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Investigating the Impact of Student Participation in a Decentralised Virtual Laboratory on the Practical Learning of Open-Source Operating System at Politeknik Mukah

Full Paper

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Abstract

The decentralised virtual laboratory approaches are advantageous from an economic and administrative standpoint, and they have also been demonstrated to be a viable alternative for delivering practical learning, enhancing student achievement, and improving learning outcomes. Using the decentralised virtual laboratory approach, students can perform laboratory tasks on their own laptops or workstations at any time, location, and pace. Type-2 or hosted hypervisors are important virtualization technologies for the strategy because they allow several virtual machines to run concurrently on the host computer. Students participating in this study deploy Oracle VM VirtualBox, which is mostly hosted on Windows machines, to perform Linux administrative tasks or activities. A descriptive study of the students' post-responses leads to an investigation of their perspectives and acceptance of the approach. The primary factor that defines the effectiveness of the solution is the extent to which the approach helps students better comprehend the concept. This study concludes that the approach provides strong support for the hypothesis that participation in a decentralised virtual laboratory has a positive effect on students' perceptions of and motivation for hands-on learning. This method can continue to be adopted because it has a beneficial effect on students' decisions to continue their majors and study plans at Politeknik Mukah.

Keywords: - Virtualization technology, practical learning, open-source operating system, Linux

1. Introduction

Wang et al. (2015) claim that learning in a virtual environment is increasingly important. This is because learning outcomes in virtual environments can determine and describe the abilities of students directly. According to W. I. Bullers, Burd, and Seazzu (2006), virtualization technology has proven to be extremely beneficial in the case of practical courses. The technology also substantially supports the utilisation and improves the manageability of the traditional laboratory (Koratagere et al., 2023; Stackpole, Koppe, and Guay, 2008; Ruth, 2013).

The use of virtualization technology in education during the COVID-19 pandemic has become an essential tool for remote learning (Affouneh et al., 2021; Alvarado-Silva et al., 2023). The studies revealed that virtualization technology allows for synchronous and asynchronous learning, which provides flexibility for students and educators.

The hosted or type-2 hypervisor is an important virtualization technology in education because of the meaningful features to facilitate the teaching of different practical courses. This technology requires a host operating system to be installed beforehand. To enable users to run multiple guest operating systems in their own application window, at the top of the host operating system there is a software layer called hypervisor or virtual machine manager. Chen et al. (2011) found that by employing a decentralized virtualization model they could provide students with the opportunities to learn and practice the skills they need to succeed in the real-world.

1.1 Background

With the availability of the free and open-source Oracle VM VirtualBox software, students can run virtual machines on their computers to complete laboratory exercises (Li, 2009). Although Windows is a host operating system, it has reliable support for Linux as a guest operating system and many types of proprietary operating systems (Sayler, Grunwald, Black, White, & Monaco, 2014).

Previous studies have found that VirtualBox enables educators to create easily distributable decentralised virtual laboratory environments. However, we must also investigate the motivation and perceptions of students regarding perceived learning. Specifically, whether students are motivated to participate in a decentralised virtual laboratory and whether they find working with the environment an appealing aspect of practical learning.

Students participating in the decentralised virtual laboratory are evaluated on aspects of their professional demeanour and technical skills, including critical thinking and teamwork. The study can also provide information on whether this new approach has a positive effect on students' major studies, including their future course selections.

1.2 Research Objectives

The main goal of this research is to investigate the implementation of the decentralised virtual laboratory through VirtualBox, a distributed hosted (type-2) hypervisor solution. This paper will focus on the research question, "Are students motivated by participating in a decentralised virtual laboratory and finding that working in the environment is an interesting aspect of learning computing?" Hence, this paper will discuss the following objective: to evaluate the impact of student participation in a decentralised virtual laboratory on the practical learning of the open-source operating system course at Politeknik Mukah.

1.3 Research Scopes

This study focuses on the model of the virtual laboratory that is customised to the course's and instructor's needs. At Politeknik Mukah, students enrolled in the DFN30053 Open-Source Operating Systems course (previously known by the code DFN4023) participated in the study.

