. This problem is further complicated by the dynamic transitioning and elevating skill sets required in IT professionals. Additionally, Litecky, Igou, and Aken (2012) indicate that it is imperative for graduates to obtain the skills required for stable, long term employment based on global uncertainty and weakening economic conditions. On the supply side of the issue, the number of schools graduating students with skills based IT-related degrees remains historically low, while other geographic and demographic problems such as the trends in IT toward global outsourcing as well as the impending retirements of seasoned employees threaten a further overall reduction of IT workers (Dychwald, Erickson, & Morison, 2006). Simply from the supply and demand perspective, the net result is a widening gap between a growing demand for IT workers and an insufficient supply of IT workers possessing advanced skills. Exasperating the problem even further, based on the growing complexities of networking systems and continuous attacks from hackers across the globe, the expectations of skilled IT workers

today are much more technically advanced than the expectations of IT workers were just a few years ago.

From an academic standpoint and based on the research performed by Longenecker, Feinstein, and Babb (2013), the IT computing industry enable businesses and organizational systems the power that will drive the world's economies for decades to come. Therefore, academia must maintain an acute awareness of the importance of preparing graduates to meet the need for skilled IT workers all the while training them to configure and defend infrastructure networks that are under attack and in many cases infested with network security breaches of an increasing and threatening nature. Martin and Woodward (2013) conclude that educators need to train a large scale cyber security workforce in order to keep up with continuing threats to our critical network infrastructure and electronic assets across private, public, and government networks. From a non-business standpoint, LeClair, Abraham, and Shih (2013) found that protecting personally identifiable and financial information stored and accessed across the Internet is also a primary concern and the need for IT workers trained to mitigate risk in this area should be of the utmost importance.

Lack of Skills in IT Graduates

In stark contrast to the previous section that focused on the need for skilled IT workers, the summary of literature review in this section will attempt to highlight the issue of a serious lack of skill sets available from the current and potentially the future pool of IS graduates. This convergence of opposing concerns may lead researchers to further address the issue of building online or cloud-based lab environments in an exigent

manner to help educational institutions bridge the gap between the trained and untrained IS graduates across academia. This in turn will facilitate the preparation of IS students in order to meet the demand for organizations to draw from a larger pool of skilled IT workers that will ultimately configure and manage our critical network infrastructures across the globe. Several years ago, Tarafdar and Gordon (2007) found that professional knowledge and the skill capability of IS employees is a significant part of an organization's ability to maintain strategic and financial competitiveness in the marketplace. More than four years later, that finding has not changed since VanDerweken and Ubell (2011) found the shortage of network administration and cyber security professionals could lead to organizations compromising their security by tasking non-proficient IT workers to adequately prepare for attacks against critical infrastructure. This problem would very easily impact their strategic and financial posture as well as producing a number of other potential vulnerabilities related to business continuity and industry competition. Lowden, Hall, Elliot, and Lewin (2011) believe that in order to address these problems, universities will need to prepare students with analytic capabilities and a battery of applied practical skills which make them more ready to be successful in the IT workplace.

However, results of Madan et al.'s (2012) study indicated there are literally thousands of U.S based academic institutions that are failing to serve up web-based course content, instruction, and hands-on technical lab experiments to their students on a regular and consistent basis. Furthermore, Radermacher and Walia (2013) discovered that many educators, industry leaders, and academic researchers have indicated that IS students are deficient in technical skills and understanding of concepts that will be important for them

to be successful in the workforce. The results of this review indicate that graduating students are lacking in many different areas including but not limited to hands-on and technical skill capabilities based on limited access to lab environment and instructions.

In their study on how to educate an effective cyber security workforce, LeClair et al.'s (2013) found that an impending challenge in the domain of cyber security is the lack of a trained and educated cyber workforce that can recognize vulnerabilities and defend organizational networks against cyber-attacks. In support of LeClair's study, Suby (2013) found that information security professionals worldwide pointed to the shortage of skilled cyber security professionals and that organizational managers are not completely satisfied with the quality of education and the skill levels in networking and cyber security job applicants.

To address some of these problems, Simon (2013) suggested that the industry is placing much more of an emphasis on recruiting individuals with an understanding of technology and IS. According to Brandel 2010, the goal of recruitment in the IS field is to find high-quality and skilled individuals appropriate for an organization at the lowest cost possible. However, in many cases, companies sometimes find that these new employees are not always up to speed regarding performance and when that happens, frequent turnover and instability in the department or across the organization can occur including a lack of quality enterprise-wide IS development, integration, and maintenance that may become a result.

O'Neil (2014) further indicates that current economic conditions coupled with the challenge of competing in the global markets have forced a recalculation of approaches to the utilization of IT workers across the U.S. industry. IT management across the industry

is beginning to identify a requirement to have more workers take on greater responsibilities in the area of impact, production, and services rendered in order to be agile enough to compete in this dynamically and fast moving global marketplace. The end result will foster an atmosphere that much more is expected of entry-level IT workers and the bar will be raised for our school systems to produce this type of workforce. Ultimately, the demand for IT workers possessing enhanced technological skills who can take on greater responsibility has produced new research and studies that contributes to the argument of the lack of an available and highly skilled workforce in IT.

Online or Cloud-Based Lab Environments

Traditionally, online or cloud based lab environments have been leveraged across educational institutions to help prepare students with mastering the IT skill levels that meet or exceed industry requirements. The selected studies on cloud based or online lab environment artifacts summarized in the following pages of this chapter provide insight and direction related to the construction and implementation of virtualized online or cloud based lab platforms that can be accessible from anywhere, anytime, and from any device. All of the studies found related to this domain tend to focus on the construction of the online or cloud-based lab environment artifacts based on industry standards and best practices but not specifically design principles derived from DSR since there are no studies that adequately address this preferred and advanced method of artifact construction and evaluation.

In an early study related to cloud-based virtualized lab environments, Begnum, Koymans, Krap, and Sechrest (2004) introduced the Linux operating system as a

virtualization foundation together with Linux virtualization administration tools used to support hands-on experiments for college courses in computer networking and system administration. Their work set a benchmark for scaling lab environments with good performance that could be duplicated cost effectively across educational networks. Additionally, Vollrath and Jenkins (2004), as well as Stockman, Nyland, and Weed (2005) developed a fully accessible laboratory environment with centralized delivery of virtual machines using Virtual PC and VMware Workstation for performing labs on virtualization platforms using remote desktop protocol and secure shell for remote access to the virtual machines. Their work made an important contribution to building online cloud-based lab environments because around the same time Wagner and Wudi, (2004) found that prior to virtualization technology, an isolated environment of physical laboratory equipment would need to be installed, configured, and managed for the purpose of performing laboratory experiments. This type of environment was originally considered very expensive and demanded a high degree of administrator attention, technical expertise, and overhead.

As the technology continued to move toward advanced virtualization and cloud-based lab environments, Border (2007) managed to assemble four industry standard technologies that consisted of VMware Workstation VMs (virtual machines) running through Remote Desktop, Microsoft Terminal Services and Remote Assistance that were integrated to provide remote access for multiple users. In a similar study, Gaspar, Langevin, and Armitage (2007) performed a comprehensive review on the application of virtualization technology in computing education and developed a complete set of

laboratory experiments for operating system and network security courses that were delivered on virtual machines locally and through remote access authentication.

Continuing in the educational domain of cloud-based lab environments, Yang (2007) explained their findings of using Virtual PC technology to gain cost savings and accessibility to the laboratory in system administration education courses and developed the project design based on their classroom teaching practice and experience. Also in the educational domain, Du and Wang (2008) presented an extensive array of instructional laboratory exercises in their study for computer security courses using virtual machines in the lab environment. Similarly, Duignan and Hall (2008) found that the use of virtualization technology in computer networking, security, and system administration courses is important since access to this type of lab environment contributes to an overall positive student learning experience based on the educational constructivist approach. Continuing to build on the constructivist and experimental learning approach to IS education, Lunt et al. (2008) outline six broad goals and fourteen program outcomes in curriculum guidelines for undergraduate degree programs in IT that require formally scheduled hands-on laboratories for most of the courses.

In comparing benefit versus risk of online or cloud based lab environment, Stackpole (2008) discussed the successes and failures in the current evolution of using virtualized laboratory exercises in networking and security distance education programs and courses. Additionally, Anderson, Joines, and Daniels (2009) presented the Xen Worlds project, which was designed to provide a virtualized laboratory environment with 24/7 access to support students enrolled in the Information Assurance program at Iowa State University. The use of this type of virtualization environment in distance education minimized risk

since the students were assigned their own VMs eliminating security issues inherent with shared hardware. Li (2009) also discussed the advantages and limitations of a decentralized design lab environment over a centralized system that can be managed more effectively either when the student is in the classroom or outside the classroom.

In support of a desire to train students on real world equipment, Li, Toderick, and Lunsford (2009) found that a large number of courses in the areas of computer networking and security as well as systems administration require a strong skills based hands-on laboratory component designed to help students practice with imitated production systems that will help them reinforce fundamental concepts related to principles learned in the classroom. Stewart, Humphries, and Andel (2009) also eluded to requirements that support the skills based hands-on lab components and studied different ways to leverage operating system virtualization and other similar techniques to create virtual network environments consisting of dozens of nodes on moderately equipped hardware. Furthermore, in the study conducted by Wang et al. (2010), their proposed Lab Manager provided a skills centered hands-on environment that was easily isolated from the operational networks while allowing anywhere and anytime remote access as long as the student had Internet connectivity.

From an economic perspective, Yan (2011) found that online or cloud-based lab environments will require minimum overhead cost and will provide increased lab availability together with an open and collaborative lab learning architecture that will ultimately benefit the student. In addition, Madan et al. (2012) discovered that cloud computing will positively impact the total cost of ownership by lowering the cost structure of all industries including education using IT resources.

From a student learning perspective, Pena-Rios et al. (2012) analyzed multiple learning theories with related technologies that spawn innovation, including new forms of advanced educational laboratory environments that present a complete paradigm shift compared to legacy laboratory environments. In support of this, Dinita, Wilson, Winckles, Cirstea, and Jones (2012) proposed a laboratory as a service (LAAS) model that focuses on setting up online or cloud based lab environment for delivery of simulated network hardware resources that enhance student learning outcomes.

Recent studies conducted by Pickard, Spence, and Lunsford (2012), and Cronin, Pauli, and Ham (2013) address the problem of a lack of hands-on experience through network equipment configuration available for students enrolled in their courses. At the same time they address the issue of properly preparing students for today's work environment through hands-on lab exercises and experience.

After researching several potential solutions, Pickard et al. (2012) decided to deploy NDG's Netlab system in order to make physical machines available across the Internet. Through the use of this system, students log into the remote lab environment with a PC or laptop configured with a web browser connected to the Internet and authenticating with an account ID and password generated by the instructor. Once authenticated into the system, students are then able to use a built-in calendar to schedule lab time on an available Point of Delivery or POD setup consisting of virtual machines, routers, switches, and firewalls. Students can schedule reservations in advance for any day or time as long as the system was not already reserved by another student. At the end of a student lab reservation the Netlab+ server archives the final device configurations; resets

all equipment back to a baseline; and frees up the POD through the calendar for another student to use.

Cronin et al. (2013) also researched several possible lab solutions to address the problem of a lack of hands-on remote access security labs available for their cybersecurity program at Dakota State University. Their research included a review of Microsoft Hyper-V, VMware, and the NDG Netlab+. According to Cronin et al. (2013), the Microsoft Hyper-V was not an immediate option because it was released around the same time their lab project was starting and it did not have the large-scale management capabilities central to their overall system design requirements. Afterwards, they reviewed NETLAB+ and found that it was a great product, especially based on the ability to integrate the system with hardware devices such as routers, switches, and firewalls. However, because of the default baseline configuration and scaling limitations, it was decided that NETLAB+ was not a good fit for their environment. According to their research, NETLAB+ would be a great solution to review for any institution that is not initially planning on large-scale lab deployment environments. Cronin et al. (2013) eventually selected VMware vCloud Director to handle the management and provisioning of resources across their cloud-based lab environment since it is scalable and offers more configuration parameters than currently available in the NETLAB+ environment.

Another promising cloud-based virtual laboratory education platform developed by Xu and Huang (2014) called V-Lab provides a contained sandbox and scalable environment for hands-on experiments using virtualization technologies including Citrix, KVM Cloud Platform, and OpenFlow switches. According to their research, hands-on experiments are essential for computer network security education, however, legacy laboratory solutions

usually require significant effort to build, configure, and maintain and often do not support scalability or remote access. The V-Lab system can be securely accessed through OpenVPN and students can remotely control the virtual machines while performing the lab exercises. The V-Lab platform also provides a web-based interface that can be used for resource management, knowledge sharing, and contribution.

The artifact system at the center of this dissertation report ultimately bridges the skills gap between the documented need for skilled IT workers and deficiencies in skilled IS graduates.

Design Science Research Theory and Principles

Design theory plays an important role in deriving DSR principles that can be used in the effective construction, implementation, and assessment of the online or cloud based lab environment to prepare students for success in the global IT workforce.

Walls, Widmeyer, and El Sawy (1992) directly addressed the role of theory in DSR by proposing that IS design theory should be prescriptive, which integrates descriptive theories into design paths that improve IS. Walls et al. (1992) found that explanatory theories tell ‘what is’, predictive theories tell ‘what will be’, normative theories tell ‘what should be’, and design theories tell ‘how to.’

The *how to* in Walls (1992) design theory started to gain traction when March and Smith (1995) found the utility to a community of users, the uniqueness of the artifact, and the clarity that result from design theory are the conditions that must be adhered to in order to make a lasting contribution to DSR. Along the same thread, Markus, Majchrzak,

and Gasser (2002) argued that design theories prescribe effective development practices and system solutions for a pre-defined set of user requirements.

Analyzing design theory from a slightly different perspective, Hevner (2004) indicated in his study that DSR is naturally informed by not only theory but also according to the ever changing needs of business. According to his work, theories inform researchers and subject matter experts about information system performance that may positively affect organizational efficiencies. In support of Hevner's study, Venable (2006) found that theory building itself plays a central role in DSR similar to natural and social sciences as it occurs in the beginning, throughout, and at the end of DSR.

When examining the structural nature of theory in IS, Gregor (2006) found that constructs, models, methods, and principles derived from design theory should be evaluated for completeness, simplicity, consistency, ease of use, and the quality of the overall results obtained. Similarly, Gregor and Jones (2007) deduced that IS design theory extrapolates the creation of guidelines from comparable artifacts and design theories can be based on those artifacts that are either products, methods, or a combination of both. Likewise, according to Peffers et al.'s design methodology resulting from theory make up a system of principles, practices, and process applied to a specific division of knowledge. This type of methodology may help IS researchers develop, present, and publish high quality DSR in IS that is accepted as rigorous and relevant in IS research domains.

Based on recent findings in the study by Gregor and Hevner (2013), DSR approaches are appropriate when the author stakes a claim to a knowledge contribution and can affirmatively back it up with grounded evidence for the worth of the research. Their study

ultimately shares the idea that significant contributions to advancing knowledge in IS domains guided by DSR could be based on partial theory, incomplete theory, or sweeping generalization in the form of a new design artifact.

Strengths and Weaknesses

There are a number of studies in this literature review that are strong and support the problem, research questions, and hypothesis in this dissertation report. However, there are a few studies that are weak and the following section will attempt to summarize both the strong and weak points of some of the key studies involved in the four main topics discussed in the literature review: (a) need for skilled IT workers, (b) lack of skill in IS graduates, (c) educational online or cloud based lab environments, and (d) DSR theory and principles.

Based on the review of literature related to the need for skilled IT workers, several authors such as Luftman and Kempaiah (2007), Khoo (2012), Hawk et al. (2012), and Litecky et al. (2012) support the need for skilled employees by emphasizing an increased demand for operational services across organizational networks that require workers who possess the technical skills that are needed to successfully configure and defend these systems. Locasto et al. (2011), Rowe et al. (2011), and Leclair et al. (2013) indicate there is a global shortage of cyber security specialists and strong demand for employees that have advanced cyber security configuration skills because of increasing threats to organizational networks. Awad et al. (2012), Longnecker et al. (2013), and Martin and Woodward (2013) found there is a growing need for networking and security graduates in the technical job market and especially for students who are fully prepared to configure

and defend networks with the skills they developed while in school. The single study by Abraham and Chengalur-Smith (2010) emphasized the importance for organizations to maintain an adequate security plan but not much of an emphasis on the need for skilled IT workers.

In the lack of skills in IS graduates literature, Madan et al. (2012) and Leclair et al. (2013) found that academic institutions are failing to provide skills based training and the overall result is a poorly trained cyber security workforce. Radermacher and Walia (2013) and Simon and Jackson (2013) indicate that students do not have the necessary skills to meet employer expectations and employees often do not perform skills based procedures on technical equipment as expected. The studies conducted by Tarafdar and Gordon (2007), Lowden et al. (2011), and Suby (2013) didn't seem to drive the point for the lack of skills in IS workers because they focused more on how Universities should prepare students with practical skills and how skills capable IS employees contribute to overall organizational competitiveness.

The online or cloud based lab environment studies indicated strength based on systems that previously and currently exist across academia. In the early studies conducted by Border (2007), Yang (2007), and Du and Wang (2008), the remote laboratory emulation, multi user, remote access and Novel laboratory environment systems provided limited access for students to conduct labs both inside and outside of the classrooms. Stackpole (2008), Anderson et al. (2009), and Li et al. (2009) developed proprietary and open source remote virtual lab environments for systems administration and information assurance programs that allowed students access from any location as long as they had Internet access. Wang et al. (2010), Yan (2011), and Dinita et al. (2012) developed the

most advanced systems through the use of VMWare VCenter lab manager, XenDesktop based remote access laboratory, and cloud-based laboratory solutions all designed to provide 24/7 student access to complex networking laboratory environments. The early studies by Begnum et al. (2004), Vollrath and Jenkins (2004), and Wagner and Wudi (2004) are considered weak because they used virtual machines running on single hosts and user-mode Linux that effectively provided systems that didn't allow remote access from outside the classroom. Additionally, Stockman et al. (2005) and Duignan and Hall (2008) had problems with providing remote access because of issues with copying large virtual machines across the network and multiple virtual machines sharing single host machine physical resources.

The design theory section of the literature review had several strengths and a couple of weaknesses related to the problem, research questions, and hypothesis in this dissertation report. Some of the strengths associated with the literature review of design theory is that Walls et al. (1992) and Markus et al. (2002) both used design theory in order to produce an effective information system and emergent knowledge process. Hevner et al. (2004) developed a conceptual structure with guidelines for understanding, implementing, and evaluating design science research. Gregor (2006) and Venable (2006) emphasized how theory and the structural nature of theory plays an important role in advancing design science research in IS. Additionally, Peffers studied and developed a design science research methodology for the production of DSR in IS. The weaknesses related to the literature of design theory came from the study by March and Smith (1995) in their proposal to combine design and natural science activities. An additional weakness was

found in the study by Gregor and Hevner (2013) who developed guidance for design science research and publishing unrelated to the problem in this dissertation report.

Gaps in the Literature

The majority of studies related to the artifact construction and assessment of online or cloud-based lab environments reviewed in this dissertation report are insufficient compared to this study considering they are not based on tested DSR principles and practices. This constitutes a significant gap in literature since there are no studies that directly address DSR principles related to the construction and assessment of cloud based lab environment artifacts. However, there are a number of general DSR studies that can be leveraged to extrapolate and develop emerging procedures and specifications required to effectively build and evaluate the cloud based or online lab environment which is the goal of this study.

Research Methods in Similar Studies

The method adopted in this dissertation report parallels that described by Peffers et al. (2008) and includes the following steps: (1) identify problem; (2) define solution objectives; (3) design and development; (4) demonstration; (5) evaluation; and (6) communication. The Peffers et al. research process offers a useful synthesized general model that is used in this study to build on various other DSR approaches.

The research studies listed in Table 1 have been analyzed to provide a comparison between DSR process elements developed by Peffers et al. (2008) and the elements of the methods deployed in studies that are similar to the selected research methodology in this

dissertation report. Additionally, the blending of Peffers et al.'s DSRM process elements with these selected studies will facilitate the emergence and development of procedures and specifications required to effectively build and evaluate the artifact proposed in this study.

Synthesis of the Literature

Because the artifact design in this dissertation report is based on the need for skilled IT workers, lack of skills in IS graduates, online or cloud based lab environments, and design science theory related to artifact construction of laboratory equipment that can be accessed remotely from anywhere, anytime, and from any device; it was necessary to synthesize the literature specifically related to this problem domain in order to present an overall logical perspective.

The need for skilled IT workers is clearly obvious in the study conducted by Longenecker et al. (2013). Their findings indicated students must develop confidence in skill based abilities because as they enter the workforce, they will need to incorporate computing skills along with traditional IS knowledge and interpersonal abilities required to configure, manage, and defend information system networks. In the study conducted by Awad et al. (2012), the employment demands for specialized positions in networking and security were analyzed in three areas: locally, regionally, and globally. The information, reports, published studies, and articles regarding existing market requirements and future demand were searched in order to reach a good characterization of the market overall and the results consistently indicated a growing demand for the employment of skilled IT workers.

