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Using a Virtual Computing Laboratory to Foster Collaborative Learning for Information Security and Information Technology Education

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Using a Virtual Computing Laboratory to Foster Collaborative Learning for Information Security and Information Technology Education

Abstract

Virtual computer laboratories have been an excellent technological solution to the problem of providing students with hands-on experimentation in information technology fields such as information security in a cost effective and secure manner. A virtual computer laboratory was utilized in this work as a collaborative environment for student learning with the goal of measuring its effect on student learning and attitudes toward laboratory assignments. Experiments were carried out utilizing specially-designed computer-based laboratory activities that included student assessments and surveys upon their completion. The experiments involved both small groups and individual students completing their respective laboratory activities and subsequent assessments/surveys. The analysis of the data collected from both versions of the activity showed that students who performed the collaborative version of the activity benefited more than students who completed it on their own with respect to their learning and attitudes towards the subject areas covered in the laboratory activities.

Keywords

Virtual Computing, Collaborative Learning, Information Security Education

Cover Page Footnote

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INTRODUCTION

In the last decade, advances in virtual computing have led to a rise in the use of Virtual Computer Laboratories (VCLs) as a means of providing students with hands-on experimentation in the information technology area, particularly in the growing field of information security. A VCL consists of virtual machines (VMs), which are hardware emulations running on physical computers that can be loaded with various actual operating systems. Using virtualization software, a single computer can host multiple VMs. This enables students to control multiple VMs with different operating systems at the same time. Being hardware emulations, as opposed to software simulations that are used in technological training, VMs have fully functional operating systems and all of the functionality normally associated with actual physical computers. They are valuable in that VMs can be configured such that students cannot corrupt or change their setup. Once a student logs out of a properly configured VM, its operating parameter return to their default settings and the physical computers on which the VM's are utilized are unchanged. Therefore, students can experiment with complex and high-risk operations without the fear of violating institutional computer usage policies and changing the states of physical laboratory computers.

VCLs can be used to enhance student learning in various ways. In fields such as information security, where hands-on experimentation with different computer operating systems is extremely important, VCLs are used to teach students the skills necessary in the corporate world where a broad range of information technologies exist. Students usually have limited options to learn and test advanced information security skills on actual campus computers due to strict information technology policies that limit computing privileges. This can be remedied by granting students administrative privileges on VMs without any concern due to the fact that VMs can be isolated from campus networks. In asynchronous distance learning, VCLs enable students to perform self-paced, hands-on information security activities remotely (Konak & Bartolacci, 2012; Konak, Ryoo, & Kulturel-Konak, 2014). Therefore, VCLs are frequently used in information security education as shown in Table 1. However, it can be seen in the table that the focus of most VCL research is the technical design of VCLs and not their effectiveness as an educational tool. The related VCL literature either introduces the technical specifications of VCLs such as the virtualization technology used, network configurations and settings, topology design, student interface design, and VM configurations or describes the details of hands-on activities that can be performed utilizing VCLs.

Table 1. ***VCLs References List Related to Information Security***

Laboratory/ Reference	**VCLTarget Area**	**Focus of the Paper**
Open Virtual Lab (Anisetti et al., 2007)	Computer Networking	Technical Design
V-Lab (Bhosale & Livingston, 2014).	Network Security	Technical Design
(Bullers et al., 2006)	Network, Security, Database	Technical Design
(Nabhen & Maziero, 2006)	Computer Networking	Hands-on Activities
VLabNet (Powell et al., 2007)	Computer Networking	Hands-on Activities
NVLAB (Wannous & Nakano, 2010)	Computer Networking	Technical Design
(Li, 2006)	Networking, Development	Technical Design
SWEET (Gaffer et al., 2012)	Cryptography	Technical Design
(Garcia et al., 2012)	Information Systems	Technical Design
Integrated Virtual Environment (Hamada, 2008)	Theory of Computation	Technical/Pedagogical
Tele Lab (Hu et al., 2005)	Network Security	Technical Design
xSec (Hu & Wang, 2008)	Computer Security	Technical Design
Velnet (Kneale, 2004)	Computer Networking	Technical Design
CenLavi (Tran et al., 2013)	Computer Networking	Technical Design
Virtual Lab (Son et al., 2014)	Network Security	Technical Design
The Collaboratory (Wright, 2007)	Computer Science/Engineering	Technical Design
Tele-lab (Willems & Meinel, 2009).	Information Security	Technical Design