2. Literature Review

A computer laboratory employed virtualization technologies as early as 2002 (Stockman, 2003). However, due to the high cost and unproven dependability of x86 virtualization technology, it has not been widely implemented in education or industry until more recently. Various courses have successfully included practical learning learning using a virtual laboratory during the past few years.

In 2016, Potkonjak et al. (2016) reviewed the most recent stage in the progress of virtual laboratories and virtual worlds in various fields, including science, technology, and engineering. Virtualization technology provides a cost-efficient way for education institutions to organise high-quality practical tasks in related disciplines. This technology increases the flexibility of a virtual laboratory by allowing for the creation of various hands-on activities involving various components. A virtual laboratory allows students to modify system configuration that regularly cannot be changed in a real system, as well as damage resistance.

2.1 Practical Courses Learning

In virtual laboratories, virtualization technology is frequently used to deliver immersive computer science and information technology education. Particularly in the learning of operating systems or system administration (Vollrath and Jenkins, Adams and Laverell, 2005; Nieh and Vaill, 2006; Ruth, 2013), computer networks and administration (Nakagawa et al., 2003; Steffen, 2004; Nabhen and Maziero, 2006; Bower, 2010; Chen et al., 2010; Mok, Lee, and Tan, 2012), and network security (Mamajonov & Abdunazarov, 2023; P. Li et al., 2008; Wu, 2010; Zaki et al., 2010; Peltsverger and Zheng, 2013; L. Xu, Huang and Tsai, 2014; Xu et al., 2014; Wang et al., 2015). The type-2 hypervisor has also been used in teaching software engineering (Sommerville, 2013; Ma et al., 2014) and database administration (Cranitch and Rees, 2009; Ruth, 2013).

From an educational perspective, the hosted (type-2) hypervisor technology becomes the main selection or dominates most cases (Bower, 2010). The main factor is due to security concerns as well as facilitating administrative matters when a host operating system is used. Virtual machines run on host machines are user-level processes and do not have privileges to affect host operating systems. Thus, even if the user is logged in as administrator (called root or superuser in a Linux system) on a virtual machine, they have no special ability to engage in malicious activities or to do harm to the host computer or the network.

VMware Workstation Player and Oracle VM VirtualBox are the two main free (no-cost) desktop software packages for running virtual machines (Li, 2009; Bower, 2010; Xu et al., 2014; Hale et al., 2016; Hamdani and Utama Siahaan, 2016). For each virtual machine on both platforms, the virtual disc drive is just an image file to represent a drive that has different guest operating systems. They feature a virtual network to support network adapters, including a bridge, network address translation (NAT), and an internal network. Users can view, configure, save, start, and stop virtual machines in both software packages.

2.2 Decentralised Virtual Laboratory Approach

Li (2010) classifies laboratory virtualization techniques as either centralised or decentralised. Li, Jones, and Augustus (2011) discuss the use of VMware Workstation and Oracle VM VirtualBox in the development of several types of virtual laboratories from the perspective of higher education. However, a centralised remote laboratory strategy is not the optimal answer for us due to the high expense of building, deploying, and maintaining a data centre. This type of distribution also requires that every student has access to high-speed Internet in any place (Li, 2009).

Studies on the decentralised virtual laboratory have determined the approach's advantages over the deployment of a centralised laboratory. By utilising a decentralised virtual laboratory approach, it might offer students the chance to study and practise the skills necessary for success in the actual system (Mitra & Gupta, 2020; Vollrath and Jenkins, 2004; Nieh and Vaill, 2006; Li, 2009; Ruth, 2013; Ma et al., 2014; Seeling, 2014; Wang et al., 2015). Generally, these methods include the arrangement of many virtual machines for distribution to students. Students are then able to complete laboratory tasks on their own computers or workstations. Students must understand how to configure the hypervisor so that virtual computers can be organised into a virtual network.