Table 1

Similar SRM Elements Blended with Peffer's DSR Methodology

Peffer's DSRM Process Elements	Walls, Widmeyer, and El Sawy (1992)	March and Smith (1995)	Markus, Majchrzak, and Gasser (2002)	Hevner, March, Park, and Ram (2004)	Gregor and Hevner (2013)	Venable (2013)	Gregor and Jones (2007)
Problem identification and motivation objectives of a solution	Kernel theories	Theorize	Emergent knowledge process	Relevant problems	Realizing problem	Problem space	Kernel theories
Design and Develop	<ul style="list-style-type: none"> • Design Methods • IT product design • IS develop approach 	<ul style="list-style-type: none"> • Constructs • Models • Methods • Implement 	<ul style="list-style-type: none"> • TOP modeler IS • Development 	Produce viable artifact Artifact iterative search process	Analyzing literature Design exaptation	Solution technology Technology invention	Purpose and scope Design theory
Demonstrate			Predictive ability	Evaluation methods	Demonstrate novel artifact proof of concept		Expository instantiation
Evaluation	Testable process	Artifact performance and utility		Rigorous evaluation	Summative evaluation	Technology evaluation	Testable propositions
Communicate				Artifact replication	Communicate schema		

According to the Bureau of Labor Statistics (2014), IT Network and Computer System Administrators have a projected job growth outlook that is higher than average as summarized in Table 2.

Table 2

BOLS Jobs Outlook

Job characteristic	Network and computer systems administrator	Computer network architect	Computer systems analysts	Information security analysts
2012 median annual hourly pay	\$72,560 (\$34.88)	\$91,000 (\$43.75)	\$79,680 (\$38.31)	\$86,170 (\$41.43)
Entry level education	Bachelor's degree	Bachelor's degree	Bachelor's degree	Bachelor's degree
Jobs in 2012 (N)	366,400	143,000	520,600	75,100
Job outlook 2012-2022	12%	15%	25%	37%
Employment change 2012-2022	42,900	20,900	127,700	27,400

The need for skilled IT workers with an emphasis in security continues to grow as cyber warfare in networking is also taking shape across the globe and is defined as “actions by a nation state to penetrate another nation’s computers or networks for the purposes of causing damage or disruption” (Clarke & Knake, 2011, p. 11). During his first term in office, President Barack Obama declared America’s digital infrastructure to be a strategic national asset with network security and the cyber spectrum entering the fifth domain of warfare in addition to land, sea, air, and space. In this context, network

and cyber-attacks could target critical infrastructure, financial systems, government, and national defense systems of a nation in order to pose threats and destruction to national assets for social and/or political motivations. Therefore, the protection of cyber assets requires a multipronged approach that requires the coordination of government, academia and industry (Abraham & Chengalur-Smith, 2010).

Additionally, The Bureau of Labor Statistics (2014) data show that Network Systems and Data Communication Analysts and Network and Computer Systems Administrators (i.e., the areas that are closely related to cyber security) are projected to experience above average employment growth through 2018, 53% and 23%, respectively.

Based on the literature, outlook, and statistics, there is clearly a need for IT workers that will only continue to increase during the next several years and into the next decade. However, the pool of available skilled IS graduates appears to be diminishing and the problem will continue to persist unless educational institutions ramp up their efforts in preparing students to be successful in the global IT workforce. Over the past several years and due to the lack of skills in IS graduates, the overall goal of recruitment has been to find high quality and skilled workers appropriate for an organization at the lowest cost possible. However, some organizations find that new IT workers do not always perform on the job as expected and this generally can be found in IS departments where a mix of knowledge and skills are required. As a result, when new candidates do not perform as expected, frequent turnover and instability in the organization can occur along with a lack of quality enterprise-wide IS development, integration, and required maintenance.

In many cases, organizations look to universities to provide such qualified candidates, therefore, it is important to explore if individuals who intend to work in this discipline are

adequately prepared by the academic institutions they attend. Universities are ultimately responsible for preparing and graduating IS students with the skills necessary to succeed in a rapidly changing technological environment. Because high-quality employees enhance the quality and performance of enterprise-wide IS within an organization, communicating and understanding the skills required for IS work is extremely important and therefore, the need for graduates with current and up to date skills capability is of constant concern.

According to LeClair et al. (2013), an impending challenge in the domain of cyber security that has been echoed in a number of studies (Assante & Tobey, 2011; Locasto et al., 2011; Rowe, et al. 2011; VanDerwerken & Ubell, 2011) is the lack of a trained and educated cyber workforce that can recognize vulnerabilities and defend organizational networks against cyber-attacks. For example, a recent study conducted by the world's largest not-for-profit information security professional body, International Information Systems Security Certification Consortium 2 in partnership with Booz Allen Hamilton with over 12,000 information security professionals worldwide, pointed to the shortage of skilled cyber security professionals (Suby, 2013). The study also reveals that organization managers are not completely satisfied with the quality of network and cyber security job applicants.

For this reason, online or cloud based lab environments are needed to help prepare the present and future IT workforce to compete for these skills based positions. However, there are no recent studies that directly address the construction of cloud-based lab environment based on design science principles; although there are a number of studies that carry out research based on the importance of remote access lab environment

availability used to moderate hands-on practical skill experience in IS education programs. Madan et al.'s (2012) study discovered that problems such as platform security, technical standards, regulatory, and other services in e-learning platforms are not well resolved in literature and warrant further research and exploration. This issue provides an opportunity to significantly advance IS toward a unified and affordable artifact system that can be leveraged to facilitate effective online or cloud-based laboratory solutions across academia. Additionally, Yan (2011) discovered there are very few studies that speak to the issues of remote access lab architecture design complexity, scalability, and use for on-ground/online throughout this problem domain. This is the very reason Yan explored cloud computing technology in computer and information science education for practical use in the classroom and remote connectivity locations. Yan (2011) found that this type of lab architecture environment will require minimum lab overhead cost and will provide increased lab availability together with an open and collaborative lab learning architecture that will, ultimately, benefit the student.

Madan et al. (2012) discovered that when associated to legacy IT service provisioning models, cloud computing has several advantages: minimal up-front initial investment in hardware, software, and technical staff to manage servers; reduced launch time; enhanced performance; redundancy and scalability; distributed fault-tolerance; clustering; accessibility; and on-the-go mobility that provides users with access to network resources from any device such as a mobile phone, computer, laptop, and/or tablet. According to their study, cloud computing will positively impact the total cost of ownership by lowering the cost structure of all industries using IT resources. The end result will have an indirect impact on business creation and the economic performance both locally and

globally. According to Madan et al. (2012), this will also benefit the education sector and especially in schools with programs delivered in e-learning or remote access platforms. Their study found that in both organizations and schools, cloud computing has attracted significant momentum and attention as an opportunity that could prove to be extremely beneficial because of the built-in flexibility and pay for use cost structure. Madan et al. further indicated that in e-learning cloud environments, users will have access to digital services clearly through a plethora of devices at any time and from anywhere. The users can obtain the necessary networking, computing services, and applications seamlessly from any position on the planet as long as they have Internet connectivity. The IS network and physical space will become integrated because of ubiquitous computing capability that will ultimately drive this de-facto standard vehicle of e-commerce and education into the future.

According to Wang et al. (2010), virtualization systems and related technology that could have been leveraged to enhance lab environments were available as far back as the early 1960s at the International Business Machines (IBM) organization, but the use of this type of technology in education didn't actually begin until the early 2000s. According to their study, cloud-based lab environment systems have recently been more widely deployed at colleges and universities for teaching IT courses. These types of courses require hands-on experiments in which students would need administrative access in order to learn network administration, security, virtualization, storage technology, and enterprise computer architecture. Wang et al. (2010) also indicates that evaluation studies show a highly positive response to the use of dedicated equipment and technology in computing education. However, Wagner and Wudi, (2004) found that

insulating laboratory environments from the outside world not only significantly increased the costs to build and maintain that environment, but also created inconvenience for the students and instructors with such problems as lack of always on availability, increased cost, and time in lab constraints. Shortly after the release of several virtualization products, researchers and educators began to explore different techniques to create virtual computing environments for computer and IS educational courses.

A recent study conducted by Pena-Rios et al. (2012) focused on developing models and tools to enhance education for students learning from remote locations. This study analyzed multiple learning theories with related technologies that spawn innovation, including new forms of advanced educational laboratory environments that present a complete paradigm shift compared to legacy laboratory environments. According to their research, laboratory activities are based on constructivist pedagogy where exposure to hands-on lab activities are extremely important since it provides learners with an opportunity to practice conceptual knowledge and to work collaboratively, interacting with equipment and performing analysis on experimental data. Several years prior to this study, Vollrath and Jenkins (2004) also successfully experimented with and deployed remote desktop protocols and secure shell for secure remote access to the virtual machines, storage systems, and lab environment.

The fundamental features proposed in Wang et al.'s (2010) lab manager significantly enhanced the process to design and conduct hands-on experiments from remote locations for teaching information system and technology related courses. Wang et al. found, in general, the system was satisfactory in terms of performance, ease of maintenance, and friendliness of the user interface. However, as a new product, Wang et al. indicated it still

required a steep learning curve for both faculty members and students using it. According to Wang et al., another issue arose when there were too many machines running concurrently in the system and that performance degradation was noticeable especially during heavy workloads taking place simultaneously within the server clusters. Providing a work around for that problem, Wang et al. recommended that students should avoid using all of their machines at the same time and when the virtual machines were not in use, they should be powered down or suspended to save the limited computation and memory resources.

In order to improve performance and leverage computing resource utilization between local machines and on shared storage, Stackpole, Koppe, Haskell, Guay, and Pan (2008) developed a decentralized virtualization environment. In this laboratory environment, VMware Workstation and Servers were used for the virtualization platform since they provided the linked-clone feature and offered the most advanced guest operating system support. Virtual machines that were physically created were stored on local machines, while the virtual machines of linked-clones were stored in a shared storage. This design not only alleviates the work burden of the network significantly, but also improves the use of and accessibility to the computer systems since the consistent states of the virtual machines are stored in the shared storage and users can access their virtual machines remotely from anywhere at any time.

Dinita et al. (2012) found in their study that local computer hardware resources have traditionally been relied upon in many university classrooms to support the delivery of outcomes that require hands-on practical experiences. This type of environment limits the student exposure to heterogeneous networks because of constraints such as having the

ability to quickly restructure the architecture or maintain a persistent environment based on business requirements or specific topologies. Virtualization and remote lab access would potentially bridge this gap by facilitating the capability to change topologies and environments on demand with persistent configuration.

According to the curriculum recommendations in Lunt et al.'s (2008) study, the words apply, accomplish, demonstrate, employ, use, and integrate should be included in IT programs to provide a strong underlying application component. However, Lunt et al. firmly believes that students are unlikely to acquire essential practical hands-on knowledge based on part of the curriculum recommendations without a significant experiential learning component such as unaltered access to structured and unstructured skills based labs in their program of study.

As mentioned previously, Stewart et al. (2009) studied different ways to leverage operating system virtualization and other similar techniques to create virtual network environments consisting of dozens of nodes running on low performance hardware. Additionally, Du and Wang (2008) presented an extensive array of instructional laboratory exercises in their study for a computer security course also using virtual machines in the lab environment and Li et al. compared a number of virtualization techniques and products that are currently in use and have built a set of complex hands-on laboratories that are used for their networking and security courses. Another comprehensive evaluation study by Duignan et al. (2008) shows the use of virtualization technology in computer networking, security and system administration education is effective and positive. The results of their study indicate the application of skills based labs through the use of virtualization in education will most likely continue in the future.

As a result of the findings in previous research and in order to advance the IS skill capability of students preparing them to confidently enter the workforce, universities and schools not only need cloud-based lab environments with 24/7 global access capability, they will also need processes and procedures that facilitate the effective design, construction, implementation, and management of these highly scalable systems around the clock. The cloud-based lab architecture system at the center of this dissertation report was created based on guidance from DSRM and principles designed to meet and exceed this requirement.

In order to build an effective cloud based lab environment, procedures and specifications based on DSR principles must be developed in order to guide the effective construction and assessment of this type of environment. These principles that are based on the foundation of design theory are important because according to Venable (2006), theory building plays a central role as it occurs in the beginning, throughout, and at the end of DSR. According to his work, discovering theories in IS starts with an idea for not yet existing or developed technology that ultimately provides solutions to otherwise known problems. The work by Hevner et al. (2004) also includes portions of design theory based on Markus et al. (2002) as well as Walls et al. (1992) stating that design artifacts rely on kernel theories that are practical, adaptable, and assessed through the experience and overall problem solving capability of the researcher.

Based on their proposed specifications for IS design theory, Gregor and Jones (2007) found that design theory consists of something in the theoretical world of man-made objects including but not limited to system models. According to their proposal, a design theory instantiated would have a physical existence in the real world. For this reason,

design and action in IS continues to be a significant process despite the fact that they are not always recognized as theories. Therefore, the importance of design knowledge and work in the context of theory remains a paramount consideration when constructing physical artifacts such as the cloud based lab system artifact constructed in this study.

Design theories lead researchers to extrapolate specific instructions for the construction of artifacts such as decision support systems used to capture knowledge required to facilitate the formation of curriculum in IS and computer science education or in the case of this study, remote lab environment architecture used to enhance skill levels of IS graduates. Gregor and Jones (2007) further indicate that the distinguishing attributes of design and action theories are they tend to focus on how to do something by prescribing explicit design and development instructions for technological artifacts.

According to their research, IS design theory show the principles inherent to the design of IS artifacts that accomplish something based on a combination of knowledge from both human behavior and IT. In their work, Gregor and Jones concluded that because the term design is both a noun and a verb, a theory can be about the principles underlying the form of the design and also about the act of implementing the design in the real world. As depicted in Table 3, Gregor and Jones contended that any and all design theory should include at a minimum: (a) purpose and scope, (b) constructs, (c) principles of form and function, (d) artifact mutability, (e) testable propositions, (f) justificatory knowledge, (g) principles of implementation, and (h) expository instantiation.

Table 3

Eight Components of Information System Design Theory

Component	Description
1. Purpose and Scope	The system will be used to provide 24/7 access to network lab environment with technical assistance to degree seeking students and continuing education professionals.
2. Constructs	Theoretically, the system will enhance student learning based on round the clock access to cloud-based lab environment.
3. Principle of Form and Function	The system will be designed to enhance the student experience by providing real equipment accessible from anywhere in the world with built in advanced operating system and networking lab exercises.
4. Artifact Mutability	The argument is made the system will be designed with built-in scalability and technical upgrade capability that will occur seamlessly and without end user interruption.
5. Testable Propositions	Analysis will be run to prove cloud-based network lab environments are consistently accessible, better performing, and more effective than classroom-based lab environments.
6. Justificatory Knowledge	The approach proposed will be based on system design theory from the design sciences that give a basis and explanation for the overall design.
7. Principles of Implementation	Construction of the experimental system and implementation in practice by (a) establishing system objectives, (b) defining system functionality, (c) developing the system, and (d) evaluating the system.
8. Expository Instantiation	Examples will be provided based on fully operational and testable expository system. The system will require Web access and consist of rack-based servers and storage, virtual machines, networking infrastructure, and imbedded step-by-step labs.

According to the study conducted by Gregor and Hevner (2013), theory is seen as an abstract entity, an interconnected set of statements about relationships among constructs that wishes to describe, explain, understand and potentially predict the future (Gregor, 2006). The type of theory that formalizes knowledge in DSR is termed design theory, the fifth of the five types of theory in Gregor's taxonomy. This type of theory gives prescriptions for design and action through the explanation of how to do something such as building a cloud-based lab artifact.

Design methods are key insights or unique essential truths resulting in added universal solutions in order to achieve better experiences for users with products, services, environments and systems they rely upon. The design methodology developed by Peffers et al. (2007) may help IS researchers develop, present, and publish high quality DSR in IS that is accepted as rigorous and relevant in IS research domains. For DSR, a methodology would include three elements: (a) principles in concept that define what is meant by DSR, (b) practice rubrics, and (c) procedures for following through and presenting the research. According to Gregor (2006), a design methodology can build on specific studies of what has worked in practice, on projected relationships that are known but not fully understood, and on fully developed design theory principles.

Based on the work recently published by Gregor and Hevner (2013), some examples of how DSR has been used in IS and IT research are included in Table 4.

Table 4

How DSR has been used in IS

Article	Knowledge Contribution
A Multilevel Model for Measuring a Firm's Competitive Strategies and Information Systems Capabilities (McLaren et al. 2011)	Improvement through a more fine-grained model for diagnosing the individual IS capabilities that contribute to the overall fit between a firm's competitive strategies and IS capabilities.
Improving Employees' Compliance Through Information Systems Security Training: An Action Research Study (Puhakainen and Sipponen 2010)	Improvement through the development of a theory-based training program.
Detecting Fake Websites: The Contribution of Statistical Learning Theory (Abbasi et al. 2010)	Improvement that can more accurately detect various categories of fake web sites.
Making Sense of Technology Trends in the Information Technology Landscape: A Design Science Approach (Adomavicius et al 2008)	Improves technology forecasting methods by providing structured input and formal analysis of the past and current states of the IT landscape.
Using Cognitive Principles to Guide Classification in Information Systems Modeling (Parsons and Wand 2008)	Improvement that includes rules used to guide the construction of semantically clearer and more useful models.

Summary

This chapter focused on identifying literature based on what is already known about the problem and analyzing the literature to discover potential solutions that align with the problem statement, research questions, and hypothesis. The chapter began with the justification for the study by selecting papers for the review based on relevancy to design science, cloud based lab environments, IS graduates, and IT workers. The chapter then formed the chronological summarization of existing studies based on the four main topic areas of (a) need for skilled IT workers, (b) lack of skill in IS graduates, (c) educational online or cloud based lab environments, and (d) DSR theory and principles. The chapter

further identified the strengths and weaknesses as well as gaps in the literature reviewed as they related to the four main topic areas and the problem statement. The overall goal of the literature review was met by synthesizing the foundational studies that were used to guide the extrapolation and development of procedures and specifications based on DSR to facilitate the artifact building methodology used to direct the construction and evaluation of the online cloud-based lab environment in this study.

Chapter 3

Methodology

Overview of Research Methodology

This chapter of the dissertation report will address the research problem and the methodology of how to accomplish the stated goal of building and assessing an artifact used to support remote lab environments using a two phased research approach. The first phase of the research focused on the principles that were followed during the artifact construction in the form of extrapolating specifications and procedures from design science. The second phase of the research rigorously assessed the effectiveness of the artifact through demonstration and evaluation.

In order to show relevance and build a partial link between the problem in this study and the contribution it will make to solving problems discovered in IS and education domains, the seven guidelines for effective research developed by Hevner et al. (2004) were reviewed and mapped to facilitate the development of the cloud-based lab environment model in this report that can be followed by others. The seven design science guidelines of Hevner et al. begin with the knowledge that DSR must produce an artifact in the form of a method (algorithms and practices), model (abstractions and representations), construct (vocabulary and symbols) or an instantiation (implemented and prototype). The guidelines of Hevner et al. introduce a structure to plan and evaluate the DSR process that will provide relevancy and rigor to solution results. Hevner et al. argued that the IS artifact should be at the center of subject matter examined by all IS research. Hevner et al.'s research also indicates the artifact defines the characteristics that

facilitate all phases of IS development including analysis, design, implementation, use, and evaluation.

Numeric Guidelines

Numeric Guideline 1: Viable Artifact

Numeric Guideline 1 is that the research must produce a viable artifact. In support of guideline number one, this dissertation report will lay the groundwork to facilitate the design, implementation, and assessment of a comprehensive cloud-based computer and IS lab architecture prototype system that can accommodate the inclusion of built-in lab exercises that are globally accessible from anywhere and anytime. Hevner et al. (2004) supports this primary goal by stating, “knowledge and understanding of a design problem and its solution are acquired in the building and application of the artifact” (p. 82).

According to Gorgone et al. (2002), cloud computing infrastructure in IS education mainly contains hardware, networking, operating system software, and technical support. Their study reinforces the idea that to keep up-to-date with quickly changing technology architecture, IS students and faculty should have unaltered access to equipment and components equal to those used throughout the industry. This type of access is recommended to prepare students for work in their profession and for faculty to contribute research to the advancement of the knowledge base related to the field.

Gorgone et al. (2002) has found that while a handful of university computing laboratories support the necessity of IS programs, specially designed architecture resources are needed to maintain curriculum requirements including systems expansion and network infrastructure scalability having more advanced and emerging technologies.

According to the findings in their study, the success of any IS program, including graduate preparedness to enter industry will be based on access to skills based experience with emerging lab environments that have adequate instructional and technical support.

In the past, there have been successful attempts to use this type of training lab architecture in an academic context such as through the use of Netlab+ that was illustrated and described by Dinita et al. (2012), Cronin et al. (2012), and Pickard et al. (2012) . Although some of the hardware and software solutions in Netlab+ reviewed by Dinita, Cronin, and Pickard are similar to the system reported in this study and can provide some of the desired features, the small scale proof of concept of this artifact including open source, multi-vendor, and upgraded hardware/software combined with built-in step-by-step labs makes the elucidation of the system in this dissertation report a novel approach.

According to Gregor and Hevner (2013), the development of an innovative artifact that can benefit an organization will be seen as a contribution to knowledge notwithstanding the fact of whether or not the artifact completely works as designed in the initial stages.