Overall, VCLs have reduced the cost of maintaining specialized computer laboratories. At the same time, they have made campus computing resources available to students on an anytime and anywhere basis. Because of these advantages, VCLs are slowly replacing traditional computer laboratories in information security education. In addition to their technological, logistical, and financial benefits previously described, VCLs also promise new opportunities to enhance student learning through pedagogical approaches that involve active, collaborative, and problem-based learning. Due to the fact that the topology of a VCL is defined within software rather than through physical wired connections, it is easy to create and modify VCL configurations to support collaborative hands-on activities. In addition, VCLs allow students to interact and collaborate in ways that are not possible with regular campus computers. Therefore, VCLs can support collaborative information security activities, which are impossible to perform in traditional institutional computer laboratories.

Despite these capabilities inherent in VCLs that facilitate collaborative learning in information security, the literature points to the fact that the academic community has failed to take advantage of them. Hands-on activities for this area of study have been traditionally designed for individual students rather than group work. The research in this paper focuses on the pedagogical benefits of VCLs as an environment for hands-on collaborative learning. Our primary objective is to study whether collaborative hands-on activities are more effective than individual ones in the context of a VCL. Our main hypothesis at the onset of this work is that collaborative hands-on activities lead to higher student satisfaction and learning as compared to individual activities in the context of being conducted on a VCL. As seen in Table 1, the focus of the majority of papers in the information security literature is to introduce the technical aspects of VCLs. The value of VCLs as a medium to enhance student learning through collaborative learning has been understated in the existing literature. This work addresses this gap in the education literature and teaching practice involving VCLs. In the light of the collaborative learning theories briefly described in the next section, we present our findings to answer the following research questions:

I. Do collaborative hands-on activities lead to higher student satisfaction than individual hands-on activities in VCLs?

II. Do collaborative hands-on activities improve students' learning outcomes such as competency, interest, and knowledge more than individual hands-on activities in VCLs?

AN OVERVIEW OF COLLABORATIVE LEARNING THEORIES

In the field of information security, many hands-on laboratory activities can be very long and tedious when compared to such activities in other information systems courses. Due to the nature of such exercises, students can feel overwhelmed as they follow voluminous, step-by-step instructions that guide them through each task of the activity. In such cases, a hands-on activity can easily turn into a mundane algorithmic sequence of steps that students undertake without fully understanding the concepts behind them. In such situations, one of three courses of actions can be taken by the instructor with respect to such activities: allowing students to work together towards a shared goal (collaborative learning), allowing students to work independently toward individual goals, or pitting students against each other in a form of competition where there is a single goal that cannot be realized by all (Laal & Godsi, 2012).

Collaborative learning aids students by allowing fellow students to assist in the transfer of knowledge during the activity, and benefits the instructor in that a greater understanding of the minutia of the laboratory exercises is gained. Collaboration helps to develop a sense of shared knowledge as the activity is performed. Therefore, this notion fits well with the concept of positive interdependence where members in a group have a common goal and realize that working together benefits both individuals and the group as a whole. In the context of the hands-on information security laboratory activities, the benefits of positive interdependence present a strong argument for the use of collaborative learning. As Laal (2013) collaborative learning creates a shared goal where group members increase the learning of all. Laal and Ghodsi (2012) outline some of the benefits of collaborative learning as promoting critical thinking skills, developing social support system for learning, reducing learning anxiety, and increases student self-esteem.

A key concept that is applicable to our work is Bayer's model of “Collaborative-Apprenticeship Learning” (Bayer, 1990). Bayer has built on the notion that learning is a social process and that “scaffolded” instruction is very effective in aiding learning. Of the four principles encompassed in the Bayer model, one is especially applicable: that working in collaboration with a course instructor and peers under the auspices of an apprenticeship process, students are able to construct knowledge beyond what they could do independently. Instructional scaffolding entails providing the necessary resources, instructional guidance, and other supporting materials necessary for a student to complete a learning task. Ideally, instructional scaffolding allows a student to complete a learning task on his or her own and is varied throughout the process of task completion. Wass, Harland, and Mercer (2011) apply the notion of the ZPD and scaffolding to undergraduate university students. Their work reports that verbal scaffolding and communication with both peers and instructors build critical thinking skills that allow students to accept responsibility for their own learning and that of their peers as well.