3. Research Methodology

There are two sets of research hypotheses investigated in this study that correspond to the research objective. Each set has a null and an alternative hypothesis:

H_{1o}: Student participation in a decentralised virtual laboratory has no impact on student motivation to study the Linux operating system.

H_{1a}: Student participation in a decentralised virtual laboratory has a positive impact on student motivation to study the Linux operating system.

H_{2o}: Student participation in a decentralised virtual laboratory has no impact on student decisions on major studies and future elective courses.

H_{2a}: Student participation in a decentralised virtual laboratory has a positive impact on student decisions on major studies and future elective courses.

3.1 Data Source

The research was conducted during two semesters at Politeknik Mukah, Sarawak. The participants in this research consisted of a total of 136 diploma students enrolled in open-source operating system courses. One section with 67 students served as the control group, while the other section with 69 students served as the experimental group. The participants will be selected based on the following criteria:

a) Has fundamental knowledge of operating systems and networking connections.
b) Has experience using the desktop environment and basic Linux commands.

However, the participants will be chosen through convenience sampling, which is one of the non-probability sampling methods (Kasunic, 2005).

3.2 Data Collection

The data collection is done during the experiment period by two methods: questionnaire and students' assessment results. The procedures of the experiment in this study were based on three overall steps: conventional laboratory orientation for all students, deployment of a decentralised virtual laboratory for the experimental group, and a post-experiment survey for the experimental group. The same lecturer conducted both groups with the same laboratory topics, which consisted of two parts: practical activities on the real machines (the orientation phase) and decentralised virtual laboratories (the treatment phase).

3.3 Data Analysis

A questionnaire survey was conducted among students that participate in decentralised virtual laboratory (DVL) includes some background information as well as a series of response statements that use a Likert scale. The background information includes student ID, gender, programme, and self-reported Linux system administration ability. The Likert scale uses five points from “strongly disagree” to “strongly agree,” with “neutral” as the midpoint value.

The Likert section of the survey consists of three sections: the first section focuses on student perceptions of motivation, the second on student perceptions of learning, and the third on student decisions on major studies and future elective courses. Individual pre- and post-survey responses are not matched when post-experiment surveys are administered. Tables 1 to 3 show each of the three types of questions. The Likert scale responses were converted to ordinal numbers between 1 and 5, with 1 representing "strongly disagree" and 5 representing "strongly agree."

Table 1. Set of questions about students' perceptions of motivation

Item ID	Description
VL 1	Participating on the DVL gives me a better appreciation for the usefulness of virtualization technology.
VL 2	I have a greater awareness of the potential for virtualization technology to benefit practical learning due to participating on the DVL.
VL 3	I wanted to involve on the DVL because I want to share to the people the benefit from the virtualization technology.
VL 4	Participating in the DVL inspires me to use my computing skills to help others.
VL 5	Knowing that my involvement will help to improve learning approach motivates me to do my best on the DVL.
VL 6	Working in groups in DVL utilizing a virtual laboratory has increased my interest in computing.
VL 7	I enjoyed working on the DVL because it allowed me to perform the laboratory tasks in any machine without the

	need to install the platform/software.
VL 8	Participating on the DVL project increases my interest in open-source technology.
VL 9	I enjoyed participating on the DVL because the project can positively impact the preparation and completion of my laboratory tasks.
VL 10	Participating on the DVL increased my confidence in my computing ability.
VL 11	Participating in the DVL environment made me more comfortable with computing.