Numeric Guideline 2: Technology-Based Solutions

Numeric Guideline 2 is that the researcher must develop technology-based solutions to important and relevant business problems. The technology solution that addresses problem in this dissertation report is the primary motivation of the study and will potentially impact student preparedness to enter highly technical network and computer system administration jobs since the artifact is specifically designed to prepare IS graduates for this type of profession.

In theory, provided the students are better prepared in the form of enhanced skill sets since they have access to cloud-based lab architecture in their degree programs, the opportunity exists for them to capitalize on increasing demand for highly technical jobs in IT. Thus, the artifact constructed in this study will help to resolve a business problem by preparing information system graduates to enter the workforce while increasing the pool of skilled IT workers available to meet organizational employment demand.

Numeric Guideline 3: Artifact Utility, Quality, and Efficacy

Numeric Guideline 3 is that the utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well executed evaluation methods. According to Hevner et al. (2004), rigorous design evaluation provides important information to the design science researcher that allows them to generate valuable feedback that will assist with the artifact's design and development. Hevner et al. identified five methods that can be used to evaluate artifacts: (a) observational (case studies or field studies), (b) analytical (static or dynamic analysis), (c) experimental (controlled experiments or simulations), (d) testing (black or white box testing), and (e) descriptive (informed arguments or scenario generation). During construction, the artifact constructed in this study was evaluated for performance based on functionality through black box testing methods. The results from the series of black box tests were used to improve the procedures and specifications derived from DSR to facilitate the dynamic construction process and evaluation of the artifact. The procedures that were used to evaluate the artifact are

1. Visually and physically verify component interface connectivity and link lights.
2. Test component connectivity through the use of Ipconfig, Ping, and Tracert utilities.

3. Create test user accounts and verify access and authentication capability.
4. Test battery of pre-defined labs and step-by-step procedures from remote locations.
5. Monitor/analyze component CPU, memory, and drive space during lab testing.
6. Measure/analyze bandwidth consumption with Catci network monitoring system.
7. Make adjustments based on findings and repeat steps 1 through 6.

The system testing was accomplished after the initial construction of the artifact based on the approved design topology and component selection of the prototype cloud-based lab system outlined in the following sections of this chapter.

Numeric Guideline 4: Clear and Verifiable Contributions

Numeric Guideline 4 is that the research must provide clear and verifiable contributions in the areas of design artifact, design foundations, and/or design methodologies. Based on results from their recent study, Gregor and Hevner (2013) conclude that the field has not completely reached an understanding as to what clearly defines a contribution to knowledge from a DSR project and this deficiency ultimately limits the acceptance and impact of DSR in the IS community. Hevner et al. (2004) indicates that in addition to a knowledge contribution, effective DSR should make clear contributions to the practical application settings from which the research problem is drawn.

Recent debates in the IS community have centered on the importance of contributing to practice via IS research. The German *Wirtschaftsinformatik* community has published a memorandum calling for greater recognition of design oriented IS research and has drawn attention to the close working relationship of industry and academia in Europe (Österle et

al. 2011). Responses to this type of concern highlights the openness of the IS community and its research journals to DSR projects and emphasize the need to publish work in both theory and practice (Baskerville& Myers, 2009).

In general, one of the main criteria regarding the contribution and value of DSR ties back to whether or not the problem is relevant. In other words, if the IS artifact has value to businesses in the context of some problem, then the researchers have made a contribution to practice. In this study, the artifact will add value to the organization because it will potentially provide solutions that may positively impact the preparedness of students who enter the IS workforce and help them maintain those highly technical jobs in the industry.

Numeric Guideline 5: Artifact Construction and Evaluation

Numeric Guideline 5 is that the application of rigorous methods in both the construction and evaluation of the design artifact. According to Hevner et al. (2004), rigor is ultimately derived from the knowledge base and successful design of an artifact is primarily based on the researcher's selection of techniques to develop the same justifying the overall theory and evaluation thereof. Thus, the artifact must be constructed and evaluated rigorously and remain relevant throughout the DSR process. In essence, the primary purpose of rigorous evaluation determines whether or not the artifact works and scientific methods should be strictly adhered to in order to make that qualified determination. In this case, testing methods were developed to determine if the lab environment architecture worked effectively and supported multiple experimental groups simultaneously. The artifact development used design procedures and specifications

proven to provide students with around the clock accessibility to high performance and reliable cloud-based lab architecture.

Numeric Guideline 6: Utilizing Available Means and Satisfying Laws

Numeric Guideline 6 is that the search for an effective artifact must utilize available means to reach desired ends while satisfying laws in the problem environment.

Ultimately, the design of the proposed artifact in this study is nothing more than a search process with the purpose of discovering a problem solution in the form of deriving design procedures and specifications based on DSR that facilitate effective artifact construction and evaluation of an educational cloud-based lab environment. According to Simon (1996), problem solving consists of utilizing available means to reach a desired end while satisfying laws within the domain. Effective design in this case requires knowledge in the area of both the application and solutions domain that were demonstrated in the artifact field-testing and effectiveness analysis results.

According to Gregor and Hevner (2013), the goal of DSR in the improvement quadrant is to create better solutions in the form of more efficient and effective products, processes, services, technologies, or ideas. Researchers must contend with a known application context for which useful solution artifacts either do not exist or are clearly suboptimal. Researchers will draw from a deep understanding of the problem environment to build innovative artifacts similar to the cloud-based lab environment outlined in this dissertation report as solutions to important problems. The key challenge in the improvement quadrant is to clearly demonstrate that the improved solution genuinely advances on previous knowledge and this was demonstrated throughout the construction and evaluation of the cloud-based lab environment in this study.

Numeric Guideline 7: Effective Presentation

Numeric Guideline 7 is that the research must be presented effectively both to technology-oriented as well as management-oriented audiences. According to Hevner et al. (2004), technology and management audiences need detail to make decisions on committing resources to building the artifact feasibly and within organizational context. In order to justify the overall effort and cost that will be required to launch the system, sufficient detail with organized appendices and presentation material will be required to capture audience attention that will clarify the problem and prove the solution convincing. The product of DSR in building this artifact is communicated in a way that implementation teams can replicate the artifact in their organizations and IS as well as academia will recognize a viable contribution to the body of knowledge (Hevner et al, 2004). The cloud-based lab system design, implementation, and evaluation process developed in this study including specifications and procedures is communicated in the form of a Virtual Publication (VPUB) electronic manual that is available to all academic institutions at <http://ecpi.mobi/vcastle>. See Appendix F.

Specific Research Methods Deployed

The DRSM used to address the research problem along with the design procedures and specifications that were used to construct the artifact in this report were derived from design science principles using a systematic approach for building cloud-based lab architecture related to the problem domain. Based on the summation and blending of design theory elements synthesized from the literature review, a set of procedures and specifications were developed based on DSR principles and methodologies that were

used to facilitate the construction, implementation, and evaluation of the cloud-based laboratory artifact. The overall goal was to transition the emergent DSR theory into design application that was extrapolated and leveraged to guide the construction and evaluation of the artifact.

Based on Hevners' DSR principles 1 and 5 from the previous section of this chapter, Table 5 illustrates a model for the artifact construction procedure using the iterative prototyping methodology guided by the literature that was used to derive specific answers to the research questions outlined in chapter 4 of this dissertation report. Hevner's Principles 1 and 5 specifically map to the construction of the artifact reported in this study.

The methodical approach that supported the artifact design, construction, and evaluation including derivation of answers to the research questions in this study focused on four specific knowledge base areas from Peffer et al.'s (2007) DSRM listed below and then outlined in Table 6:

- Knowledge base principles that will identify the requirements the solution must meet in order for the cloud-based lab artifact to be successful.
- Knowledge base principles that will be followed to guide the design and construction of the cloud-based lab artifact.
- Knowledge base principles that will be followed to evaluate the performance and effectiveness of the cloud-based artifact.
- Knowledge base principles that will be followed to communicate and replicate the cloud-based lab artifact.

Table 5

Artifact Construction Associated with *Hevners' Design Principles 1 and 5*

Hevners' design principles	Artifact Construction	
	Methods	Technologies
<p>1. The research must produce a viable artifact.</p> <p>5. Rely on the application of rigorous methods in both the construction and evaluation of the design artifact.</p>	<ul style="list-style-type: none"> • Apply principles, instructions and specifications based on DSR to design and construct prototype lab environment • Procure the equipment rack, network devices, software, and media. • Assemble and interconnect devices in accordance with the design topology • Install and configure the Windows Operating Systems on PC-A, PC-B, and PC-C • Apply Class C logical addressing scheme to devices across the topology • Test local and remote connectivity through the use of the ping and tracert utilities • Integrate and activate the built-in Network Development Group (NDG) labs • Test and Repeat 	<ul style="list-style-type: none"> • Visio • Cisco Routers • Cisco ASA firewall • Cisco Zone protection firewall • Windows Secure shell server • Cisco LAN switches • Microsoft LAN servers • Microsoft LAN client • Storage • IPV4/IPV6 • Cat5e/serial cables • Windows XP/7/8 • Server 2003/2008 • Fedora core 16 • Ping and Tracert

Table 6

Peffers' DSRM blended with Activity, and Knowledge Base Framework

DSRM	Activity description	Knowledge base
Problem identification and motivation	There are no principles related to the effective artifact construction and evaluation of cloud-based lab environments.	Literature Review to understand the problem's relevance and current solutions including weaknesses.
Define the objectives of a solution	<ol style="list-style-type: none"> 1. The system must be web based. 2. The system must be accessible 24/7. 3. The system must be accessible from anywhere. 4. The system must perform well. 5. The system must be easy to use. 6. The system must be centralized. 7. The system must support embedded labs. 	Knowledge of feasibility, methods, theories, and technologies that help define the objectives.
Design and Development	Design and construction of the artifact that can be evaluated to solve the problem.	Application of methods theories and technologies to create an artifact that solves the problem.
Demonstration	Demonstrate the use of the system in an educational environment.	Indicate how the system can be used to solve the problem.
Evaluation	How effective does the system prepare students with skills based networking experience.	Evaluation techniques using variables.
Communication	Diagram and communicate the problem for replication in educational environments.	Knowledge of education culture related to online lab systems.

The DSRM process developed by Peffers et al. (2007) and adopted to derive design procedures and specifications for the artifact construction and evaluation in this study is based on three objectives for the DSRM methodology described above. First, it is consistent with prior DSR theory and practice since it has been represented in the IS literature and it has been conveyed in DSR literature throughout the discipline. Second, it provides a nominal process for conducting DSR in IS. Third, it establishes a mental model for the characteristics of research outputs.

Based on Peffers et al.'s (2007) DSRM, Figure 1 illustrates the design methodology that was used as a model to write the design procedures and specifications required to guide construction of the online or cloud-based lab environment in this dissertation report.

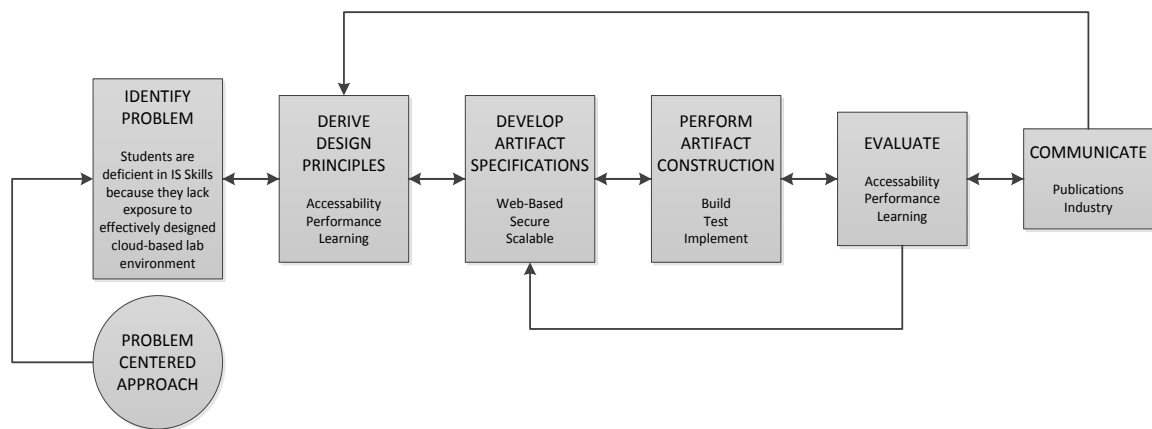


Figure 1. Proposed Design Methodology

Based on Hevner et al.'s (2004) DSR Principles 3 and 5, Table 7 defines the methods that were used to collect data for the artifact effectiveness evaluation including how the data was analyzed. Hevner's Principles 3 and 5 specifically map to the evaluation of the artifact proposed in this study.

Table 7

Artifact Effectiveness Evaluation Associated with Hevners' Design Principles 3 and 5

Artifact effectiveness evaluation		
Hevners' design principles	Techniques	Variables
3. The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well executed evaluation methods.	<ul style="list-style-type: none"> • MANOVA • Multiple Regression Analysis 	<ul style="list-style-type: none"> • The dependent variable will be the achievement of configuring the network settings and connectivity of a pre-defined secure network topology consisting of routers, switches, host machines, servers, and firewall devices as measured by a comparative analysis of the pretest and posttest completion percentage across the control and experimental groups.
5. Rely on the application of rigorous methods in both the construction and evaluation of the design artifact.	<ul style="list-style-type: none"> • Nonrandomized Control Group Pretest • Nonrandomized Control Group Posttest 	<ul style="list-style-type: none"> • The independent variables are the classroom-based lab environment and the cloud-based lab environment. • The second dependent variable will consist of time and user interaction spent on the classroom lab and the cloud based lab environment learning network security configuration skills.

Novel Design Procedures and Specifications

Based on previous chapters and sections of this study, Table 8 displays the specifications and procedures derived from Hevner et al.'s (2004), Peffers et al.'s (2007), and Gregor and Jones's (2007) DSR used to provide and define the nine design specifications including technologies, procedures, and techniques required to guide the design, construction, and evaluation of the cloud based lab environment artifact otherwise known as VCASTLE (Virtualization, Cloud, and Security Technology Learning Environment) at the center of this dissertation report.

Artifact Design

The VCASTLE system was designed primarily based on Hevner's principle 5 through the application of rigorous design methods.

The initial design and specifications used to build VCASTLE starts with the NDG Netlab+ Server baseline recommendations as described in the studies performed by Dinita, Cronin, and Pickard. The NDG Netlab+ Server was selected as the central device in the VCASTLE system because it provides a secure platform for users to schedule, configure and interact with physical and virtual lab equipment from both local and remote locations.

The minimum NDG design recommendations and certified hardware were modified for the VCASTLE system and upgraded to include high performance equipment in order to meet future scalability requirements and high demand expectations. The following list of replacement hardware and software included in the design of the VCASTLE system that is central to this report are currently not supported by NDG:

Table 8

DSR Derived Design Principles and Specifications

Design Specifications	Technology	Procedures	Techniques
1: Design VCASTLE system for accessibility, performance, and learning. Draw physical and logical topology.	Microsoft Visio Adobe Photoshop	Apply DSR derived principles to facilitate design of VCASTLE system.	Apply Industry Best Practice to design VCASTLE
2: Develop Artifact Specifications for Web-Based Access, Security, and Scalability.	NDG Netlab Appliance Rack Mounted Devices Firewalls Virtual Machines Storage	Apply DSR derived principles to facilitate development of the VCASTLE system specifications.	Calculate resources required to support 30 students simultaneously logged into the system
3. Procure equipment required to build the cloud-based lab system	Microsoft Word quantity and cost sheet	Order equipment	Accept bids from multiple vendors
4: Build and configure VCASTLE system that incorporates both physical and virtual machines that are globally accessible on a 24/7 basis.	Zone Protection Firewall LAN Routers/Switches LAN Servers/Clients Storage/IPV4/IPV6 Cat5e/Serial Cables Windows XP/7/8 Server 2003/2008	Apply specifications to build VCASTLE system. Assemble and interconnect devices and topology Install and configure operating systems Apply logical addressing	Apply Industry Best Practice to build VCASTLE system.

(continued)

Design specifications	Technology	Procedures	Techniques
5: Test VCASTLE system for positive connectivity from both local and remote locations.	TCP/IP Utilities Ping Tracert Ipconfig	Test Local and Remote Connectivity. Test and Repeat.	Bottom Up Approach - OSI Model
6: Integrate Labs that will prepare students to effectively configure the prototype environment.	NDG Lab Builder	Integrate skills based networking administration and cyber security labs	NDG lab integration process
7: Transition the VCASTLE system into production mode.	NDG Class Scheduler	Build groups Enroll students Evaluate	Schedule class and Administer skills based pretest to experimental and control groups
8: Evaluate the effect of the VCASTLE system based on student learning	Cisco packet tracer guided and graded skills-based test.	Compare pre and post test results	Administer skills based post exams to groups
9: Evaluate the accessibility, and use of cloud-based lab architecture	CATCI, Performance Monitor	Black-Box Testing	Monitor and analyze throughout the experiment
10: Communicate the process for replication across Academia	Build a Virtual Publication (VPUB)	Create and Publish	Author ibook and convert to HTML5 for wide-spread distribution

1. The NDG recommended Dell R720 rack mount server with Intel processor, Serial Attached SCSI (SAS) internal storage, and 72 GB of Ram was replaced with
2. Cisco UCS blade servers with 192 GB of Ram and external SAN connection capability.
3. The NDG recommended Dell R720 rack mounted server internal SAS storage was replaced with an EMC VNX 5100 storage array.
4. The NDG recommended VMware ESXi Version 5.1 was replaced with VMware ESXi Version 5.5.
5. The NDG recommended VMware vCenter Version 5.1 was replaced with VMware vCenter 5.5.



Figure 2. Initial prototype design of the VCASTLE rack mounted system.

Artifact Specifications

The base VCASTLE system specifications are documented in accordance with NDG's installation guide (Network Development Group, 2011) that can be retrieved from http://www.netdevgroup.com/support/documentation/NETLAB_Installation_Guide.pdf.

The ESXi 5.5 and vCenter Server 5.5 specifications including new features documented in a technical white paper (VMWare, 2014) and designed for inclusion into the VCASTLE system can be retrieved from <http://www.vmware.com/files/pdf/vsphere/VMware-vSphere-Platform-Whats-New.pdf>

The UCS B440 M2 server specifications designed for inclusion into the VCASTLE system and documented in a spec sheet (Cisco Systems, 2011) can be retrieved from http://www.karma-group.ru/Sites/karma/Uploads/UCS_B440_M2.813913e4e7c079cb67f9cee696f46449b.pdf.

The EMC VNX 5100 series appliance specifications documented in an EMC white paper (EMC, 2104) and designed for inclusion into the VCASTLE system can be retrieved from <http://www.emc.com/collateral/hardware/white-papers/h8217-introduction-vnx-wp.pdf>.

Artifact Equipment Requirement

The minimum certified hardware/software requirements partially used to build the base VCASTLE system in accordance with NDG's Netlab+ system requirements (n.d.) can be retrieved from <http://www.netdevgroup.com/products/requirements/>.

The upgraded hardware/software required including cost to build the VCASTLE system as outlined in this DR are listed in Table 9.

Table 9

Cloud-Based Lab Environment Components

Component	Quantity	Estimated cost
Hardware		
Cisco UCS B440 M2 high performance blade server, QuadIntel Xeon 7500 series processors, 192 GB memory (Upgrade), 40GB I/O throughput	2	\$22,000.00
EMC VNX 5100 (Upgrade)	1	\$8846.00
NDG Netlab+ PE Server	1	\$39,000.00
Cisco 1941 with security technology package license w/2 GE, 2 EHWIC slots, 256MB CF, 512MB DRAM, IP Base	6	\$7,668.00
ASA 5505 appliance with SW, 10 Users, 8 ports, 3DES/AES	2	\$1,158.00
Cisco 2901 IOS 15.1.4M4(MD)	2	\$1750.00
Catalyst 2960 24 10/100	6	\$5,394.00
4 Post enclosed rack - 24U 19"	1	\$750.00
10-32 Rack screws and cage nuts	200	\$30.00
Cat5e straight Ethernet 10' cables	24	\$97.25
Cat5e crossover Ethernet 10' cables	24	\$97.25
Cisco HWIC-16A asynchronous serial card	2	\$475.00
CAB-HD8-ASYNC octal serial cable	2	\$175.00
APC 7900 120v switched rack PDU	2	\$450.00
CAB-SS-V35MT V.35 cable DTE/DCE 20'	4	\$280.00
2-port serial WAN interface card	6	\$35.00
Software		
2901 IOS version 15.1.4M4(MD)	1	Included
2960 IOS version 12.2.25	6	Included
Windows 7 Professional (Upgrade)	6	Academic license
VMWare VSphere 5.5 (Upgrade)	1	Academic license
VMWare ESXi 5.5 (Upgrade)	1	Academic license
Total		\$88,205.50

Artifact Construction

The VCASTLE system was assembled primarily based on Hevner's principles 1 and 5 through the production of a viable artifact that rely on the application of rigorous construction methods. The VCASTLE is an expensive rack mounted networking and storage system, therefore, rigorous construction and maintenance requirements were followed in accordance with industry standard best practices and guidance (Cisco, 2014) retrieved from <http://axeapps.com/guidelines/Guidelines-and-Best-Practices.pdf>.