Several researchers have found that groups performed better than individuals on computer-based problem solving tasks and also that the skills learned through group work transferred to later individual work (Amigues & Agostinelli, 1992; Blaye, Light, Joiner, & Sheldon, 1991; Mevarech, 1993). Hamada (2008) shows that students' motivation for independent learning in the theory of computation is enhanced by a collaborative virtual environment. As a result of a comprehensive meta-analysis involving 158 cooperative learning studies, Johnson, Johnson, and Stanne (2000) report that cooperative learning has generally a positive impact on student attitudes toward the subject matter and learning. Similarly, Lou, Abrami, and d’Apollonia (2001) report that group learning with computer technology leads to higher knowledge gain than individual learning based on a meta-analysis of 122 studies. Konak, Clark, and Nasereddin (2014) report that the level of student-to-student interaction is a significant factor in determining student learning and interest. Information security students are expected to grow professionally as independent learners in order to cope with the rapidly changing world of information technology and the Internet. Therefore, it is important for students to develop an interest in exploring relevant subject matters in more depth beyond classroom training. This is one of the reasons that the impact of collaborative work on student interest in the subject areas of the laboratory activities is also studied in this research.

BRIEF DESCRIPTION OF THE COLLABORATIVE VIRTUAL COMPUTING LABORATORY (CVCLAB)

Virtualization is an approach for decoupling the underlying physical resources of a computer from the operating systems, applications, and users. In a traditional server environment, a physical computer hosts one instance of an operating system while supporting multiple applications. With virtualization, the server, storage, and network become a logical representation of these items. These resources are controlled through software and can be shared between multiple VMs. In a virtualized environment, a single physical computer, called the “host”, can run many VMs or “guests” with different operating systems, network connections, storage devices, and applications. The concept of virtualization is different from an operating system simulation because a VM has the complete capabilities of an actual computer. Therefore, there is no difference between a VM and an actual computer from the perspective of end users.

We designed and implemented a VCL called Collaborative Virtual Computer Laboratory (CVCLAB) in order to provide students with an environment in which they can experiment with complex and high-risk information security and computer networking techniques and skills without any concern for violating university computer use policies. The CVCLAB includes several specialized VCLs for collaborative learning as shown in Figure 1. More details about the CVCLAB and hands-on activities can be found at the CVCLAB website (http://ist.bk.psu.edu/cvclab). Students can access these VCLs via a web browser or a client interface from anywhere utilizing an Internet connection. The descriptions of the VCLs of the CVCLAB are as follows:

Basic Networking And Security Virtual Labs (BNSVL)

The BNSVL is primarily intended for introductory computer networking and information security courses. This VCL includes VMs of three types: client VM

(C), server VM (S), and target VM (T) as shown in Figure 1. C-type VMs have Windows 7 or Linux as the operating systems; and students are granted full administrative privileges on them. Each C-type VM is pre-installed with network and security software tools such as network scanning and enumeration, system security audit, packet sniffing, intrusion detection, footprinting, cryptography, firewall, anti-virus, and malware detection and removal packages. S-type and T-type VMs are for instructor use only. S-type VMs provide network services such as DHCP, DNS, file server, routing etc. for the virtual network. S-type VMs are also used as routers to interconnect different virtual network segments. Instead of connecting all C-type VMs through a single network, they are organized into several virtual network segments connected with a backbone network. This topology allows more realistic and advanced hands-on collaborative activity capabilities. In addition, student teams can take on roles such as attackers and defenders in different network segments.

T-type VMs can be utilized by the instructors to simulate real-life scenarios. For example, instructors may set up T-type VMs to simulate numerous operating system vulnerabilities and ask students to perform penetration testing using security tools available in C-type VMs. Students are able to temporarily install and test software packages on C-type VMs. To facilitate collaborative activities, communication protocols, such as FTP, Telnet, HTTP, Windows Messenger, Internet Relay Chat, and Network File Sharing are enabled in the C-VMs.