Table 2. Set of questions to assess student perceptions of learning

Item ID	Description
LA 1	I can list the administrative systems plan for Linux system in a real-world environment.
LA 2	I am comfortable that I could manage and performing Linux system configuration in a virtual environment.
LA 3	I can list the steps in the installation process of Linux operating system.
LA 4	I can describe the configuration files of various services in various Linux distribution system.
LA 5	I am sure that I can actively practice more on command-line interface (CLI) utilizing commands to perform tasks in Linux.
LA 6	I have gained some confidence in managing user and local group accounts in Linux.
LA 7	I am confident that I can manage the sudoers settings, ownerships and permissions on files and directories for security reasons in Linux.
LA 8	I can use the appropriate tools and techniques in managing and creating partitions or file systems in Linux.
LA 9	I can manage networks and printers, able to access remotely Linux system via various services (SSH, RDP, VNC).
LA 10	I am confident that I can create and update repositories to manage software packages (install, remove, update) in Linux.
LA 11	I can describe the drawbacks and benefits of Linux distribution system to society.
LA 12	I can describe the drawbacks and benefits of Linux distribution system to business.
LA 13	I can use all tools and techniques employed in a virtual machine to solve problems in the real machine.
LA 14	I can participate in the PBT (Problem-based Task) team's interactions to complete the task in DVL.
LA 15	I can identify when peers are behaving in an unprofessional manner in the DVL.
LA 16	Participation in the DVL has improved my understanding of how to behave like a system administrator.

Table 3. Set of questions to examine the student's decisions on major studies and future elective courses

Item ID	Description
OT 1	Participation in the DVL has caused me to consider networking systems as a major.
OT 2	Participation in the DVL has positively improve my learning outcomes in courses related to networking and system/server management.
OT 3	Participating in DVL has caused me to consider of having a machine with adequate specification for my learning in future.
OT 4	Participation in the DVL has caused me to consider taking further other related courses.
OT 5	The subject matter of this DVL is highly relevant to my future practical learning approach.
OT 6	I have a high level of experience in the DVL subject matter.
OT 7	Overall, I am very satisfied with my learning in the DVL environment.

4. Finding and Analysis

This section describes the data analysis and discussion of the post-survey results. Table 4 provides an overview of all students, including their participation in the decentralised virtual laboratory and the survey (experimental group). Most of the surveys were distributed in hardcopy form in the post-virtual laboratory phase or at the end of the project, which may have contributed to the high average response rate of 98.57%.

Table 4. Summary of student population

Num. of Students	Control	Experimental	Administered	Num. of Surveys	Response Rate
137	67	70	69	69	98.57%

4.1 Student Motivation

From Table 5, a mixed picture is presented by the responses to survey items related to the student motivation of a decentralised virtual laboratory (DVL). The null hypothesis is that the mean height of items is equal to 3 (neutral). In our data, the mean was above 3 for all but one item, VL 9: "I enjoyed participating in the decentralised virtual laboratory because the project can positively impact the preparation and completion of my laboratory tasks," for which the mode was 2.99 (below 3). Therefore, we conclude that the student agrees with the rest of the eight items.

Table 5. Mean, median and mode for item VL 1 to VL 11

Item	Mean	Median	Mode
VL 1	4.71	5.00	5
VL 2	4.67	5.00	5
VL 3	3.28	3.00	3
VL 4	3.22	3.00	3
VL 5	4.72	5.00	5
VL 6	4.48	5.00	5
VL 7	4.74	5.00	5
VL 8	4.74	5.00	5
VL 9	2.99	3.00	3
VL 10	3.39	3.00	3
VL 11	3.54	3.00	3

When looking at the survey items related to the impact on student motivation from participation in a decentralised virtual laboratory, the mode for item VL 1, VL 2, VL 5, VL 6, VL 7, and VL 8 is 5. While the mode for the other five items is 3, this includes items VL 3, VL 4, VL 9, VL 10, and VL 11. In addition, the median for six items is 5, including items VL 1, VL 2, VL 5, VL 6, VL 7, and VL 8. The median for items VL 3, VL 4, VL 9, VL 10, and VL 11 is 3.

4.2 Student Perceptions on Learning Impacts

This section includes survey questions pertaining to students' perceptions on the impact of learning, specifically their Linux system administration skills. As shown in Table 6, the survey results indicated a mean greater than 3 for all questions except one, LA 10: " I am confident that I can create and update repositories to manage software packages (install, remove, update) in Linux," which had a mean less than 3. Participating in a decentralised virtual laboratory enables students to acquire administrative abilities, as indicated by the fact that the student agrees with nearly all the claims.