The first step in the construction process included unpacking and assembling the equipment racks that will be used to house and secure the lab devices. Afterwards, the Cisco UCS B200 M3 blade servers were mounted in the racks and installed in accordance with the installation and service notes (Cisco Systems, 2010) that can be retrieved from http://www.cisco.com/c/en/us/td/docs/unified_computing/ucs/hw/blade-servers/install/B440.html.

Since storage is a primary concern and needs to be connected to the blade servers, the VNX 5100 was installed in the rack and configured in accordance with the system installation guide (EMC, 2012) that can be retrieved from <http://www.storagenetworks.com/documents/emc/emc-vnx5100-install.pdf>.

Next, the Cisco routers and switches were installed in the rack and configured in accordance with the installation guide (Network Development Group, 2011) retrieved from http://www.netdevgroup.com/support/documentation/NETLAB_Installation_Guide.pdf.

The post construction of the VCASTLE system including base hardware, software, modifications, and upgrades are illustrated in Figure 3.



Figure 3. VCASTLE System

The classroom lab environment was setup to use the same equipment listed for the cloud-based lab environment with the exception of the Cisco UCS blade servers, EMC VNX 5100 SAN, NDG Netlab Server+ lab integration and scheduling appliance, and WAN connections. The blade server is not required since the students will use local VMs on their desktop systems to connect to the lab equipment in the rack. The NDG scheduling and lab integration appliance is not required since the students will access the lab environment only while in the classroom. The WAN connection is not required since the students will only have physical access to the equipment in the lab classroom (see Figure 4).



Figure 4. Classroom Lab Equipment

Artifact Testing

The VCASTLE system was rigorously tested based on Hevner’s DSR principle 5 in order to prove the architecture equipment was working and performing effectively based on the design.

After the devices in the topology were connected and configured in the construction phase, the TCP/IP utility “ipconfig” was used to verify the correct address configuration of the Windows virtual machines. The “ipconfig” utility was also be used to troubleshoot connectivity problems.

1. The Cisco Operating System “show command” was used to verify and troubleshoot the configuration of the routers, switches, and firewalls.
2. The TCP/IP utility “ping” was used to determine positive connectivity between routers, switches, firewalls, and host virtual machines.
3. The TCP/IP utility “tracert” was used to determine path between the routers across the topology.
4. Performance monitor was used to measure, CPU, Memory, and drive space utilization throughout the testing and experiment phases.
5. The open source “CACTI” utility was used to measure the effectiveness of throughput between the devices in the topology and overall bandwidth consumption during use.

Artifact Lab Integration

The NDG labs that were integrated into the VCASTLE system are in synchronization with the Cisco Packet Tracer pre/post tests used to evaluate student skill level and were utilized in guiding students to effectively configure the topology as indicated in Figure 5. The labs were integrated into the VCASTLE system based on NDG’s Lab Design Guide (Network Development Group, 2006) that can be retrieved from http://www.netdevgroup.com/support/documentation/NETLAB_Lab_Designer.pdf

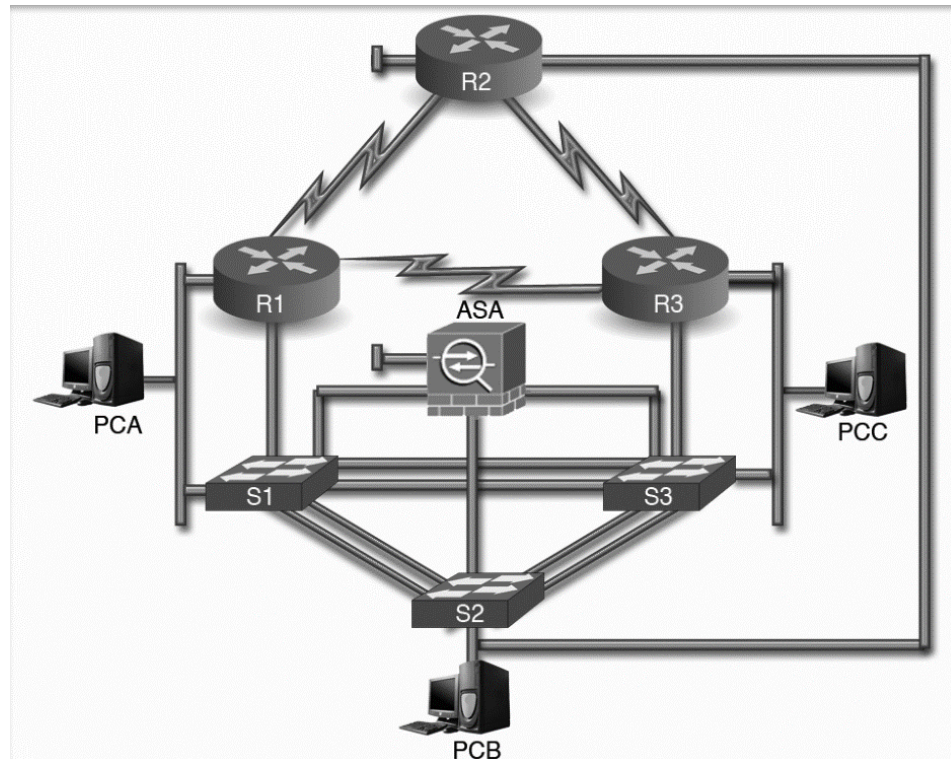


Figure 5. NDG Lab Topology

Artifact Production

The cloud-based lab environment was placed into production mode after construction and the cloud-based lab equipment were deployed in accordance with NDG's Point of Delivery (POD) assignment guide (Network Development Group, 2011) that can be retrieved from http://www.netdevgroup.com/support/documentation/NETLAB_Pod_Assignment.pdf.

Artifact Evaluation

The VCASTLE system was evaluated based on Hevner's principle 3 that states the utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well

executed evaluation methods. The steps required to evaluate the effectiveness of the artifact included the following:

1. Preliminarily, the experimental group and control groups were assessed through a common skills based pretest and posttest with permission from Cisco Systems that was timed for one hour using automated scoring functionality with a range of 0-100 percent completion.
2. The pretest and posttest was administered at the start and end of separate lab intensive experimental group courses and control group courses equally designed to prepare the students with outcomes that enable them to effectively configure a secure network environment as illustrated in appendix C.
3. The pretest and posttest was administered by a faculty member in the classroom on <http://nn.ecpi.net> and/or <http://rale.ecpi.net> and/or <http://vb.ecpi.net> prior to the start and at the end of a network defense and countermeasures five week course consisting of 15 lecture hours and 30 lab hours. The time limit to accomplish the pretest and posttest was set at 60 minutes to ensure objective and equitable results. See Appendix B.
4. After the pretest was completed, the control and experimental groups accomplished a battery of skills-based labs designed by and with permission from the NDG to prepare them to effectively configure and manage a secure networking environment. See appendix C.
5. The experimental group accomplished a series of labs in the cloud-based lab environment on <http://vcastle6.ecpi.edu> and/or <http://vcastle7.ecpi.edu> designed to prepare them to configure and manage a secure network.

6. The control group accomplished a series of labs on physical equipment in the classroom environment designed to prepare them to configure and manage a secure network.
7. The series of 10 labs (Treatment) contain the same procedures and configuration parameters required to setup and maintain a secure network for both the control and experimental groups.
8. After the labs were completed and at the end of the course for both the experimental and control groups, a posttest was administered and a comparative analysis was run against the same skills-based outcomes and by using the same measurement tool.
9. Individual system interaction time for the experimental group (proposed cloud-based lab environment using the artifact system) and control group (classroom-based lab environment using local equipment) was evaluated.
10. The main difference in access to the labs is that the experimental group had access to the VCASTLE system and labs on a 24/7 basis and the control group had access to the classroom equipment and labs only during class hours.
11. Multiple Analysis of Variance (MANOVA) and Multiple Regression Analysis were used as a statistical test procedure to determine if a significant difference resulted between the dependent variables across three experimental groups using the cloud-based lab environment and across three control groups using classroom-based lab environment. According to French, Macedo, Poulsen, Waterson, and Yu (2002), MANOVA is simply ANOVA having several dependent variables and testing the difference between more than two vectors of means.

12. The dependent variable is the achievement of configuring the network settings and connectivity of a pre-defined secure network topology consisting of routers, switches, host machines, servers, and firewall devices as measured by a comparative analysis of the pretest and posttest completion percentage across the control and experimental groups.
13. The independent variable is the traditional classroom-based lab environment and the prototype cloud-based lab artifact proposed in this study.
14. The second dependent variable consists of the amount of time and user interaction spent on the classroom lab environment and the cloud based lab environment learning network security configuration skills.
15. The results of the differences from the pre/posttest assessment of the experimental and control groups together with the dependent variables is presented in a table using the gain score tabulation method and analyzed through the Statistical Package for the Social Sciences (SPSS).
16. Answers to the research questions were extrapolated based on the results of the pre/posttest assessment analysis.
17. Artifact Communication
18. The VCASTLE system design, implementation, and evaluation process including specifications and procedures was communicated in the form of a Virtual Publication electronic manual that will be made available to all academic institutions.

Instrument Development and Validation

The instrument used to measure the pretest skill level of the students across the experimental and control groups included a simulation examination administered through a Cisco program called Packet Tracer detailed in appendix B. The pretest exam was used to assess student ability to configure a secure networking environment consisting of routers, switches, firewalls, and host machines that require connectivity and defensive posture based on pre-defined requirements.

The instrument used to prepare the experimental group to effectively configure a secure network consisted of a battery of ten cisco based hands-on lab exercises listed in appendix C and were made available through the NDG Netlab+ appliance integrated into the proposed cloud-based lab environment.

The instrument used to prepare the control group to effectively configure a secure network consisted of a battery of ten cisco based hands-on lab exercises listed in appendix C and were designed for deployment in the classroom environment through the use of physical equipment.

The instrument used to measure the posttest skill levels of the students across the experimental and control groups included a simulation examination administered through a Cisco program called Packet Tracer detailed in appendix B. The pretest and posttest exams were used to assess student ability to configure a secure networking environment consisting of routers, switches, firewalls, and host machines that require connectivity and defensive posture based on pre-defined network security requirements.

Permission from Cisco and NDG was formally granted in order to use the proprietary packet tracer software and copyright Netlab+ appliance including built-in lab exercises used to facilitate the research and analysis in this dissertation report.

Sample Population

The sample population in this study consisted of students enrolled at ECPI University across three campuses and who major in the computer and information systems (CIS) program having a concentration in cyber security. The course selected to prepare the students for the successful configuration and defensive posture of the network was CIS425 – Network Defense and Countermeasures since this course was originally designed to prepare students to secure and defend organizational networks.

For the Virginia Beach Campus class, the students were divided into two groups and selected based on non-randomization; the experimental group - A (cloud-based lab environment) consisted of 10 students scheduled for the course in a physical classroom on campus. The control group - A (traditional classroom-based lab environment) consisted of 8 students scheduled for the course in a separate physical classroom on campus.

For the Raleigh Campus class, the students were divided into two groups and selected based on non-randomization; the experimental group – B (cloud-based lab environment) consisted of 12 students scheduled for the course in a physical classroom on campus. The control group – B (traditional classroom-based lab environment) also consisted of 12 students scheduled for the course in a separate physical classroom on campus.

For the Newport News Campus class, the students were selected based on non-randomization; the experimental group – C (cloud-based lab environment) consisted of 12 students scheduled for the course in a physical classroom on campus. The control group - C (traditional classroom-based lab environment) consisted of 8 students scheduled for the course in a physical classroom on campus. The sample size of the groups had a maximum cap of 12 in order to manage the overall population, training, and assessment results.

Experimental Design

Pretest Posttest quasi-experimental design methodology was used to test the study hypothesis. This design helped test whether the two groups are different after the treatment (program). Two groups were used as described before; a control group and experimental group. Both groups took the pretest in a supervised environment and only the experimental group was subjected to the treatment (the cloud-based labs). The control group was subjected to traditional classroom-based labs. The pretest was given to both groups at the beginning of the term and at the end of the term they took the posttest as described before.

Data Analysis

To evaluate the prototype system and effectively answer the research questions in this study, quantitative data was gathered and analyzed using MANOVA, Multivariate Regression, and the SPSS data analysis package.

Skills-Based Assessment Results

Individual system interaction time for the experimental group (proposed cloud-based lab environment using the artifact system) and control group (classroom-based lab environment using local equipment) was recorded. The experimental group and control group were assessed through a common skills based pretest and posttest that was timed for one hour using automated scoring functionality with a range of 0-100 percent. The pretest and posttest was administered at the start and end of a separate, lab intensive experimental group course (CIS425) and control group course (CIS425) equally designed to prepare the students with outcomes that enabled them to effectively configure a secure network environment. The pretest and posttest was administered by a faculty member in the classroom prior to the start of the five week course and at the end of the five week course with a time-limit setting of one hour.

After the pretest was completed, the experimental and control groups accomplished a battery of ten skills-based labs designed to prepare them to effectively configure and manage a secure networking environment. The experimental group students were assigned a pre-defined series of ten labs in the VCASTLE system that were designed to prepare them to configure and manage a secure network. The control group students were assigned a series of the same ten pre-defined labs on physical equipment in the classroom environment that were designed to prepare them to configure and manage a secure network. The experimental group had access to the VCASTLE system on a 24/7 basis and the control group had access to the classroom lab environment only during class hours. After the labs were completed at the end of the CIS425 course for both the experimental group and the control group, a posttest was administered and a comparative

analysis was run against the same skills-based outcomes and by using the same measurement tool.

Study Construct

This section provides definitions of the five main constructs in this study based on research conducted by Elvyanti and Mujtahid (2015), Triantafillou, Pomportsis, and Demetriadis (2003), and Wallace and Clariana (2005).

Skills-based pretest: Timed and monitored skills-based pretest presented during the beginning of a 50 hour class.

Lab hours: The amount of time spent on the system working through the traditional classroom-based labs or the treatment cloud-based labs.

Number of Labs: The number of labs completed in the lab environment.

Skills-based posttest: Timed and monitored skills-based posttest presented during the end of the 50 hour class.

Gain: The knowledge or learning gain as measured by an increase in percentage score between the pretest and the posttest analysis.

Elvyanti and Mujtahid (2014) used pretest and posttest analysis to evaluate students' gain through case-based learning. The data showed significant increases in knowledge gain for students engaged in case-based learning when compared with the traditional model of learning pedagogies. Elvyanti and Mujtahid (2015) also used pretest and posttest to indicate student learning gain by examining some of the critical variables in learning styles and individual differences to facilitate the design of an Adaptive Educational System (AES).

Although several studies have used different construct names for the gain, all used the same methodology to calculate it. We adopted the method used in the research conducted by Wallace and Clariana (2005) of 140 incoming business freshmen to determine if they had adequate computer knowledge and skills to exempt the introductory computer fundamentals course through pretest, posttest, and knowledge gain analysis. The study calculated the differences between pretest and posttest mean and standard deviation to determine the knowledge and learning gain of students.

Format for Presenting Results

The design, development, and implementation of the artifact reported in this study was presented in support of Hevner's guideline 7 through the development and communication of a comprehensive electronic handbook that can be used by implementation teams across IS and education domains contemplating the deployment of cloud-based lab environments. The electronic handbook will include the following sections:

1. Physical network connectivity design diagram
2. Logical prototype topology design diagram
3. Artifact construction specifications
4. Minimum hardware and software requirements
5. Step-by-step artifact construction procedures
6. Step-by step artifact testing procedures
7. Step-by-step lab integration procedures
8. Transition cloud-based lab into production

The VCASTLE system design, implementation, and evaluation process developed in this study including specifications and procedures is communicated in the form of a Virtual Publication (VPUB) electronic manual that is available to all academic institutions at <http://ecpi.mobi/vcastle>. See Appendix F.

Resource Requirements

This section addresses the resources that currently exist and are under the researcher's control in order to complete the research and final dissertation report:

- hardware (appliances, blade servers, workstations, routers, switches, firewalls, storage);
- software (Windows client/server, Linux client/server, VMware Elastic Sky X Integrated, vSphere);
- packet tracer program
- cooperation with the Information Technology department;
- access to CIS curriculum and labs; and
- groups of students having access across several lab-intensive courses

Summary

Based on Hevner et al.'s (2004) seven guidelines of DSR, Peffers et al.'s DSRM, and Gregor and Jones's (2007) IS Design Theory, this chapter of the dissertation report provided the framework for the development of novel design procedures and specifications derived from DSR literature to facilitate the construction, implementation, and assessment of a comprehensive cloud-based computer and IS lab architecture artifact

(VCASTLE) that is globally accessible anytime. The research problem and the methodology of how to accomplish the stated goal of building and assessing the artifact used to support remote lab environments was accomplished by outlining a two phased research approach. The first phase of the research focused on the development of procedures and specifications that facilitate the artifact construction based on design science methodologies. The second phase of the research provided a framework for assessing the effectiveness of the artifact through demonstration and evaluation.

Chapter 4

Results

The problem examined in this study was initiated on the premise there are no design principles based on DSR that focus on artifact construction and effective evaluation of cloud-based lab environments that can be leveraged to foster technology skills in IS students.

The intention of the data analysis section of this chapter is to outline the results of the research in a systematic and organized manner through the use of MANOVA, Multivariate Regression, and the SPSS data analysis package together with the primary goal of addressing the following two research questions:

1. Can procedures and specifications be derived from DSR to guide construction of a cloud-based information system's hands-on lab architecture artifact that facilitates educational utility?
2. Are the procedures and specifications derived from DSR, and used in the construction of a cloud-based information system's hands-on lab architecture effective based on artifact use?

The first part of the findings section of this chapter reports if procedures and specifications can be derived from DSR to guide construction of a cloud-based information system's hands-on lab architecture artifact that provides educational utility. The second part of the findings section explores whether procedures and specifications derived from DSR, and used in the construction of a cloud-based information system's hands-on lab architecture are effective based on artifact demonstration.

The assumption made in this study is that procedures and specifications derived from DSR used to guide the construction of cloud-based lab architecture will have a positive effect on student outcomes and use based on skills assessment results and the number of labs completed including time spent on the system. As such, the summary section will include a statement as to whether or not the data analysis supported or rejected the following hypothesis:

H1. The procedures and specifications derived from DSR and guiding the construction of cloud-based lab architecture artifact will empower positive student outcomes as measured by hands-on configuration skills assessment results.

H2. The procedures and specifications derived from DSR will have a positive effect on the use of cloud-based lab architecture as measured by the number of labs completed and time spent on the system.

Data Analysis

Since the procedures and specifications based on DSR and required to guide the construction of VCASTLE in this study have been determined as presented in chapter 3, the remainder of research question 1 as to whether or not the system facilitates education utility can be answered by analyzing the study results data between the experimental (cloud-based) and control (traditional classroom-based) groups.

Sample Characteristics and Descriptive Statistics

The sample population in this study consisted of students enrolled at ECPI University across three campuses and who major in the computer and information systems (CIS) program having a concentration in cyber security. The course selected to prepare the students for the successful configuration and defensive posture of the network was CIS425 – Network Defense and Countermeasures since this course is designed to prepare students to secure and defend organizational networks.

As shown in Table 10, of the 62 students that participated in the experiment, 66.1 percent were male and 33.9 percent were female. The majority of the students across all three campuses were in the 30-39 age range and the majority of the sample had a Grade Point Average (GPA) that ranged between 2.1 and 3.0. Overall, the sample is quite evenly distributed in terms of gender, age, GPA, and location representing a diverse and balanced student sample population.

Initial Assessment of Validity

As a first step in the analysis, and before proceeding with testing the research questions and hypothesis in this study, the validity of the experiment was assessed.

According to Albright and Malloy (2000), experimental validity is based on the manner in which variables have an impact on both the generality of research participants and results of the research. Researchers have broken experimental validity into internal validity, and external validity.

Table 5

Sample Characteristics

Variable	<i>n</i>	%
Gender	41	
Male		66.1
Female	21	33.9
Age		
20-29 Years	23	37.1
30-39 years	37	59.7
≥ 40 years	2	3.2
GPA		
1.0 – 2.0	3	4.8
2.1- 3.0	34	54.8
3.1 – 4.0	25	40.4
Campus location		
Virginia Beach, VA	18	29.0
Raleigh, NC	24	38.7
Newport News, VA	20	32.3

Internal Validity

Internal validity refers to determining if a causal relationship exists between a single or multiple dependent variables and single or multiple independent variables. The first question should ask whether or not the results of the study were actually caused by the experiment or by some other factor (Briggs and Schwabe, 2011). In this study, we ensure that internal validity of the experiment was achieved by controlling its' threats. For the history threat, we make sure that all control and experimental group students had no previous knowledge and experience either from media or from instructors related to the experiment. To handle the maturation threat, the study carefully emphasizes that all students in this experiment were undergraduate seniors studying in the CIS security specialization and all having the same prerequisites course needed for their degree

program with no additional training through external or internal courses. To handle the testing threat, we designed the experiments so that the control groups were subjected to a traditional instruction method and mode for performing labs/tests, and the experimental groups were subjected to the proposed instructional method and mode for performing labs/tests, so no one will gain any extra knowledge by performing additional labs or retaking the test.

External Validity

According to Rothwell (2005), external validity is the extent in which the results of a study can be generalized for how data and theories from one environment apply to another environment. The single threat discovered in our experimental design through external validity was the treatment interaction effect. We designed the experiment so knowledge sharing between students in the control and experiment group will add no extra knowledge for any condition as the treatment was in the delivery method rather than the instructional method. To test for the experimental validity we conducted one-way analysis of variance (ANOVA). Table 1 in appendix E show descriptive statistics for the main study constructs; pretest, posttest, gain, lab hours, and number of labs completed.