Advanced Networking and Security Virtual Labs (ANSVL)

ANSVLs are primarily used in advanced computer networking and information security courses. This virtual lab provides students with resources to practice advanced skills for Windows or Linux-based server administration through numerous advanced server administration tasks. For example, students can activate web services on S-type VMs and then learn to implement specific web server configurations that are necessary to defend against various types of network attacks such as denial of service attacks (DoS). Depending upon a given scenario, C-type VMs may also serve as clients to test the services provided by S-type VMs. ANSVLs are also used in the delivery of online credit or non-credit programs dealing with server administration and security. Each student is assigned to a group of two C-type and one S-type VMs. In the default configuration, a student’s VMs group is connected to other students’ VMs. However, students can change the network configuration by activating or deactivating VMs network connections.

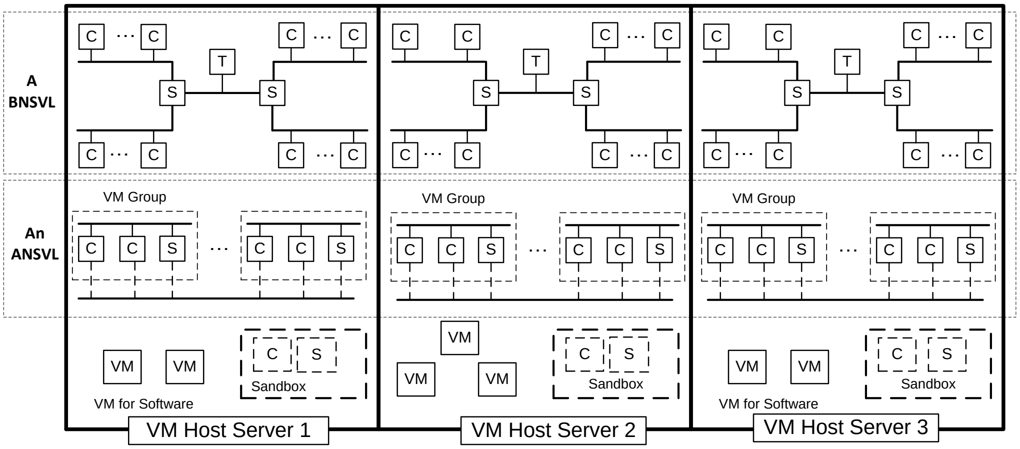

Figure 1. ***The logical architecture of the CVCLAB.***

Sandboxes

A Sandbox is a group of VMs dedicated to the exclusive use of a student or a team of students for inquiry-based learning and undergraduate research activities over extended time periods. Within a sandbox, students are allowed to create, configure, and network VMs without being limited to a prior configuration or restrictions. In addition, students are able to install and use a wide range of software packages which are available through a software library. A typical use of sandboxes is for student semester-long projects or undergraduate research activities. For example, a sandbox could be created for a student team project and be maintained by the team throughout the course of the project. Therefore, sandbox VMs have persistent storage so that students can continue to build upon their previous work. Sandboxes are an unconventional idea in terms of the application of VMs in a learning environment and have the potential to make a significant impact on student learning through the use of problem-based and collaborative learning. In particular, a sandbox is a great way to create a collaborative learning environment in which a group of students can focus on and engage in a common task for extended time periods.

RESEARCH METHODOLOGY

In this paper, we compare students' experiences and perceived learning outcomes as they performed two types of rigorous hands-on laboratory activities (a collaborative laboratory activity versus an individual one) using the CVCLAB.

Both individual and collaborative versions of the activity were designed and given to different sections of the same course.