Table 6. Mean, median and mode for item LA 1 to LA 16

Item	Mean	Median	Mode
LA 1	4.10	4.00	4
LA 2	4.62	5.00	5
LA 3	4.77	5.00	5
LA 4	4.10	4.00	4
LA 5	4.54	5.00	5
LA 6	4.83	5.00	5
LA 7	4.07	4.00	4
LA 8	3.72	4.00	4
LA 9	4.67	5.00	5
LA 10	2.90	3.00	3
LA 11	4.12	4.00	4
LA 12	4.09	4.00	4
LA 13	3.97	4.00	4
LA 14	4.12	4.00	4
LA 15	3.33	3.00	3
LA 16	3.87	4.00	4

Based on the responses from the 69 students in a decentralised virtual laboratory, the medians for all items are equivalent to their modes. Items LA 2, LA 3, LA 5, LA 6, and LA 9 had the highest median and mode values of 5. Most items related to Linux system administration ability showed a median and mode of 4, including items LA 1, LA 4, LA 7, LA 8, LA 11, LA 12, LA 13, LA 14, and LA 16. Only two items have a median and mode of 3, which are items LA 10 and LA 15.

4.3 Student Future Plan

As indicated in Table 7, all survey questions pertaining to major and study plan received a mean score greater than four. The student concurs that participation in a virtual laboratory environment motivated them to enrol in another system-related course and continue their networking systems major. Except for one item, OT 7: " Overall, I am very satisfied with my learning in the DVL environment," for which the median was 4, the median was 5 for all other items. The mode of all items exhibiting the same pattern.

Table 7. Mean, median and mode for item OT 1 to OT 7

Item	Mean	Median	Mode
OT 1	4.49	5.00	5
OT 2	4.72	5.00	5
OT 3	4.74	5.00	5
OT 4	4.59	5.00	5
OT 5	4.88	5.00	5
OT 6	4.88	5.00	5
OT 7	4.13	4.00	4

5. Conclusion

The relationships between research outcomes and research objective are summarised in Table 8. All 69 students who have successfully participated in the project have completed the post-survey. The post-survey responses were used to investigate the research objective, which was to identify the impact of student participation in a decentralised virtual laboratory on practical learning. There is strong evidence to support the claim that students agree that participating in a decentralised virtual laboratory has a positive impact and influences their decision to continue their major and study plans. The mean for all items is above 3 (above neutral), while the median and mode are 4 (agree) or 5 (strongly agree).

Table 8. Relationships between research outcomes with research objective

<table>
<tr><th colspan="2">Research Objective</th></tr>
<tr><td colspan="2">To evaluate the impact of student participation in a decentralised virtual laboratory on practical learning of the open-source operating system course at Politeknik Mukah.</td></tr>
<tr><th>Outcome</th><th>Remarks</th></tr>
<tr><td>a) Analysis of the 11 items related to the impact on student motivation in a decentralised virtual laboratory.
b) The mean above 3 is 10 out of 11 items.</td><td>• Student participation in a decentralised virtual laboratory has a positive impact on student motivation to study the Linux operating system.</td></tr>
<tr><td>c) Analysis on the 16 items related to the impact on practical skills and abilities among students in the decentralised virtual laboratory.
d) The mean above 3 is 15 out of 16 items.</td><td>• Student participation in a decentralised virtual laboratory has a positive impact on perceived learning related to practical skills.</td></tr>
<tr><td>e) A study of the seven items related to the impact on majors and study plans of students in a decentralised virtual laboratory.
f) The mean for all items is above 3.</td><td>• Student participation in a decentralised virtual laboratory has a positive impact on student decisions on major studies and future elective courses.</td></tr>
</table>

Students' perspectives on motivation and perceived learning were mixed. While the overall results appear to indicate that students gain professional experience and are motivated by participating in a decentralised virtual laboratory project, there are some confounding variables in this study. Participation in a decentralised virtual laboratory has no positive impact on the student's preparation and completion of the tasks. In addition, students have difficulties creating and updating repositories to manage software packages (install, remove, and update) in Linux. Besides that, the mean for almost all items in both categories is above 3 (above neutral). For median and mode, there are five items related to the student's motivation: 3 (neutral), and six items: 5 (strongly agree). Meanwhile, the following are the median and mode for items related to perceived learning: six items have a rating of 5 (strongly agree), while only one has a rating of 4 (agree).