Table 11 shows the ANOVA for the control group across the three campuses indicating there are no significant differences between the three groups in any of the study constructs. As a result, all control group students across the three campuses have the same level of previous knowledge, same level of instruction, same number of labs completed, and same access time available to the lab environment ensuring the validity of our analysis of this group.

Table 61

Control Group One-way ANOVA Campus-Based

Variable	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	Sig.
Pretest					
Between groups	35.708	2	17.854	1.106	.347
Within groups	403.542	25	16.142		
Total	439.250	27			
Number of labs					
Between groups	4.762	2	2.381	1.028	.372
Within groups	57.917	25	2.317		
Total	62.679	27			
Lab hours					
Between groups	53.333	2	26.667	1.608	.220
Within groups	414.667	25	16.587		
Total	468.000	27			
Posttest					
Between groups	72.548	2	36.274	2.028	.153
Within groups	447.167	25	17.887		
Total	519.714	27			
Gain					
Between groups	.001	2	.001	.590	.562
Within groups	.022	25	.001		
Total	.023	27			

The same ANOVA test was also conducted on the experimental groups at the three different campuses. Table 2 in appendix E shows the descriptive; mean and standard deviation, statistics of the five main study constructs; pretest, posttest, gain, lab hours,

and number of labs completed. Table 12 shows the ANOVA for the experimental groups of the three campuses and the results show there is no significant differences between the three groups in any of the study main constructs due to the campus location. These results indicate that all experimental group students at any campus location have the same level of previous knowledge, same level of instruction, same number of labs, and found that all have the same access time available to the lab environment. These results insure the validity of our analysis of the experimental group.

Findings

Having established that the experimental design demonstrated adequate internal and external validity, the test of the hypotheses was conducted. As stated earlier in chapter three, MANOVA and Multiple Regression Analysis were used to test our study hypotheses. SPSS was used to calculate the results of the study.

MANOVA was used to test for the efficiency of the cloud-based lab architecture. The test was run to examine the differences in gain, number of labs, and labs hours completed between the experimental and control groups. Results presented on Table 13 indicates significant differences between the experimental and control groups in the three main study constructs; gain, lab hours and number of labs at $\alpha < 0.001$.

Table 72

Experimental Group One-way ANOVA Campus-Based

Variable	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	Sig.
Pretest					
Between groups	171.071	2	85.535	1.562	.226
Within groups	1697.400	31	54.755		
Total	1868.471	33			
Number of labs	.331	2	.166	.382	.685
Between groups	13.433	31	.433		
Within groups	13.765	33			
Total	436.458	2	218.229	1.517	.235
Lab hours	4458.983	31	143.838		
Between groups	4895.441	33			
Within groups	34.737	2	17.369	.084	.919
Total	6389.733	31	206.120		
Posttest	6424.471	33			
Between groups	.006	2	.003	.358	.702
Within groups	.249	31	.008		
Total	.255	33			
Gain	171.071	2	85.535	1.562	.226
Between groups	1697.400	31	54.755		
Within groups	.022	25	.001		
Total	.023	27			

Table 83

MANOVA (Tests of Between-Subjects Effects)

Variable	Type III SS	Df	MS	F	p
Corrected model					
Gain	1.570 ^a	1	1.570	338.760	< .001
Lab hours	36.412 ^b	1	36.412	28.579	< .001
Number of labs	5944.833 ^c	1	5944.833	66.504	< .001
Intercept					
Gain	3.236	1	3.236	698.149	< .001
Lab hours	4840.024	1	4840.024	3798.914	< .001
Number of labs	134743.027	1	134743.027	1507.350	< .001
Experiment					
Gain	1.570	1	1.570	338.760	< .001
Lab hours	36.412	1	36.412	28.579	< .001
Number of labs	5944.833	1	5944.833	66.504	< .001
Error					
Gain	.278	60	.005		
Lab hours	76.443	60	1.274		
Number of labs	5363.441	60	89.391		
Total					
Gain	5.570	62			
Lab hours	5081.000	62			
Number of labs	152911.000	62			
Corrected total					
Gain	1.848	61			
Lab hours	112.855	61			
Number of labs	11308.274	61			

^aR Squared = .843 (Adjusted R Squared = .847)

^bR Squared = .526 (Adjusted R Squared = .311)

^cR Squared = .323 (Adjusted R Squared = .518)

Table 3 descriptive results in Appendix E indicate that significant differences were in favor of the experimental group for all constructs. The differences in the average gain of the experimental group was (39%) compared to (7%) for the control group and the test results shows that these differences are significant at $\alpha < 0.001$ in favor of experimental

group. In addition, the average lab hours of the experimental group (57 hours) was higher than the average lab hours of the control group (37 hours), and the test results indicate that these differences are significant at $\alpha < 0.001$ in favor of experimental group. Finally, the number of labs completed by the experimental group (9.65 labs) was higher than the number of labs completed by the control group (8.11), and the test results shows that these differences are significant at $\alpha < 0.001$ in favor of experimental group. These results ultimately support H1 and H2.

To test if each statistic evaluates a multivariate hypothesis that the population means on multiple dependent variables are equal groups, we calculated Wilik's Lambda shown in Table 14. Results indicate that Wilik's Lambda is significant at $\alpha < 0.001$.

Table 94

Multivariate Tests

Effect	<i>F</i>	Hypothesis df ^a	Error df	α
Intercept				
Pillai's Trace	.986	1406.153	3.000	< .001
Wilks' Lambda	.014	1406.153	3.000	< .001
Hotelling's Trace	72.732	1406.153	3.000	< .001
Roy's Largest Root	72.732	1406.153	3.000	< .001
Experiment				
Pillai's Trace	.851	110.169	3.000	< .001
Wilks' Lambda	.149	110.169	3.000	< .001
Hotelling's Trace	5.698	110.169	3.000	< .001
Roy's Largest Root	5.698	110.169	3.000	< .001

^aExact statistic.

To test the effect of each independent variable on the gain due to the experimental cloud-based compared to the traditional classroom-based lab environment, we conducted a Multiple Regression Analysis using the SPSS statistical package. We have created a new dummy variable (Treatment) which facilitates the measurement of students in either the experimental group or control groups. The experimental group was assigned the value (1) which means the students were subjected to the treatment, while the control group was assigned the value (0), which means the students were subjected to the traditional classroom-based lab environment. If the results show a significant effect of this variable it will be in favor of the (1) value which is the experimental group. We used two different methods to enter the variables into the regression equation; the enter method which enter all variables at once into the equation, and the stepwise which is a semi-automated process of building the model based on entering the variables into the equation based solely on the t statistics of their estimated coefficients based on the following equation:

$$\text{Gain} = F(\text{Treatment, Lab Hours, and Number of Labs})$$

$$\text{Gain} = \alpha_0 + \alpha_1 \text{Treatment} + \alpha_2 \text{Lab Hours} + \alpha_3 \text{Number of Labs} + \text{Error}$$

The results of the first method (*enter*) indicates that all of the dependent variables (Treatment, Number of Labs, and Lab Hours) have explained (.896) of the variation in the gain due to the cloud-based lab environment treatment. The model F-statistic (166.300) found to be significant at ($\alpha < 0.001$).

To study the sole effect of each independent variable, stepwise regression methods were used. Table 15 and 16 show these results. It has been found that treatment has the highest variation in the gain and explained .85 of that variation and its t-statistics (10.563) is significant at ($\alpha < 0.001$). The second variable that significantly affected the gain was

the lab hours, which explained (.041) of the variation in the gain and its t-statistics (4.192) is significant at ($\alpha < 0.001$). Results show that Number of labs found to explain only (.005) of the variation of the gain and its t-statistics is not significant at ($\alpha < 0.05$). These results confirm the treatment effect on the gain due to the proposed cloud-based lab environment which also makes this system available 24 hours a day, 7 days a week.

Table 105

Regression Model Summary

Variable	R	R ²	Adjusted R ²	SE of the Estimate	R ² Δ	F Δ	df	Sig. F Δ
Treatment	.922	.850	.847	.06808	.850	338.76	1, 60	.000
Lab hours	.944	.891	.887	.05846	.041	22.383	1, 59	.000
Number of labs	.946	.896	.890	.05761	.005	2.749	1, 58	.103

Table 116

Regression Model Coefficients

Model	B ^a	SE ^a	Beta ^b	t	Sig.
1					
(Constant)	.070	.013		5.413	.000
Treatment	.320	.017	.801	18.405	.000
2					
(Constant)	-.070	.032		-2.222	.030
Treatment	.245	.022	.708	11.332	.000
Lab hours	.004	.001	.295	4.731	.000
3					
(Constant)	-.149	.057		-2.623	.011
Treatment	.235	.022	.678	10.563	.000
Lab hours	.003	.001	.267	4.192	.000
Number of Labs	.011	.007	.089	1.658	.103

Summary

As a result of the this research and data analysis findings, the first hypothesis indicating positive student outcomes is fully supported since the overwhelming majority of the students who participated in the experiment using the cloud-based lab environment had statistically proven significant gain in pretest and posttest delta compared to the students who participated in the experiment using the classroom-based physical equipment.

H1. The procedures and specifications derived from DSR and guiding the construction of cloud-based lab architecture artifact will empower positive student outcomes as measured by hands-on configuration skills assessment results.

The second hypothesis also supported the study since the specifications derived from DSR positively influenced the use of the cloud-based system since the majority of the experimental group students completed most of the labs and significantly spent more time on the system compared to the control group students using the traditional classroom-based physical lab equipment.

H2. The procedures and specifications derived from DSR will have a positive effect on the use of cloud-based lab architecture as measured by the number of labs completed and time spent on the system.

Chapter 5

Conclusions

This chapter presents a summary of the study including relevant conclusions drawn from the data presented in Chapter 4. In essence, this chapter will provide a discussion concerning the implications for actions and recommendations for further research related to the problem outlined in Chapter 1.

Conclusions

Based on the analysis performed and the results achieved as presented in the methodology chapter 4, the specific objectives of the research questions in this study have been met based on evidence that will be presented in the following pages and paragraphs.

The first research question asked whether procedures and specifications derived from DSR and used to guide construction of a cloud-based hands-on lab architecture artifact can facilitate educational utility. The answer to this question is provided in the form of the skills-based assessment results achieved by the cloud-based laboratory environment (experimental group) students and the classroom-based laboratory environment (control group) students. The educational utility is realized in the significant positive change in pretest and posttest gain score tabulation of the experimental group students compared to the control group students. The gain is statistically significant considering both the experimental and control group students completed the exact same skills pretest in a monitored environment for 1 hour; the experimental and control group students had access to the same equipment topology throughout the study, although the experimental

group students had 24/7 access and the control group was limited to physical access only while in the classroom; both the experimental and control group students were assigned the exact same laboratory exercises that were designed to prepare them to effectively configure a secure network environment; and both the experimental and control group students completed the exact same skills posttest in a monitored environment for 1 hour.

The second research question asked whether procedures and specifications derived from DSR, and used in the construction of the cloud-based hands-on lab architecture were effective based on artifact use. The measurement used to determine artifact use in this study included the number of labs completed and the amount of time students spent on the cloud-based lab environment and the classroom-based lab environment systems. The answer to this question is provided in the results of the number of laboratory exercises completed and the amount of time spent learning how to effectively configure a secure network environment. The results of the study indicated a nearly equivalent number of labs (maximum 10) completed by the experimental and control group students with the experimental group logging a slight majority. The explanation for the minor disparity would be that some of the control group students simply didn't have enough time to complete all 10 labs since they didn't have access to the system twenty four hours a day and seven days a week.

However, the amount of time spent on the system working through those labs was significantly in favor of the experimental group students. This is most likely because the experimental group students had access to the lab equipment topology and labs twenty four hours a day and seven days a week while inside the classroom and outside the classroom compared to the control group students who only had access to the lab

equipment topology during classroom hours. Furthermore, the extended amount of time on the system for the experimental group students allowed them the opportunity for skill reinforcement by providing an environment for them to complete the battery of 10 labs without the concern about running out of time.

Limitations

One of the limitations in this study included possible threats to internal validity through the experimental and control group student selection. Since the research took place in classes the students' department heads scheduled them in, there was little control in which research group (control or experimental) each student was assigned. However, in order to deal with this issue, the courses were randomly assigned based on campus and then the students were divided into two groups (experimental or control) and selected based on non-randomization.

Another issue is that the instructors and students were aware that the researcher is a doctoral candidate and was conducting research through the classes in which they were assigned. In order to address this issue, the students were required to complete a consent form that explained voluntary participation, privacy, and the absence of danger or benefit if they agreed to participate in the study.

One possible threat to the external validity of this study is based on the type of education institution where the research was conducted. The university in which the research took place is private meaning its class schedule, structure and population may be different from other public and private institutions.

Another potential limitation that needs to be addressed involves the scalability and performance of the cloud-based lab system that is central to this research. Since only 34 students participated in the experiment, the system was not fully exercised and tested in a live environment to determine whether or not it could support additional connections simultaneously and thus provide a reasonable return on investment based on per-student cost.

Derived from the performance calculations that were recorded during the black box testing and experiment phase in Section 7 of Appendix F, the data recorded for CPU, memory, drive space, and bandwidth consumption during the experiment indicated an initial percentage peak during start up and then eventual drop to a consistent level as indicated in Table 17.

Table 17

Performance Levels for Components of the Prototype Cloud-Based System.

	% at Peak	% at Final Level
CPU	12.0	9.0
Memory	20.0	17.0
Disk Performance	2.5	0.5
Bandwidth consumption	31.0	19.0

Based on this information and calculated projections, the cloud-based system as it stands should support up to one hundred students simultaneously provided they logged into the system at the same time and shared the equipment hosted on the PODS designed in the initial prototype. Nevertheless, the system simply does not expire at the end of each

class – it can be re-used over and over with new student groups scheduled across an unspecified number of classes. Thus, the per-student cost would be difficult to calculate based on the assumption the shelf life of the system is currently unknown.

The key to leveraging the initial prototype POD resources across larger student populations is in the NDG scheduling appliance that manages the time allocation for POD usage based on intervals that must be manually scheduled by the students. Typically, this would occur after class hours when the student practices the reinforcement of skills-based activities learned during the class period. Essentially, the students have the opportunity after class to schedule lab time on the PODS for up to 8 hours thus sharing the resource during self-scheduled time-based intervals.

Another option for leveraging the initial prototype POD resources across larger student populations is to place the students into groups where they can work on lab activities in a collaborative environment. This configuration would provide an opportunity for more students to have access to equipment depending on the size of the groups sharing the POD resources. The potential problem with this structured environment is that some students may not have enough time on the system individually to establish or enforce the required skills necessary for successful entry into the IT workforce.

Implications

This study has implications for the IS education community and instructor training. More specifically, faculty form a community of practice, and the findings from this study are helping inform how they may leverage the VCASTLE system, especially in terms of

student roles, interaction, deployment of hands-on labs and accessibility. The VCASTLE system is pre-configured with written lab activities and networking topology models that can be used to supplement instruction and prepare students to effectively configure and manage a secure networking environment.

This study also has implications for the practice of instructional design and interaction design. The developers of curriculum, assessment, and instruction for the VCASTLE system may find the results useful for designing enhanced lab activities and future iterations of the POD configurations. The developers of curriculum, assessment and instruction for other lab based learning environments and e-learning courses using networking hardware equipment may find some of the lab configuration parameters and best practices relevant.

Recommendations

One of the first recommendations to enhance experimental and control group sample quality would be to expand the study to include more participants. The number of participants was limited to the network defense and countermeasure (CIS425) course schedule since it is only offered once a year across a couple of sections for each campus. The study should also attempt to leverage additional classes that can now utilize the VCASTLE system in order to build additional skill levels in other areas of networking such as virtualization, storage, email, operating systems, and active directory domains.

The second recommendation would be to allow more time for the students to complete the skills based pretest and posttest. It was observed during this study that students scored very low on the skills-based pretest which is understandable since there was a low

expectation the students would have the skill capability based on the network defense and countermeasures (CIS425) course outcomes. However, it was also observed that even though the delta percentage between the pretest and posttest for both the experimental groups and control groups was significant, most of the students in the study failed to reach the sixty five percent completion mark and this is most likely due to the fact the skills based test was limited to one hour for completion. Obviously, additional data capture and analysis would be required to prove or disprove this assumption.

The third recommendation would be to add additional labs to provide student reinforcement of key concepts that more effectively map to the outcomes required by the network defense and countermeasure (CIS425) course along with both the pretest and posttest assessment requirements. In this case, Appendix C should be modified to include the following additional course labs bringing the total number to 12:

1. Configure a Site-to-Site VPN using CCP and ADSM.
2. Configure a Remote Access VPN Client and Server

The fourth recommendation would be to consider using the Cisco packet tracer activity grader to more effectively analyze the pre/post skills assessment results based on granularity in achieving specific tasks. The activity grader in packet tracer automatically assigns assessment items from the answer tree to a default set of components that can be manually edited and assigned points based on the named component of the task. The screen capture in Figure 6 shows the level of granularity that can be assigned and weighted based on specific tasks in configuring the secure network environment.

Assessment Items	Points	Component(s)
Network		
ASA		
ACL		
?acl_inside-net?: permit ip 192.168.10...	1	ACL
Asa Object List		
inside-net		
Address: subnet 192.168.10.0...	1	my_component
Nat: nat (inside,outside...	1	Other
Class Maps		
Class Map List		
inspection_default		
Map Type: 1	1	Other
Statements		
default-inspection-traffic: default-inspe...	1	Other
DHCP Server List		
DHCP Server (inside)		
Pools		
Pool serverPool		
Start IP address: 192.168.10.5	1	Ip
Host Name: CCNAS-ASA	1	Other
IP Domain Name: ccnasecurity.com	1	Other
Management Access List		
Access Setting: ssh 172.30.3.3 255.2...	1	Other
Access Setting: telnet 192.168.10.0 ...	1	Other
Ssh Timeout: 10	1	Other

Figure 6. Cisco Packet Tracer Activity Grader

The results of this type of assessment criteria will provide researchers the ability to drill down into more specific data sets that can be used to extrapolate common misconfiguration themes in the lab environment. This information can then be used to more accurately identify and remediate individual and group skill level weaknesses.

Future Research

This study has implications for future research to design, implement, and test a process for requesting Point of Delivery Systems (PODS) in the classroom as illustrated in Figure 7 that can be used to support a wide range of computer and information systems courses that leverage VCASTLE. In support of this goal, Hevner (2007) states, “good design science research often begins by identifying and representing opportunities and problems in an actual application environment” (p. 89).

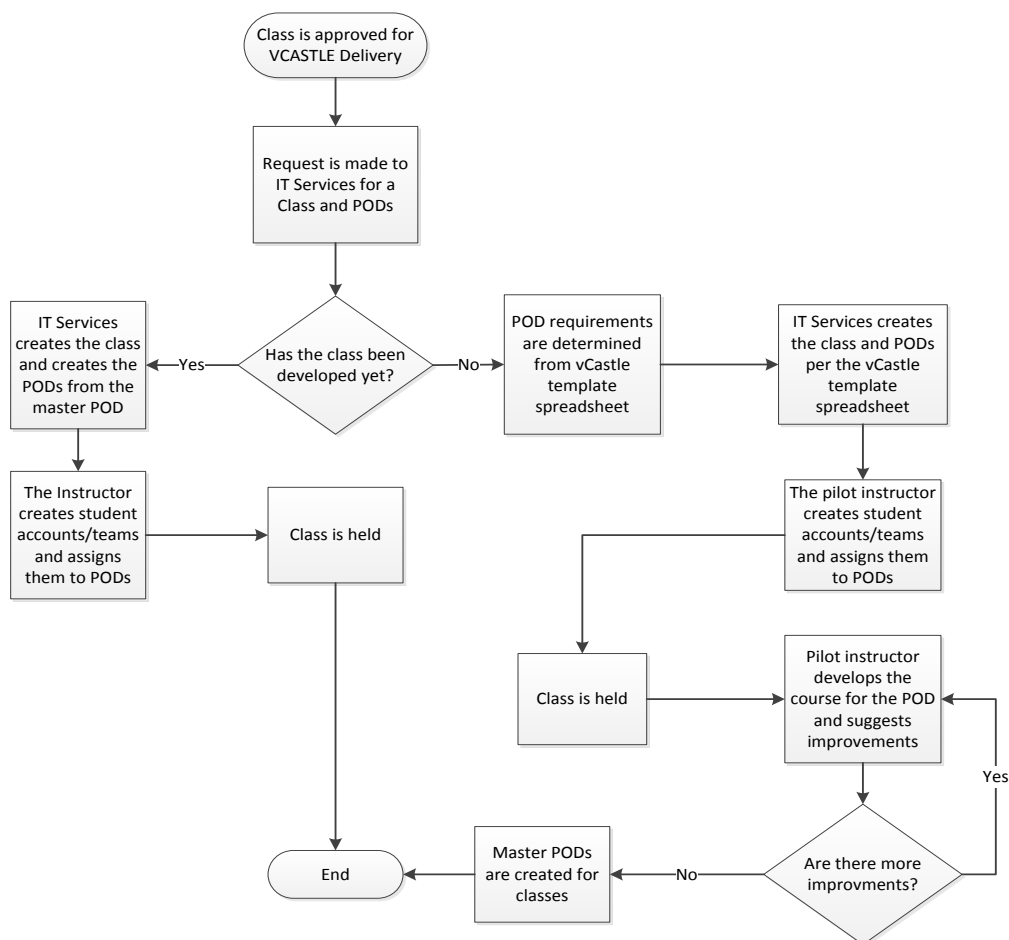


Figure 7. Point of Delivery (POD) Request Process

In order to enhance the design of the artifact presented in this dissertation report, future research should also focus on construction, evaluation, and scalability of the system for various other types of networking classes that support Operating Systems, Storage, Virtualization, Routing/Switching, and Client/Server. Additional features and enhancements such as Wide Area Network optimizers, gigabit interfaces, and upgraded memory/processing can be implemented to enhance stability, performance, power, and scalability required to support additional classes and students simultaneously. The

VCASTLE system may also include design criteria that will integrate a Virtual Technical Assistance Center (VTAC) to support asynchronous/synchronous technical and instructional support capability required to address technical issues within the lab environment on a 24/7 basis.