Description Of The Empirical Study And Hands-on Activity

To investigate the effect of collaborative hands-on activities on student learning and experience in the CVCLAB, we collected data using an empirical study where two groups of students performed two versions of a rigorous hands-on activity in the CVCLAB. One version allowed for collaborative work (CW) and the other involved individual work (IW). The hands-on activity involved database administration and security tasks such as installing a database management system, administrating user accounts and permissions, creating databases, and securing a database server. In both versions of the activity, students followed the exact same steps and were introduced to the exact same content, but students in the CW version had to work together for the successful completion of the activity. The CW version was specifically designed in such a manner that students within a given group had to collectively tackle each step of the laboratory exercise in order to complete the entire activity. In other words, the typical student strategy of "divide and conquer" for group work would not allow for successful completion of the activity. The activity was part of the regular course content and was conducted in the CVCLAB during regular class meeting times. The activity was designed to take about two hours to complete. Although in the IW version, students were not expected to work together, they were allowed to interact with one another and/or with the instructor without any restriction in order to prevent any burden on student learning.

Figure 2 illustrates the major tasks of the activity for the CW version. It should be noted that these tasks could not be performed in a traditional computer laboratory due to university security limitations. In the IW version, a student completed all tasks given in Figure 2 and tested them on a single VM. In the CW version, two students, for illustration purposes labeled A and B in Figure 2, were assigned to two networked VMs. This two-student group performed the same activity steps as in the IW version, but they were instructed to test one another's configurations remotely. For example, when student A completed the configuration of his/her database, student B tested student A's configuration by remotely connecting to his/her database server, and vice versa. Both students were expected to troubleshoot configuration mistakes that might have occurred during the installation and to make joint recommendations about installation and security problems.

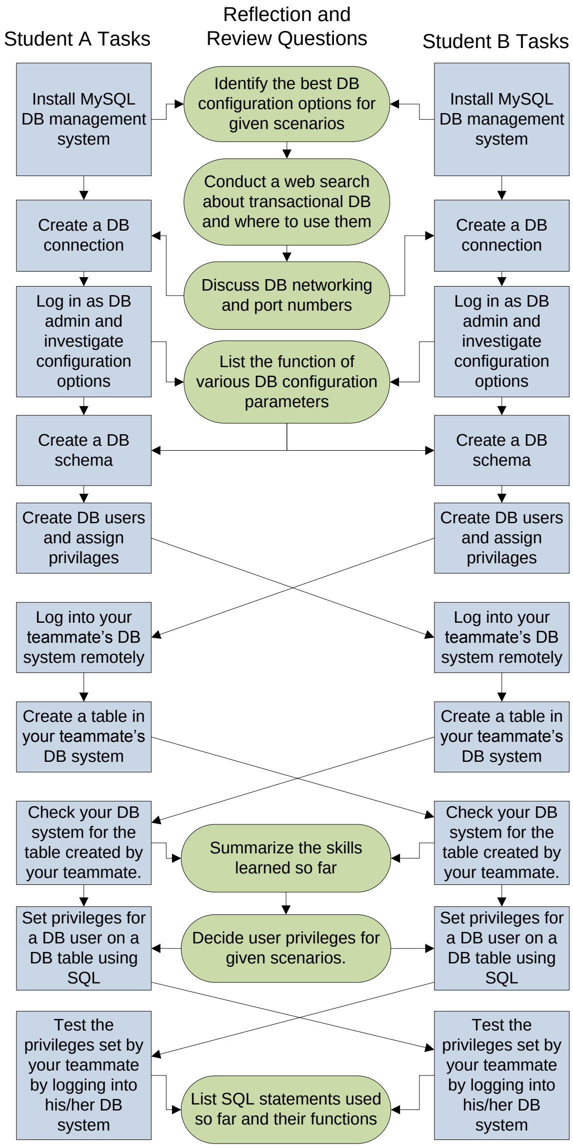

Figure 2. ***The major tasks of the CW version of the hands-on activity used in this research. In the IW version, a student completed all tasks of Student A on a single VM and performed the reflection and review steps alone.***

As students performed the steps of the hands-on activity, they were also expected to answer review questions. The review questions were of two types: basic knowledge questions related to the laboratory assignment and strategic processing questions that required critical thinking and reflection. To answer the basic knowledge review questions correctly, students were instructed to conduct brief online research or to read the help file of the database management system. These options were put forth because students were assumed to have no prior working experience with database installation and administration. Strategic processing review questions were developed to require higher level reasoning that could not be achieved by memorization. At the end of the activity, students were given a short assessment (a seven-question multiple-choice quiz) based on the activity steps and the review questions. If students had worked on the review questions diligently and answered them correctly during the activity, they would be expected to perform well on the assessment due to the fact that its questions were very similar in nature.