References

Adams, J. C. and Laverell, W. D., 2005. Configuring a Multi-Course Lab for System-Level Projects. *SIGCSE'05 Technical Symp. on Computer Science Education*, pp. 525–529.

Affouneh, S., Khlaif, Z. N., Burgos, D., & Salha, S. (2021). Virtualization of Higher Education During Covid-19: A successful case study in Palestine. Sustainability (Switzerland), 13(12). https://doi.org/10.3390/su13126583.

Alvarado-Silva, C. A., Tejeda-Ponce, A. D., Ulloa-Rubio, B., Salas-Ruiz, J. A., & Gaytan-Reyna, K. L. (2023). Analysis of the Academic Performance of Mechanical-Electrical Engineering Students during the COVID-19 Pandemic: A Case Study in a Private University in Peru. *International Journal of Information and Education Technology*, 13(5), 867–872. https://doi.org/10.18178/ijiet.2023.13.5.1881.

Bower, T. (2010). Experiences with Virtualization Technology in Education. *J. Comput. Sci. Coll*., 25(5), 311–318. Retrieved March 11, 2023 from http://dl.acm.org/citation.cfm?id=1747137.1747197.

Cranitch, G. and Rees, M., 2009. Virtualization: A Case Study in Database Administration Laboratory Work. *ASCILITE Conf*., pp. 168–174.

F. Chen, R. Chen, & Jr. Chen. (2011). A Portable Virtual Laboratory for Information Security Courses, 245–250.

Hale, J. S., Li, L., Richardson, C. N., & Wells, G. N. (2016). Containers for Portable, Productive and Performant Scientific Computing, 1–15.

Hamdani, H., & Utama Siahaan, A. P. (2016). Virtualization Approach: Theory and Application. *IOSR Journal of Electrical and Electronics Engineering*, 11(5), 187–191.

Kasunic, M., 2005. Designing an Effective Survey. Carnegie Mellon.

Koratagere, S., Koppal, R. K. C., & Umesh, I. M. (2023). Server Virtualization in Higher Educational Institutions: A Case Study. *International Journal of Electrical and Computer Engineering*, 13(4), 4477–4487. https://doi.org/10.11591/ijece.v13i4.pp4477-4487.

L. Xu, Huang, D., & Tsai, W. T. (2014). Cloud-based Virtual Laboratory for Network Security Education. *IEEE Trans. Educ*., 57, 145–150.

Li, P. (2009). Exploring Virtual Environments in a Decentralized Lab. *ACM SIGITE Newsletter*, 6(1), 4–10.

Li, P. (2010). Centralized and Decentralized Lab Approaches Based on Different Virtualization Models. *J. Comput. Sci. Coll*., 26(2), 263–269. Retrieved January 23, 2023 from http://dl.acm.org/citation.cfm?id=1858583.1858625.

Li, P., Jones, J. M. and Augustus, K. K., 2011. Incorporating Virtual Lab Automation Systems in IT Education. *Proceedings ASEE Annual Conference & Exposition.*

Ma, K., Teng, H., Du, L., & Zhang, K. (2014). Project-Driven Learning-by-Doing Method for Teaching Software Engineering using Virtualization Technology. *International Journal of Emerging Technologies in Learning*, 9(9), 26–31.

Mamajonov U.O, & Abdunazarov B.A. (2023). Organization of Information Security Mechanism for Virtualization Environment. International *Journal of Education, Social Science & Humanities*., 11(3). https://doi.org/10.5281/zenodo.7699431.

Mitra, S., & Gupta, S. (2020). Mobile Learning Under Personal Cloud with a Virtualization Framework for Outcome Based Education. *Education and Information Technologies*, 25(3), 2129–2156. https://doi.org/10.1007/s10639-019-10043-z.