Additionally, future research may include the deployment and evaluation of the system through the enrollment of international students as well as online student groups in order to effectively measure capability across a wide spectrum of classes and large-scale student use.

Summary

This study was designed to determine network administration and security skill level of students who have access to hands-on lab equipment on a 24/7 basis compared to students who have access to lab equipment only during classroom hours. An argument was made that the proposed study advances IS and education research through artifact construction and evaluation by correlating Hevner et al.'s (2004) seven steps of effective design science research theory, Peffers, Tuunanen, Rothenberger, and Chatterjee's (2007) DSR Methodology (DSRM), and Gregor and Jones's (2007) IS Design Theory to the problem statement, research questions, and hypothesis in order to develop guiding principles and specifications for building and assessing a cloud-based lab environment.

In support of the primary goal, this study derived design principles and emergent knowledge processes that supported the artifact construction through procedures that will advance the knowledge base used to design, build, and implement the cloud-based lab architecture. The IS artifact was evaluated on how effectively it provides 24/7 access that

ultimately bridged the skills gap among computer and IS graduates as demonstrated through the MANOVA and Multivariate Regression analysis through SPSS outlined in Chapter 4. The overarching goal of this study was to discover more effective or efficient solutions that led to the construction and evaluation of cloud-based lab environments thereby deriving design science principles that can be used to advance the IS and education domain body of knowledge (Hevner et al., 2004). Previous research was explored by thoroughly examining design science related to these domains and correlating the research to make recommendations for principles that will improve lab environment design, construction, implementation, and deployment in high schools, technical education centers, colleges, and universities for the overall benefit of students that will eventually work in the IS industry.

To provide visibility and distribution of the VCASTLE system design, implementation, and evaluation process developed in this study, specifications and procedures are communicated in the form of a Virtual Publication (VPUB) electronic summary that is available to all academic institutions at <http://ecpi.mobi/vcastle>. See Appendix F.

Appendix A

Summary Tables of Articles Reviewed for the Literature Review by Topic

Table A1

Selected Studies About the Need for Skilled IT Workers

Author	Article title	Main point
Luftman, J., & Kempaiah, R. M. (2007)	The IS organization of the future: The IT talent challenge	Increased demand for IT workers
Abraham, S., & Chengalur-Smith, I. (2010)	An overview of social engineering malware: Trends, tactics, and implications	Time constraints on adequate IS security training
Locasto, M. E., Ghosh, A. K., Jajodia, S., & Stavrou, A. (2011)	The ephemeral legion: producing an expert cyber-security work force from thin air	Strong demand for cyber security configuration skills
Rowe, D. C., Lunt, B. M., & Ekstrom, J. J. (2011, October)	The role of cyber-security in information technology education	Shortage of cyber security specialists
Khoo, B. K. (2012)	Towards a career skills oriented undergraduate information systems curriculum	Industry employees are in serious need for IS professionals
Awad, F., Banimelhem, O., Taqieddin, E., & Bani-Hani, R. (2012)	Undergraduate program in network engineering and security—A feasibility study	Growing demand for networking and security graduates
Hawk, S., Kaiser, K. M., Goles, T., Bullen, C. V., Simon, J. C., Beath, C. M., & Frampton, K. (2012)	The information technology workforce: A comparison of critical skills of clients and service providers	Organizations emphasize technical skills for new employees
Litecky, C., Igou, A. J., & Aken, A. (2012, May)	Skills in the management oriented IS and enterprise system job markets	Businesses continue to limit their hiring to skills-based specialists

(continued)

Author	Article title	Main point
Longenecker Jr, H. E., Feinstein, D. L., & Babb, J. S. (2013)	Is there a need for a computer information systems model curriculum	Graduate preparation for the technical job market
LeClair, J., Abraham, S., & Shih, L. (2013)	An interdisciplinary approach to educating an effective cyber security workforce	Global shortage of skilled cyber security professionals
Martin, N. L., & Woodward, B. (2013)	Building a cybersecurity workforce with remote labs	Information Systems security professionals are in demand

Table A2

Selected Studies about the Lack of Skills in IS Graduates

Author	Article title	Main point
Tarafdar, M., & Gordon, S. R. (2007)	Understanding the influence of information systems competencies on process innovation: A resource-based view	Skills capable IS employees contribute to competitiveness
VanDerwerken, J., & Ubell, R. (2011)	Training on the cybersecurity frontlines	Systems compromised by non-proficient IT workers
Lowden, K., Hall, S., Elliot, D., & Lewin, J. (2011)	Employers' perceptions of the employability skills of new graduates	Universities should prepare students with practical skills
Madan, D., Pant, A., Kumar, S., & Arora, A. (2012)	E-learning based on cloud computing	Academic institutions failing to provide skills based training
LeClair, J., Abraham, S., & Shih, L. (2013)	An interdisciplinary approach to educating an effective cyber security workforce	Poorly trained cyber security workforce
Radermacher, A., & Walia, G. (2013, March)	Gaps between industry expectations and the abilities of graduates	Students do not meet necessary skills to meet employer expectations
Simon, D., & Jackson, K. (2013)	A closer look at information systems graduate preparation and job needs: Implications for higher education curriculum enhancements	New employees do not perform skills based procedures as expected
Suby, M. (2013)	The 2013 (ISC) 2 Global Information Security Workforce Study	Managers not satisfied with employee skill levels
O'Neil, H. F. (Ed.). (2014)	Workforce readiness: Competencies and assessment	Need for a more highly skilled work force

Table A3

Selected Studies about Online or Cloud Based Lab Environments

Author	Article title	Main point
Begnum, K., Koymans, K., Krap, A., & Sechrest, J. (2004)	Using virtual machines in system administration education	User-mode Linux replaces routers and switches
Vollrath, A., & Jenkins, S. (2004)	Using virtual machines for teaching system administration	Virtual machines run on single host OS
Wagner, P. J., & Wudi, J. M. (2004, March)	Designing and implementing a cyberwar laboratory exercise for a computer security course	Physical cyber security laboratory
Stockman, M., Nyland, J., & Weed, W. (2005)	Centrally-stored and delivered virtual machines in the networking/system administration lab	Copying large virtual machine images across the network
Border, C. (2007, March)	The development and deployment of a multi-user, remote access virtualization system for networking, security, and system administration classes	Remote laboratory emulation system
Gaspar, A., Langevin, S., & Armitage, W. D. (2007)	Virtualization technologies in the undergraduate IT curriculum	Linux based virtualization system
Yang, L. (2007)	Teaching system and network administration using virtual PC	Prototype NLS-Cloud system

(continued)

Author	Article title	Main point
Du, W., & Wang, R. (2008)	SEED: A suite of instructional laboratories for computer security education	Novel Laboratory environment – SEED
Duignan, S., & Hall, T. (2008)	Using Platform Virtualization to Teach System Architectures in Undergraduate Computer Science—An Evaluation of Student Learning Experiences	Virtual machines sharing host machine resources
Lunt, B. M., Ekstrom, J. J., Gorka, S., Hislop, G., Kamali, R., Lawson, E., & Reichgelt, H. (2008)	Curriculum guidelines for undergraduate degree programs in information technology	2005 IT Curriculum guidelines
Stackpole, B. (2008, October)	The evolution of a virtualized laboratory environment	Remote virtual lab environment for systems administration students
Anderson, B. R., Joines, A. K., & Daniels, T. E. (2009, July)	Xen worlds: leveraging virtualization in distance education	Remote lab environment for information assurance program
Li, P. (2009)	Exploring virtual environments in a decentralized lab	Decentralized virtual lab on students personal computers
Li, P., Toderick, L. W., & Lunsford, P. J. (2009, October)	Experiencing virtual computing lab in information technology education	Open source virtual computing lab

(continued)

Author	Article title	Main point
Stewart, K. E., Humphries, J. W., & Andel, T. R. (2009, March)	Developing a virtualization platform for courses in networking, systems administration and cyber security education	Conceptual virtualized lab environment
Wang, X., Hembroff, G., & Yedica, R. (2010)	Using VMware VCenter lab manager in undergraduate education for system administration and network security	VMWare VCenter Lab Manager
Yan, C. (2011)	Build a laboratory cloud for computer network education	Xen-based NLS-Cloud remote access laboratory
Madan, D., Pant, A., Kumar, S., & Arora, A. (2012)	E-learning based on cloud computing	Education and Learning as a Service (ELAAS)
Pena-Rios, A., Callaghan, V., Gardner, M., & Alhaddad, M. (2012)	Remote mixed reality collaborative laboratory activities: Learning activities within the inter-reality portal	Remote mixed reality collaborative laboratory
Dinita, R. I., Wilson, G., Winckles, A., Cirstea, M., & Jones, A. (2012)	A cloud-based virtual computing laboratory for teaching computer networks	Cloud-based solution for teaching computer networks

Table A4

Selected Studies About Design Science Research Theory and Principals

Author	Article title	Main point
Walls, J., Widmeyer, G., & El Sawy, O. (1992)	Building an information system design theory for vigilant EIS	Information Systems Design Theory intended to produce effective IS
March, S. T., & Smith, G. F. (1995)	Design and natural science research on information technology	Combining design and natural science activities
Markus, M. L., Majchrzak, A., & Gasser, L. (2002)	A design theory for systems that support emergent knowledge processes	Design Theory of emergent knowledge process
Hevner, A.R., March, S.T., Park, J., & Ram, S. (2004)	Design science in information systems research	Conceptual framework and guidelines for understanding, executing, and evaluating research
Gregor, S. (2006)	The nature of theory in information systems	Structural nature of theory in IS
Venable, J. (2006)	The role of theory and theorizing in design science research	Theory and theorizing play a central role in advancing design science research in IS
Gregor, S., & Jones, D. (2007)	The anatomy of a design theory	Anatomy of design theories in IS

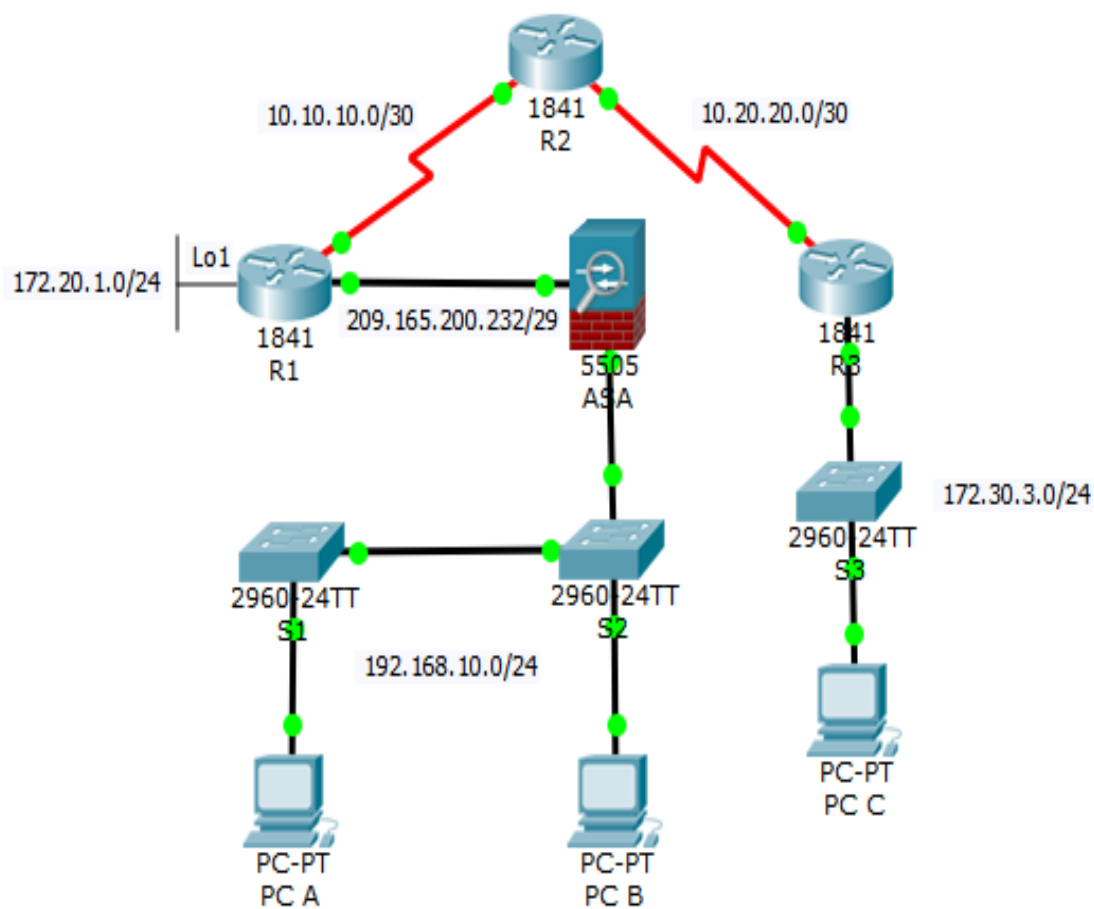
(continued)

Author	Article title	Main point
Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007)	A design science research methodology for information systems research	Design Science Research Methodology (DSRM) for production of DSR in IS
Gregor, S., & Hevner, A. R. (2013)	Positioning and presenting design science research for maximum impact	Guidance for Design Science Research positioning and publishing

Appendix B

Cisco Packet Tracer Skills Integration Pre/Post Test

Topology



Addressing Table

Device	Interface	IP Address	Subnet Mask	Default Gateway
R1	Fa0/0	209.165.200.23 3	255.255.255.24 8	N/A
	S0/0/0 (DCE)	10.10.10.1	255.255.255.25 2	N/A
	Loopback 1	172.20.1.1	255.255.255.0	N/A
R2	S0/0/0	10.10.10.2	255.255.255.25 2	N/A
	S0/0/1 (DCE)	10.20.20.2	255.255.255.25 2	N/A
R3	Fa0/1	172.30.3.1	255.255.255.0	N/A
	S0/0/1	10.20.20.1	255.255.255.25 2	N/A
S1	VLAN 1	192.168.10.11	255.255.255.0	192.168.10.1
S2	VLAN 1	192.168.10.12	255.255.255.0	192.168.10.1
S3	VLAN 1	172.30.3.11	255.255.255.0	172.30.3.1
ASA	VLAN 1 (E0/1)	192.168.10.1	255.255.255.0	N/A
	VLAN 2 (E0/0)	209.165.200.23 4	255.255.255.24 8	N/A
PC-A	NIC	192.168.10.2	255.255.255.0	192.168.10.1
PC-B	NIC	192.168.10.3	255.255.255.0	192.168.10.1
PC-C	NIC	172.16.3.3	255.255.255.0	172.16.3.1

Objectives

- Configure Basic Router Security
- Configure Basic Switch Security
- Configure AAA Local Authentication
- Configure SSH
- Secure Against Login Attacks
- Configure Site-to-Site IPsec VPNs
- Configure Firewall and IPS Settings

Configure ASA Basic Security and Firewall Settings

Scenario

This culminating activity includes many of the skills that you have acquired during this course. The routers and switches are preconfigured with the basic device settings, such as IP addressing and routing. You will secure routers using the CLI to configure various IOS features, including AAA, SSH, and Zone-Based Policy Firewall (ZPF). You will also configure a site-to-site VPN between R1 and R3. You will also secure the switches on the network. In addition, you will also configure firewall functionality on the ASA.

Requirements

Note: Not all security features will be configured on all devices, although they normally would be in a production network.

Configure Basic Router Security

Configure the following on **R1**:

- Minimum password length is 10 characters.

- Encrypt plaintext passwords.

- Privileged EXEC mode secret password is **ciscoenapa55**.

- Console line password is **ciscoconpa55**, timeout is **15** minutes, and console messages should not interrupt command entry.

- A message-of-the-day (MOTD) banner should include the word **unauthorized**.

Configure the following on **R2**:

- Privileged EXEC mode secret password is **ciscoenapa55**.

- Password for the vty lines is **ciscovtypa55**, timeout is **15** minutes, and login is required.

Configure Basic Switch Security

Configure the following on **S1**:

- Encrypt plaintext passwords.

- Privileged EXEC mode secret password is **ciscoenapa55**.

- Console line password is **ciscoconpa55**, timeout is **5** minutes, and console messages should not interrupt command entry.

- Password for the vty lines is **ciscovtypa55**, timeout is **5** minutes, and login is required.

- A MOTD banner should include the word **unauthorized**.

Configure trunking between S1 and S2 with the following settings:

- Set the mode to **trunk** and assign VLAN **99** as the native VLAN.

Disable the generation of DTP frames.

Enable storm control for broadcasts to a **50** percent suppression level.

Configure the S1 with the following port settings:

Fa0/6 should only allow access mode, set to **PortFast**, and enable BPDU guard.

Fa0/6 uses basic default port security with dynamically learned MAC addresses added to the running configuration.

All other ports should be disabled.

Note: Although not all ports are checked, your instructor may want to verify that all unused ports are disabled.

Configure AAA Local Authentication

Configure the following on **R1**:

Create a local user account of **Admin01**, a secret password of **Admin01pa55**, and a privilege level of **15**.

Enable AAA services.

Implement AAA services using the local database as the first option and then the **enable** password as the backup option.

Configure SSH

Configure the following on **R1**:

Note: The RSA key is already generated.

The domain name is **ccnasecurity.com**

The RSA key should be generated with a **1024** modulus bits.

Only SSH version 2 is allowed.

Only SSH is allowed on vty lines.

Verify that **PC-C** can remotely access **R1** (209.165.200.233) using SSH.

Secure Against Login Attacks

Configure the following on **R1**:

If a user fails to log in twice within a 30-second time span, then disable logins for one minute.

Log all failed login attempts.

Configure Site-to-Site IPsec VPNs

Note: Some VPN configurations are not scored. However, you should be able to verify connectivity across the IPsec VPN tunnel.

Configure the following on **R1**:

Create an access-list to identify interesting traffic on **R1**.

Configure ACL **101** to allow traffic from the **R1** Lo1 network to the R3 Fa0/1 LAN.

Explicitly deny all other traffic.

Configure the **crypto isakmp policy10** Phase 1 properties on **R1** along with the shared crypto key **ciscovnpa55**. Use the following parameters:

Key distribution method: **ISAKMP**

Encryption: **aes 256**

Hash: **sha-1**

Authentication method: **pre-shared**

Key exchange: **DH Group 5**

IKE SA lifetime: **3600**

ISAKMP key: **ciscovnpa55**

Create the transform set **VPN-SET** to use **esp-aes 256** and **esp-sha-hmac**. Then create the crypto map **CMAP** that binds all of the Phase 2 parameters together. Use sequence number **10** and identify it as an **ipsec-isakmp** map.

Use the following parameters:

Transform Set: **VPN-SET**

Transform Encryption: **esp-aes 256**

Transform Authentication: **esp-sha-hmac**

Perfect Forward Secrecy (PFS): **group5**

Crypto Map name: **CMAP**

SA Establishment: **ipsec-isakmp**

Bind the crypto map **CMAP** to the outgoing interface.

Repeat the site-to-site VPN configurations on **R3** so that they mirror all configurations from **R1**.

Ping the Lo1 interface (172.20.1.1) on **R1** from **PC-C**. Then on **R3**, use the **show crypto ipseca** command to verify the number of packets is more than 0, indicating that the IPsec VPN tunnel is working.

Configure Firewall and IPS Settings

Configure a ZPF on **R3** using the following requirements:

Create zones named **IN-ZONE** and **OUT-ZONE**.

Create an ACL number **110** that defines internal traffic, permitting all IP protocols from the **172.30.3.0/24** source network to any destination. Explicitly deny all other traffic.

Create a class map named **INTERNAL-CLASS-MAP** that uses the **match-all** option and ACL **110**.

Create a policy map named **IN-2-OUT-PMAP** that uses the class map **INTERNAL-CLASS-MAP** to **inspect** all matched traffic.

Create a zone pair named **IN-2-OUT-ZPAIR** that identifies **IN-ZONE** as the source zone and **OUT-ZONE** as the destination zone.

Specify that the **IN-2-OUT-PMAP** policy map is to be used to **inspect** traffic between the two zones.

Assign Fa0/1 as an **IN-ZONE** member and S0/0/1 as an **OUT-ZONE** member.