Mok, H. N., Lee, Y. L., & Tan, W. K. (2012). Setting Up a Low-cost Lab Management System for a Multi-purpose Computing Laboratory Using Virtualisation Technology. *Australasian Journal of Educational Technology*, 28(2), 266–278.

Nabhen, R. and Maziero, C., 2006. Some Experiences in Using Virtual Machines for Teaching Computer Networks. *Education for the 21st Century—Impact of ICT and Digital Resources*, pp. 93–104.

Nakagawa, Y., Suda, H., Ukigai, M. and Miida, Y., 2003. An Innovative Hands-on Laboratory for Teaching a Networking Course. *33rd ASEE/IEEE Frontiers in Education Conf*., p. T2C–14–20.

Nieh, J. and Vaill, C., 2006. Experiences teaching operating systems using virtual platforms and Linux. *ACM SIGOPS Operating Systems Review*, pp. 1–4.

P. Li, Mohammed, T., Toderick, L., Li, C. and Lunsford, P., 2008. A Portable Virtual Networking Lab for IT Security Instruction. *ASEE Annual Conference & Exposition.*

Peltsverger, S., & Zheng, G. (2013). Practical Privacy Labs. Proceedings - 10th IEEE International Conference on Computer and Information Technology, CIT-2010, *7th IEEE International Conference on Embedded Software and Systems, ICESS-2010, ScalCom-2010*, 137–138.

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., & Jovanović, K. (2016). Virtual Laboratories for Education in Science, Technology, and Engineering: *A Review. Computers & Education*, 95, 309–327.

Ruth, M. (2013). Experiences Teaching Mixed Mode Systems Administration Courses Using

Decentralized Virtual Machines. *Consortium for Computing Sciences in Colleges*, 19–25.

Sayler, A., Grunwald, D., Black, J., White, E., & Monaco, M. (2014). Supporting CS Education via Virtualization and Packages: Tools for Successfully Accommodating "Bring-Your-Own-Device" at Scale. *Proceedings of the 45th ACM Technical Symposium on Computer Science Education*, 313–318.

Seeling, P. (2014). Work in progress: Portable Student Labs implementation, (June), 2–5.

Sommerville, I. (2013). Teaching Cloud Computing: A Software Engineering Perspective. *Journal of Systems and Software*, 2330–2332.

Stackpole, B., Koppe, J. and Guay, L., 2008. Decentralized Virtualization in Systems Administration Education. *Proceedings SIGITE'08 Conf*., pp. 249–253.

Steffen, G. D., 2004. Teaching Local Area Networking in a Secure Virtual Environment. *ASEE Annual Conference & Exposition*, pp. 13671–13677.

Stockman, M., 2003. Creating Remotely Accessible Virtual Networks on a Single PC to Teach Computer Networking and Operating Systems. *4th Conference on information Technology Curriculum.*

Vollrath, A. and Jenkins, S., 2004. Using Virtual Machines for Teaching System Administration. *J. Comput. Small Coll*., 20(2), pp. 287–292.

W. I. Bullers, Burd, S. and Seazzu, A. F.,2006. Virtual Machines - An Idea Whose Time Has Returned: Application to Network, Security, and Database Courses. *Proceedings SIGCSE'06 Technical Symp. on Computer Science Education*, pp. 102–106.

Wang, J.-C., Cheng, W.-F., Chen, H.-C., & Chien, H.-L. (2015). Benefit of Construct Information Security Environment Based on Lightweight Virtualization Technology. *IEEE International Carnahan Conference on Security Technology*.

Wu, Y. A. (2010). Benefits of Virtualization in Security Lab Design. *ACM Inroads*, 1(4), 38–42.

Xu, W., Madison, K., Flinn, M., & Kwok, W. (2014). Applying Virtualization Technology in Security Education. *Procedia - Social and Behavioral Sciences, 141, 10–14.*

Zaki, M. M., Erman, H., Azman, M. A. N., Faizal, A. M., & Rahayu, S. S. (2010). Virtualization Technology in Teaching Information Technology Security. *3rd Regional Conference on Engineering Education and Research in Higher Education.*