Configure an IPS on **R3** using the following requirements:

Note: Within Packet Tracer, the routers already have the signature files imported and in place. They are the default XML files in flash. For this reason, it is not necessary to configure the public crypto key and complete a manual import of the signature files.

Create a directory in flash named **ipsdir** and set it as the location for IPS signature storage.

Create an IPS rule named **IPS-RULE**.

Retire the **all** signature category with the **retired true** command (all signatures within the signature release).

Un-retire the **IOS_IPS Basic** category with the **retired false** command.

Apply the rule inbound on the S0/0/1 interface.

Configure ASA Basic Security and Firewall Settings

Configure VLAN interfaces with the following settings:

For the VLAN 1 interface, configure the addressing to use **192.168.10.1/24**.

For the VLAN 2 interface, remove the default DHCP setting and configure the addressing to use **209.165.200.234/29**.

Configure hostname, domain name, enable password, and Telnet console password using the following settings:

The ASA hostname is **CCNAS-ASA**.

The domain name is **ccnasecurity.com**.

The enable mode password is **ciscoenapa55**.

Create a user and configure AAA to use the local database for remote authentication.

Create a local user account of **Admin01** with a secret password of **Admin01pa55** and a privilege level of **15**.

Configure a local user account named **admin** with the password **adminpa55**. Do not use the **encrypted** attribute.

Configure AAA to use the local ASA database for Telnet and SSH user authentication.

Configure Telnet for local ASA console access and SSH for remote ASA console access.

Allow Telnet access from the inside **192.168.10.0/24** network with a timeout of **10** minutes.

Allow SSH access from the outside host **172.30.3.3** with a timeout of **10** minutes.

Configure the ASA as a DHCP server using the following settings:

Assign IP addresses to inside DHCP clients from 192.168.10.5 to 192.168.10.30.

Enable DHCP to listen for DHCP client requests.

Configure static routing and NAT.

Create a static default route to the next hop router (**R1**) IP address.

Create a network object named **inside-net** and assign attributes to it using the **subnet** and **nat** commands.

Create a dynamic NAT translation to the outside interface.

Modify the Cisco Modular Policy Framework (MPF) on the ASA using the following settings:

Configure **class-map inspection default** to **match default-inspection-traffic**, and then exit to global configuration mode.

Configure the **policy-map** list, **global policy**. Enter the **class inspection default** and enter the command to **inspect icmp**. Then exit to global config mode.

Configure the MPF **service-policy** to make the **global_policy** apply globally.

Appendix C

CIS425 - Network Defense and Countermeasures Course Labs

Table C1

Control and Experimental Groups Skills-Based Labs

Classroom and Cloud Based Labs	Description
1. Configuring Devices using the Cisco Configuration Professional (CCP)	The objective of this lab is to verify the routers and personal computers in the topology are configured properly for use with CCP.
2. Securing the Router Administrative Interfaces	In this lab, students will build a multi-router network and configure the routers and hosts. They will use various CLI tools to secure local and remote access to the routers through SSH, analyze potential vulnerabilities, and take steps to mitigate them including management reporting to monitor router configuration changes.
3. Configuring a Site to Site Virtual Private Network	In this lab, students will build and configure a multi-router network, and then use Cisco IOS and CCP to configure a site-to-site IPsec VPN.
4. Configure a Remote Access VPN Server and Client	In this lab, students will build a multi-router network and configure the routers and hosts. Students will then configure a remote access VPN between a client computer and a simulated corporate network.
5. Configure Clientless and AnyConnect Remote Access SSL VPNs Using ASDM	In part 1, students will configure the topology and non-ASA devices. In part 2, students will prepare the ASA for ASDM access. In part 3, students will use the ASDM VPN wizard to configure a clientless SSL remote access VPN and verify access using a remote PC with a browser. In part 4, students will configure an AnyConnect client-based SSL remote access VPN and verify connectivity.
6. Securing Administrative Access with AAA and Radius	In this lab, students will build a multi-router network and configure the routers and hosts. They will then use CLI commands and CCP tools to configure routers with basic local authentication by means of

AAA. The students will also install RADIUS software on an external computer and use AAA to authenticate users with the RADIUS server.

7. Configuring CBAC and Zone Based Firewalls
In this lab, students will build a multi-router network and configure the routers and hosts. They will also use AutoSecure to configure a CBAC firewall and CCP to configure a zone-based policy firewall.
 8. Configuring the ASA Firewall Command Line Interface
In part 1 of the lab, students will configure the topology and non-ASA devices. In Parts 2 through 4, students will configure basic ASA settings and the firewall between the inside and outside networks. In part 5, students will configure the ASA for additional services such as DHCP, AAA, and SSH. In Part 6, students will configure a DMZ on the ASA and provide access to a server in the DMZ.
 9. Configuring an Intrusion Prevention System from Command Line Interface
In part 1 of this lab, students will configure the Cisco IOS Intrusion Prevention System (IPS), which is part of the Cisco IOS Firewall feature set. IPS examines certain attack patterns and alerts or mitigates when those patterns occur. In part 2, students will configure IPS using the Cisco IOS CLI on one router and CCP on another router, and then test IPS functionality on both routers. In part 3, students will load the IPS Signature package from a TFTP server and configure the public crypto key using the Cisco IOS CLI and CCP.
 10. Configure ASA Basic Settings and Firewall Using ADSM
The focus of this lab is on the configuration of the ASA as a basic firewall. In part 1, students will configure the topology and non-ASA devices. In part 2, students will prepare the ASA for ADSM access. In part 3, students will use the ADSM start-up wizard to configure the ASA settings as a firewall between the inside and outside networks. In part 4, students will configure additional ASA settings through the ASA. In part 5, students will configure a DMZ on the ASA and provide access to a server in the DMZ.
-

Appendix D

Student Consent Form for Participation in Research Study



Consent Form for Participation in the Research Study Entitled:

Building Cloud-Based Information Systems Lab Architecture: Deriving Design Principles that Facilitate the Effective Construction and Evaluation of a Cloud-Based Lab Environment

Funding Source: None

IRB Protocol #: 11151401

Principal Investigator:

Thomas Trevethan

5555 Greenwich Road

Virginia Beach, Va. 23462

Co-Investigator:

James Parrish, Ph.D.

3301 College Ave.

Ft. Lauderdale, Fl. 33314

For questions/concerns about your research rights, contact:

Human Research Oversight Board (Institutional Review Board or IRB)

Nova Southeastern University

(954) 262-5369/Toll Free: 866-499-0790

IRB@nsu.nova.edu

Initials: _____ Date: _____ Page 1 of 4

Site Information:

ECPI University

5555 Greenwich Road

Virginia Beach, Va. 23462

<http://vcastle6.ecpi.edu/>

<http://vcastle7.ecpi.edu>

<http://vb.ecpi.net/>

<http://rale.ecpi.net>

<http://nn.ecpi.net>

What is the study about?

You are invited to participate in a research study. The goal of this study is to derive design principles and emergent knowledge processes that support artifact construction through procedures that will advance the knowledge base used to design, build, implement, and assess a cloud-based hands-on lab architecture.

Why are you asking me?

We are inviting you to participate because you are currently enrolled in the CIS Network Security program at ECPI University. There will be between 30 and 60 participants in this research study.

What will I be doing if I agree to be in the study?

You will complete a non-graded skills-based pretest at the beginning of the study and non-graded skills-based posttest at the completion of the study. You will also be interviewed by the researcher who will ask questions about your satisfaction with the cloud-based lab environment. The pretest and posttest will each take one hour and the interview will last no more than 10 minutes.

Is there any audio or video recording?

No

What are the dangers to me?

Risks to you are minimal, meaning they are not thought to be greater than other risks you experience on any given day.

Initials: _____ **Date:** _____ **Page 2 of 4**

Are there any benefits to me for taking part in this research study?

There are no benefits to you for participating.

Will I get paid for being in the study? Will it cost me anything?

There are no costs to you or payments made for participating in this study.

How will you keep my information private?

The pretest or posttest will not ask you for any information that could be linked to you. All information obtained in this study is strictly confidential unless disclosure is required by law. The IRB, regulatory agencies, or the principle investigator may review research records.

What if I do not want to participate or I want to leave the study?

You have the right to leave this study at any time or refuse to participate. If you do decide to leave or you decide not to participate, you will not experience any penalty or loss of services you have a right to receive. If you choose to withdraw, any information collected about you **before** the date you leave the study will be kept in the research records for 36 months from the conclusion of the study and may be used as a part of the research.

Other Considerations:

If the researchers learn anything which might change your mind about being involved, you will be told of this information.

Voluntary Consent by Participant:

By signing below, you indicate that:

- a. this study has been explained to you
- b. you have read this document or it has been read to you
- c. your questions about this research study have been answered
- d. you have been told that you may ask the researchers any study related questions in the future or contact them in the event of a research-related injury
- e. you have been told that you may ask Institutional Review Board (IRB) personnel questions about your study rights
- f. you are entitled to a copy of this form after you have read and signed it
- g. you voluntarily agree to participate in the study entitled:

Initials: _____ **Date:** _____ **Page 3 of 4**

Building Cloud-Based Information Systems Lab Architecture: Deriving Design Principles that Facilitate the Effective Construction and Evaluation of a Cloud-Based Lab Environment

Participant's Signature: _____

Date: _____

Participant's Name: _____

Date: _____

Signature of Person Obtaining Consent: _____

Date: _____

Appendix E

Campus and Treatment Based Descriptive Statistics

Table E1

Control Group Descriptive Statistics Campus-Based

Variable	Campus	Mean	Standard Deviation
Pretest	VA Beach	4.38	3.93
	Raleigh	3.83	3.30
	Newport News	6.50	5.01
Number of Labs	VA Beach	7.75	1.39
	Raleigh	8.58	1.56
	Newport News	7.75	1.58
Lab Hours	VA Beach	37.00	4.14
	Raleigh	35.67	4.66
	Newport News	39.00	2.83
Posttest	VA Beach	10.50	3.82
	Raleigh	10.83	4.73
	Newport News	14.25	3.77
Gain	VA Beach	0.06	0.03
	Raleigh	0.07	0.03
	Newport News	0.08	0.03

Table E2

Experimental Group Descriptive Statistics Campus-Based

Variable	Campus	Mean	Standard Deviation
Pretest	VA Beach	9.60	9.42
	Raleigh	4.00	5.08
	Newport News	6.50	7.48
Number of Labs	VA Beach	9.80	0.63
	Raleigh	9.58	0.67
	Newport News	9.58	0.67
Lab Hours	VA Beach	59.60	15.01
	Raleigh	59.08	9.86

	Newport News	51.83	11.13
Posttest	VA Beach	46.60	16.55
	Raleigh	44.17	12.19
	Newport News	45.83	14.42
Gain	VA Beach	0.37	0.09
	Raleigh	0.40	0.09
	Newport News	0.39	0.09

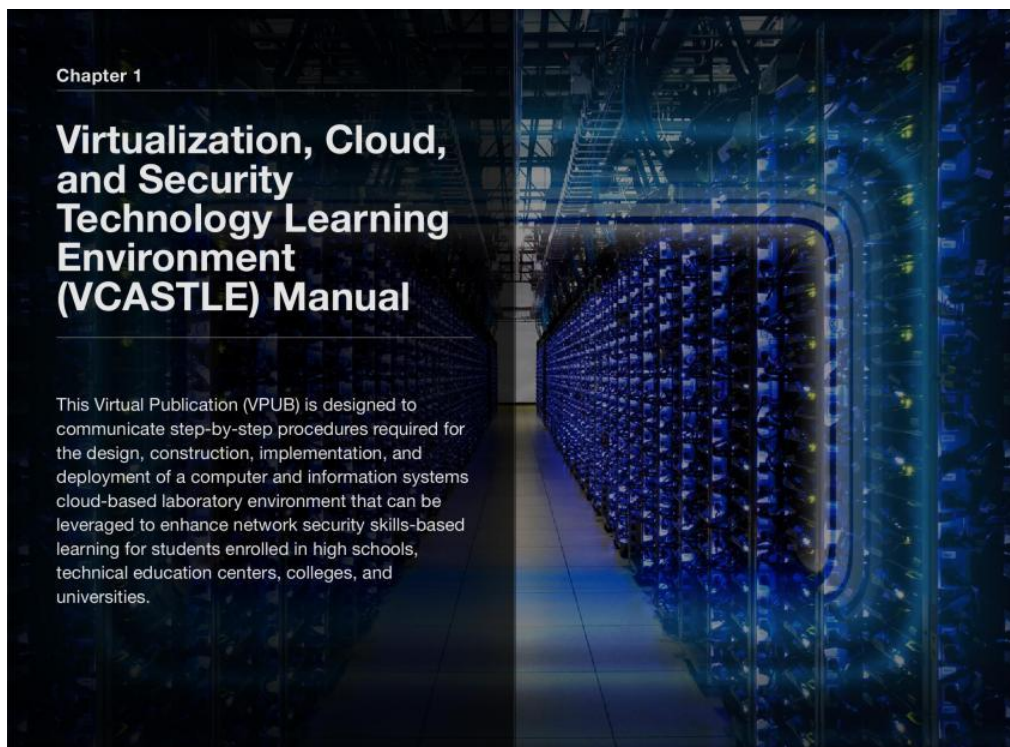
Table E3

Descriptive Statistics Treatment-Based

Variable	Campus	Mean	Standard Deviation
Gain	Control	0.07	0.03
	Experimental	0.39	0.09
Number of Labs	Control	8.11	1.52
	Experimental	9.65	0.65
Lab Hours	Control	37.00	4.16
	Experimental	56.68	12.18

Appendix F

VCASTLE Design Procedures and Specifications



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Section 1

Physical Network Connectivity Design

The VCASTLE system design and implementation process based on design science research including specifications and procedures for construction is communicated in this publication and is available to all academic institutions at

<http://ecpi.mobi/vcastle>



The Virtualization, Cloud, and Security Technology Learning Environment (VCASTLE) system was customized based on the Network Development Group (NDG) foundation platform. The minimum NDG design recommendations and certified hardware were modified for the VCASTLE system and upgraded to include high performance equipment in order to meet future scalability requirements and high demand expectations. The following list of replacement hardware and software included in the design of the VCASTLE system that is central to this publication and are currently not supported by NDG:

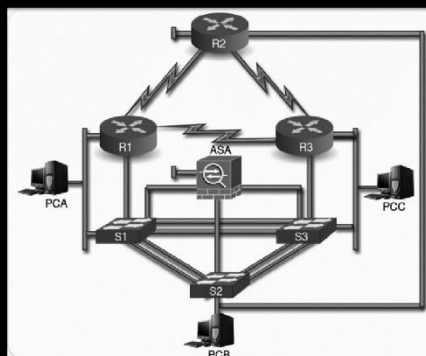
1. The NDG recommended Dell R720 rack mount server with Intel processor, Serial Attached SCSI (SAS) internal storage, and 72 GB of Ram was replaced with Cisco UCS blade servers with 192 GB of Ram and external SAN connection capability.
2. The NDG recommended Dell R720 rack mounted server internal SAS storage was replaced with an EMC VNX 5100 storage array.
3. The NDG recommended VMware ESXi Version 5.1 was replaced with VMware ESXi Version 5.5.
4. The NDG recommended VMware vCenter Version 5.1 was replaced with VMware vCenter 5.5.

Section 2

Logical Prototype Topology Design Diagram

The VCASTLE system design and implementation process based on design science research including specifications and procedures for construction is communicated in this publication and is available to all academic institutions at

<http://ecpi.mobi/vcastle>



http://vcastle7.ecpi.edu/local/ev/AECCNAS11_0011_25AA_ED80_4F44_E6AC/doc/CCNASv11_CH10_LabA.pdf - Windows Internet Explorer
 http://vcastle7.ecpi.edu/local/ev/AECCNAS11_0011_25AA_ED80_4F44_E6AC/doc/CCNASv11_CH10_LabA.pdf

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CCNA Security

IP Addressing Table

Device	Interface	IP Address	Subnet Mask	Default Gateway	Switch Port
R1	FA0/0	209.165.200.225	255.255.255.248	N/A	ASA E0/0
	S0/0/0 (DCE)	10.1.1.1	255.255.255.252	N/A	N/A
R2	S0/0/0	10.1.1.2	255.255.255.252	N/A	N/A
	S0/0/1 (DCE)	10.2.2.2	255.255.255.252	N/A	N/A
R3	FA0/1	172.16.3.1	255.255.255.0	N/A	S3 FA0/5
	S0/0/1	10.2.2.1	255.255.255.252	N/A	N/A
ASA	VLAN 1 (E0/1)	192.168.1.1	255.255.255.0	NA	S2 FA0/24
ASA	VLAN 2 (E0/0)	209.165.200.226	255.255.255.248	NA	R1 FA0/0
ASA	VLAN 3 (E0/2)	192.168.2.1	255.255.255.0	NA	S1 FA0/24
PC-A	NIC	192.168.2.3	255.255.255.0	192.168.2.1	S1 FA0/6
PC-B	NIC	192.168.1.3	255.255.255.0	192.168.1.1	S2 FA0/18
PC-C	NIC	172.16.3.3	255.255.255.0	172.16.3.1	S3 FA0/18

8.50 x 11.00 in



1. The base VCASTLE system construction specifications are documented in accordance with NDG's installation guide (Network Development Group, 2011) that can be retrieved from http://www.netdevgroup.com/support/documentation/NETLAB_Installation_Guide.pdf.
2. The ESXi 5.5 and vCenter Server 5.5 specifications including new features documented in a technical white paper (VMWare, 2014) and designed for inclusion into the VCASTLE system can be retrieved from <http://www.vmware.com/files/pdf/vsphere/VMware-vSphere-Platform-Whats-New.pdf>
3. The UCS B440 M2 server specifications designed for inclusion into the VCASTLE system and documented in a spec sheet (Cisco Systems, 2011) can be retrieved from <http://www.karma->

group.ru/Sites/karma/Uploads/UCS_B440_M2.813913e4e7c079cb67f9cee696f46449b.pdf.

4. The EMC VNX 5100 series appliance specifications documented in an EMC white paper (EMC, 2104) and designed for inclusion into the VCASTLE system can be retrieved from <http://www.emc.com/collateral/hardware/white-papers/h8217-introduction-vnx-wp.pdf>.



The minimum certified hardware/software requirements partially used to build the base VCASTLE system in accordance with NDG's Netlab+ system requirements (n.d.) can be retrieved from <http://www.netdevgroup.com/products/requirements/>.

The upgraded hardware/software required including cost to build the VCASTLE system as outlined in this DP are listed in table 10.

Table 12. Cloud-Based Lab Environment Components

Hardware	Quantity	Estimated Cost
Cisco UCS B440 M2 High Performance Blade Server, Intel Processor, 192 GB Memory (Upgrade)	2	\$22,000.00
EMC VNX 5100 (Upgrade)	1	\$8846.00
NDG Netlab+ PE Server	1	\$39,000.00
Cisco 1941 with Security Technology Package License w/2 GE, 2 EHWIC slots, 256MB CF, 512MB DRAM, IP Base	6	\$7,668.00
ASA 5505 Appliance with SW, 10 Users, 8 ports, 3DES/AES	2	\$1,158.00
Cisco 2901 IOS 15.1.4M4(MD)	2	\$1750.00
Catalyst 2960 24 10/100	6	\$5,394.00
4 Post Enclosed Rack - 24U 19"	1	\$750.00
10-32 Rack Screws and Cage Nuts	200	\$30.00
Cat5e Straight Ethernet 10' Cables	24	\$97.25
Cat5e Crossover Ethernet 10' Cables	24	\$97.25
Cisco HWIC-16A Asynchronous Serial Card	2	\$475.00
CAB-HD8-ASYNC Octal Serial Cable	2	\$175.00
APC 7900 120v Switched Rack PDU	2	\$450.00
CAB-SS-V35MT V.35 Cable DTE/DCE 20'	4	\$280.00
2-Port Serial WAN Interface Card	6	\$35.00
Software	Quantity	Cost
2901 IOS Version 15.1.4M4(MD)	1	Included
2960 IOS Version 12.2.25	6	Included
Windows 7 Professional (Upgrade)	6	Academic License
VMWare VSphere 5.5 (Upgrade)	1	Academic License
VMWare ESXi 5.5 (Upgrade)	1	Academic License
Hardware/Software	Total	
	\$88,205.50	

Section 5

Step-By-Step VCASTLE Construction Procedures

The VCASTLE system was assembled primarily based on Hevner's principles 1 and 5 through the production of a viable artifact that rely on the application of rigorous construction methods. The VCASTLE is an expensive rack mounted networking and storage system, therefore, rigorous construction and maintenance requirements were followed in accordance with industry standard best practices and guidance (Cisco, 2014) retrieved from <http://axeapps.com/guidelines/Guidelines-and-Best-Practices.pdf>.

1. The first step in the construction process included unpacking and assembling the equipment racks that will be used to house and secure the lab devices. Afterwards, the Cisco UCS B200 M3 blade servers were mounted in the racks and installed in accordance with the installation and service notes (Cisco Systems, 2010) that can be retrieved from

http://www.cisco.com/c/en/us/td/docs/unified_computing/ucs/hw/blade-servers/install/B440.html.

2. Since storage is a primary concern and needs to be connected to the blade servers, the VNX 5100 was installed in the rack and configured in accordance with the system installation guide (EMC, 2011) that can be retrieved from <http://muegge.com/dmfiles/EMC/Documentation/VNX/VNX5100.pdf>.
3. Next, the Cisco routers and switches were installed in the rack and configured in accordance with the installation guide (Network Development Group, 2011) retrieved from http://www.netdevgroup.com/support/documentation/NETLAB_Installation_Guide.pdf.

Section 6

Step-By-Step VCASTLE Testing Procedures

The screenshot displays a network topology diagram within a web browser window. The diagram shows a central ASA (Cisco Adaptive Security Appliance) connected to various network devices. Key components include:

- Routers:** R1 (192.168.1.1), R2 (192.168.2.1), and R3 (192.168.3.1).
- Switches:** S1 (192.168.4.1), S2 (192.168.5.1), and S3 (192.168.6.1).
- Servers/PCs:** PC A (192.168.7.1), PC B (192.168.8.1), and PC C (192.168.9.1).
- Storage:** EMC VNX 5100 storage system.
- External Network:** Represented by a cloud icon.

Below the diagram, the interface provides instructions for a lab exercise:

Click on the content factor below to view the lab instructions.

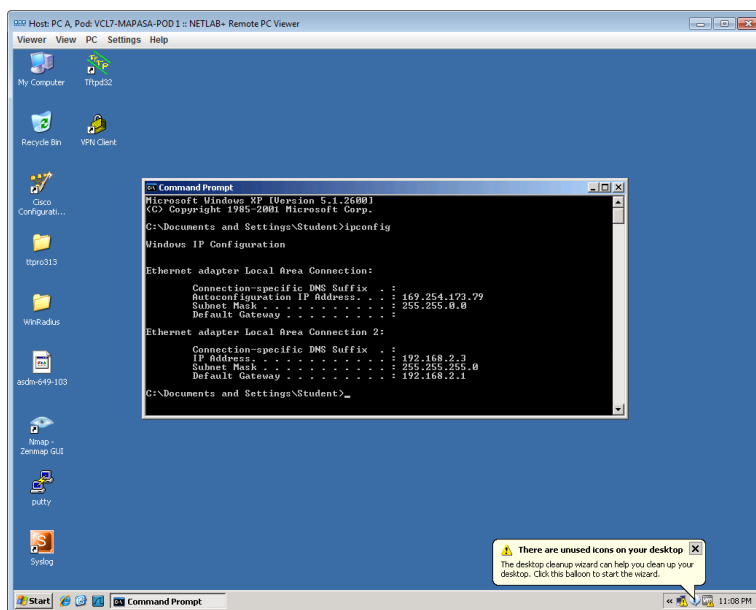
You are using a NETLAB Multi-purpose Academy Prod (MAP) with ASA for this exercise.

You will access the equipment console remotely using NETLAB CLI on a device in the picture to open a console connection. If the CLI are implemented, you get a job on them to verify access the hardware of vlab and vncase.

NETLAB should have automatically configured the devices for Step 1, Step 2 through 9. You may check the lab exercise by reviewing the basic IP configuration on Part 1, Step 4.

10A Configuring ASA Basic Settings and Firewall Using CLI [Show Lab Content]

The VCASTLE system was rigorously tested based on Hevner's DSR principle 5 in order to prove the architecture equipment was working and performing effectively based on the design. After the devices in the topology were connected and configured in the construction phase, the TCP/IP utility "ipconfig" was used to verify the correct address configuration of the Windows virtual machines. The "ipconfig" utility was also be used to troubleshoot connectivity problems.



```
Host: PC A, Pod: VCL7-MAPASA-POD 1 :: NETLAB- Remote PC Viewer
Viewer View PC Settings Help

My Computer  Tftp32
Recycle Bin  VPN Client
Cisco Configurat...
tftp313
WinRadus
ashm-649-103
Nmap - Zennap GUI
putty
Syslog

C:\Documents and Settings\Student>ipconfig

Windows IP Configuration

Ethernet adapter Local Area Connection:

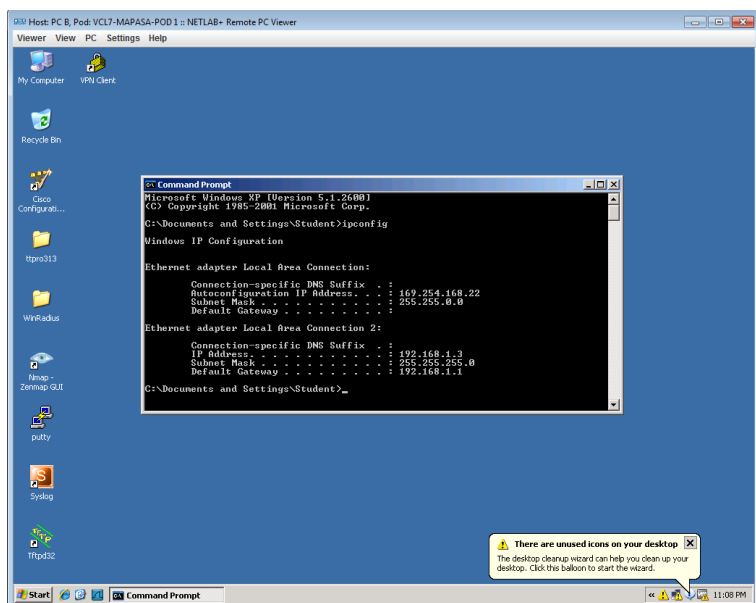
    Connection-specific DNS Suffix  . : 
    Autoconfiguration IP Address. . . : 169.254.173.79
    Subnet Mask . . . . . : 255.255.0.0
    Default Gateway . . . . . : 

Ethernet adapter Local Area Connection 2:

    Connection-specific DNS Suffix  . : 
    IP Address. . . . . : 192.168.2.3
    Subnet Mask . . . . . : 255.255.255.0
    Default Gateway . . . . . : 192.168.2.1

C:\Documents and Settings\Student>_

There are unused icons on your desktop
The desktop cleanup wizard can help you clean up your
desktop. Click this balloon to start the wizard.
```



```
Host: PC B, Pod: VCL7-MAPASA-POD 1 :: NETLAB- Remote PC Viewer
Viewer View PC Settings Help

My Computer  VPN Client
Recycle Bin
Cisco Configurat...
tftp313
WinRadus
Nmap - Zennap GUI
putty
Syslog
Tftp32

C:\Documents and Settings\Student>ipconfig

Windows IP Configuration

Ethernet adapter Local Area Connection:

    Connection-specific DNS Suffix  . : 
    Autoconfiguration IP Address. . . : 169.254.168.22
    Subnet Mask . . . . . : 255.255.0.0
    Default Gateway . . . . . : 

Ethernet adapter Local Area Connection 2:

    Connection-specific DNS Suffix  . : 
    IP Address. . . . . : 192.168.1.3
    Subnet Mask . . . . . : 255.255.255.0
    Default Gateway . . . . . : 192.168.1.1

C:\Documents and Settings\Student>_

There are unused icons on your desktop
The desktop cleanup wizard can help you clean up your
desktop. Click this balloon to start the wizard.
```



```

Host: PC C, Pod: VCL7-MAPASA-POD1 :: NETLAB - Remote PC Viewer
Viewer View PC Settings Help

Command Prompt
C:\Documents and Settings\Student>ping 209.165.200.225

Pinging 209.165.200.225 with 32 bytes of data:

Reply from 209.165.200.225: bytes=32 time=35ms TTL=253
Reply from 209.165.200.225: bytes=32 time=18ms TTL=253
Reply from 209.165.200.225: bytes=32 time=18ms TTL=253
Reply from 209.165.200.225: bytes=32 time=18ms TTL=253

Ping statistics for 209.165.200.225:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
    Approximate round trip times in milliseconds:
        Minimum = 18ms, Maximum = 35ms, Average = 22ms

C:\Documents and Settings\Student>tracert 209.165.200.225

Tracing route to 209.165.200.225 over a maximum of 30 hops:
  0  1 ms  <1 ms  <1 ms  172.16.3.1
  1  21 ms  21 ms  21 ms  192.2.2.2
  2  27 ms  26 ms  26 ms  209.165.200.225

Trace complete.

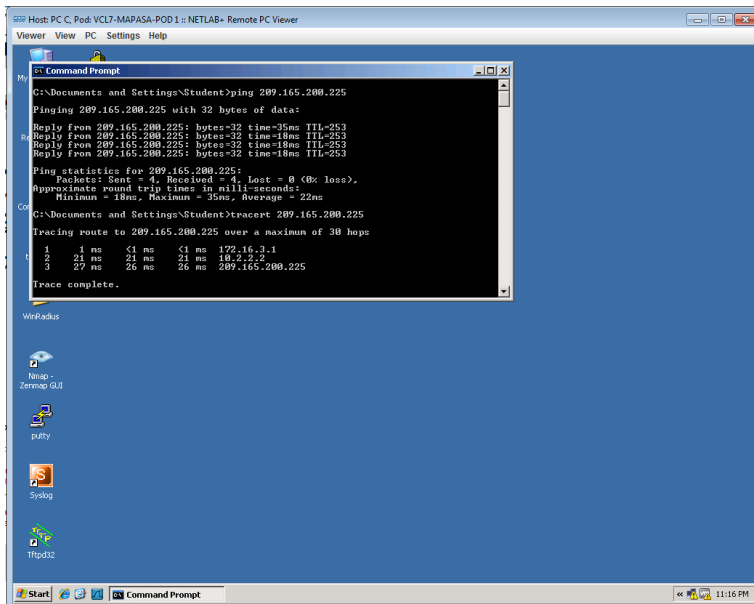
```

Section 7

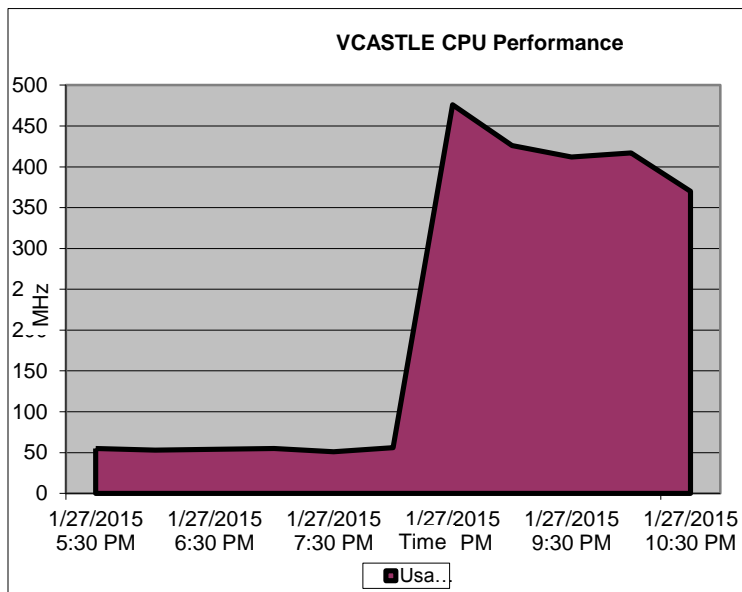
Step-By-step VCASTLE Testing Procedures - Continued

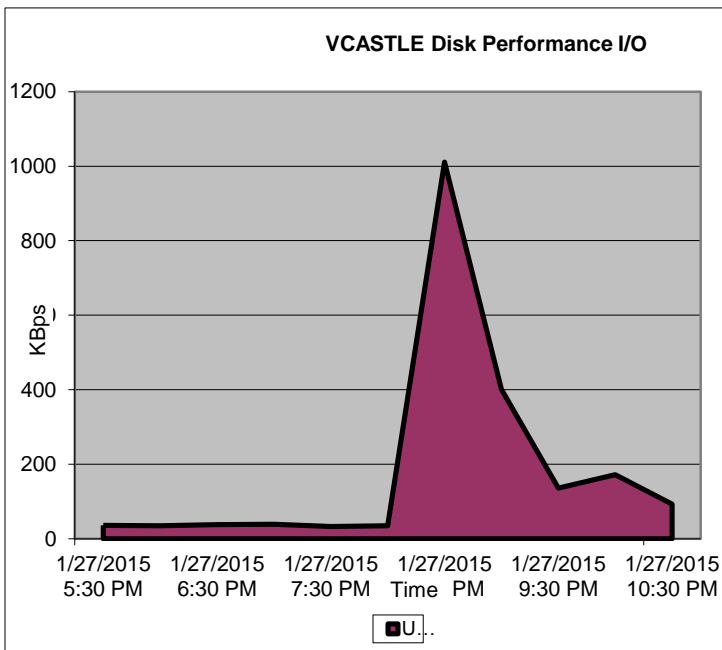
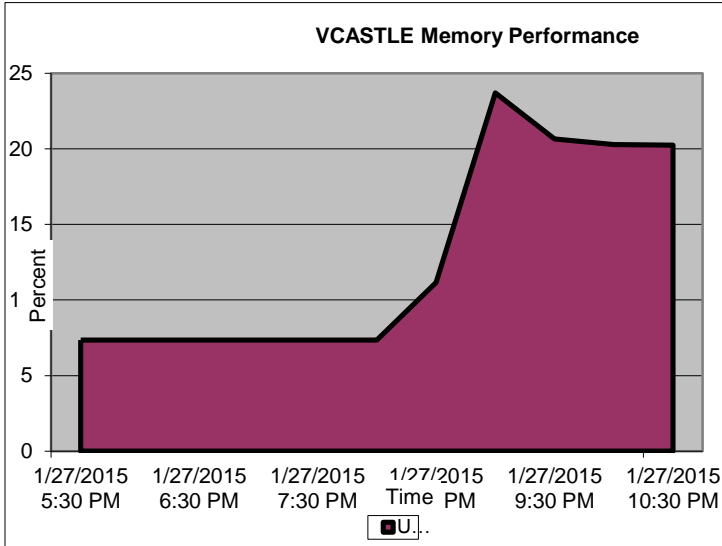
The screenshot displays the VCASTLE web interface for CCPI University. The main content area shows a network topology diagram with nodes labeled R1, R2, S1, S2, PC A, PC B, and various interfaces. Below the diagram, there are instructions for the lab exercise, including a link to '15A Configuring ASA Basic Settings and Firewall Using CLI'.

The TCP/IP utility “tracert” was used to determine path between the routers across the topology.

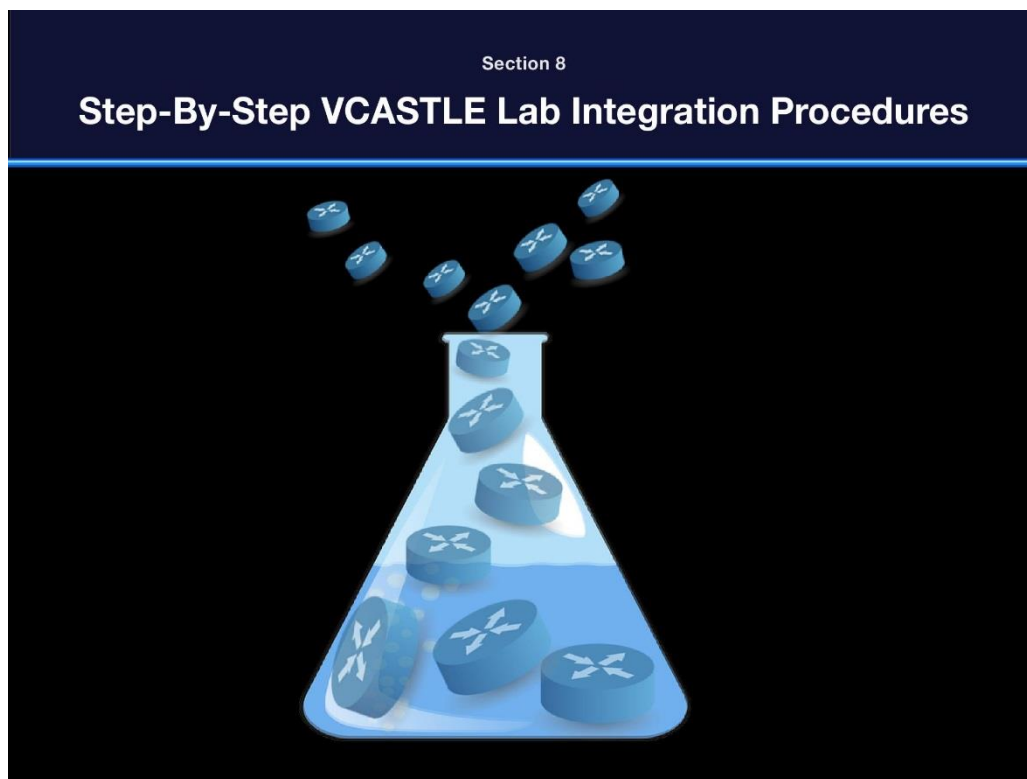
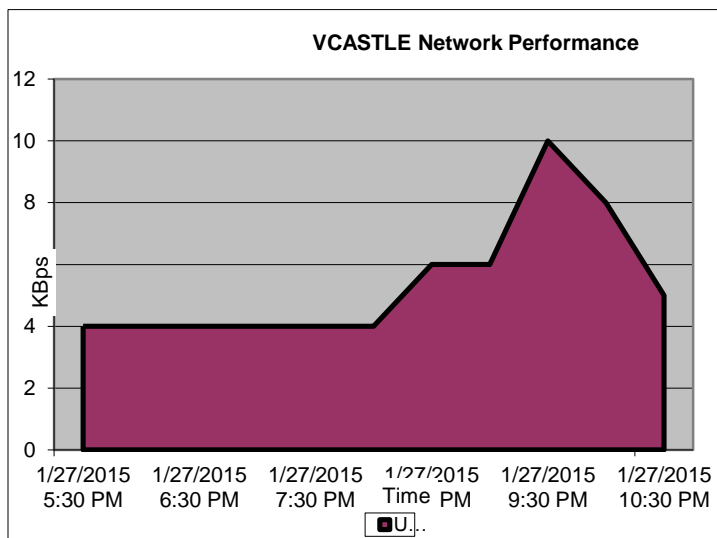


Performance monitor was used to measure, **CPU**, **Memory**, and **drive** utilization throughout the testing and experiment phases.





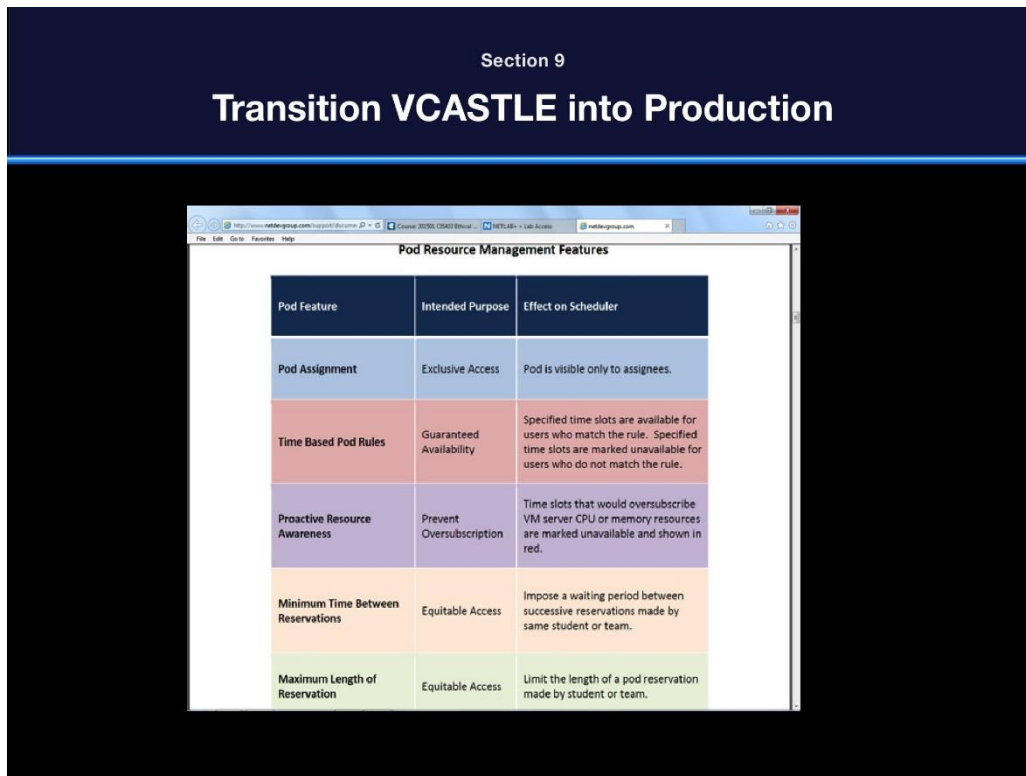
The open source “CACTI” utility was used to measure the effectiveness of throughput between the devices in the topology and overall bandwidth consumption.



The NDG labs that were integrated into the VCASTLE system are in synchronization with the Cisco Packet Tracer pre/post tests used to evaluate student skill level and were utilized in guiding students to effectively configure the topology as indicated in figure 3. The labs were integrated into the VCASTLE system based on NDG's Lab Design Guide

(Network Development Group, 2006) that can be retrieved from

http://www.netdevgroup.com/support/documentation/NETLAB_Lab_Designer.pdf



The cloud-based lab environment was placed into production mode after construction and the cloud-based lab equipment were deployed in accordance with NDG's Point of Delivery (POD) assignment guide (Network Development Group, 2011) that can be retrieved from

http://www.netdevgroup.com/support/documentation/NETLAB_Pod_Assignment.pdf.

Section 10

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