Participants And Assignment Of The CW And IW Groups In The Experiments Conducted

Pursuant to the research questions previously stated, we conducted experiments utilizing the CVCLAB for the CW and IW versions described above. The participants in these experiments were 97 first year students in an introductory level database class at a four-year college that is part of a larger university system. Although students had some basic database knowledge and skills acquired during the semester, none of them had installed and secured a database management system previously. Because of the small class sizes, the experiments were conducted over four consecutive semesters. The targeted class had two sections each semester, a night and a day section. In a semester, a randomly selected section of a class was exposed to the CW version and the other section was exposed to the IW version. The sections were swapped in the next semester to eliminate any bias between night and day sections although there were no significant Grade Point Average (GPA) differences between the sections. In one of the semesters, the class was only offered in a single session. For this case, the class was randomly divided into the CW and IW versions, and the groups performed the activities in different classrooms. In total, 52 and 45 students completed the CW and IW versions of the activity respectively. As demonstrated in the following section, both groups rated the difficulty or "challenge" of the activity in a nearly identical fashion. This should indicate a similar academic and technical background for both groups and validate the random assignment of students to IW and CW groups.

For all of the sections involved throughout the various semesters, the activity was a part of the regular course content. This being the case, all students were required to complete the activity and put forth a normal effort towards its completion. After completing the activity, students were instructed to fill out a questionnaire first and then complete the quiz. Students were asked for a signed-consent for the questionnaire, and if they did not give consent, they were not expected to complete the questionnaire and their quiz scores were excluded from this study.

Data Collection Questionnaire And Validation Of The Questionnaire

A questionnaire was utilized to measure student experiences during the activity and their perceived learning outcomes. The questionnaire had three sections: (*i*) two questions to measure overall student satisfaction about the CVCLAB and the activity, (*ii*) 24 questions intended to measure students' perceptions about the activity, their perceived learning outcomes, the level of peer interaction, and (*iii*) finally two open-ended questions. These questions were operationalized with a seven-point Likert scale, ranging from "Strongly Agree" (1) to "Strongly Disagree" (7). An exploratory factor analysis was performed to verify the anticipated factors effecting students' learning experiences as well as to evaluate the convergent validity of the extracted latent variables. First, a preliminary exploratory factor analysis was run to investigate the questionnaire items with low factor loadings. After removing three questions with weak convergent validity, the final factor analysis was performed to validate the mapping of the 21 remaining questions into extracted six latent variables. Table 2 illustrates the extracted latent variables, their associated questions, the correlations between the questions and the latent variables, and Cronbach's alpha values indicating the internal consistency of the latent variables. The latent variable values were calculated by averaging their related question scores for each case. The latent variables are explained as follows:

Interaction: Interaction is a measure of the extent to which students interacted with one another during the activity. In the CW version, students worked in groups of two to answer review questions and test one another's system configurations. In the IW version, student-to-student interaction was voluntary and not built in the activity. During the activity, we observed students, even for the IW version, helping each other mainly for troubleshooting problems encountered.

Reflection: As seen in Figure 3, students were also faced with scenarios that required them to solve simple problems and reflect upon what they were performing in the activity. The reflection latent variable was intended to measure how much students engaged in reflection activities. In the CW version, reflection was also collaborative.

Challenge: This latent variable was intended to measure students' perceived difficulty in completing the activity.

Usefulness: This latent variable was intended to measure at what level students found activity useful and engaging as an educational tool at the personal level.

Competency: This latent variable measured students' perceived learning outcomes as a result of the activity. Competency is different from the former latent variables because the objective was to measure a perceived outcome of performing the activity, whereas the former ones were intended to measure student experience during the activity.

Table 2. ***The survey questions, latent variables, and the reliability measures***

Question/ Latent Variable (Cronbach's α)
Usefulness (0.97)
The time I spent for the activity was worthwhile.
I find the activity useful to me.
I would like to do more of similar activities, even if it is time consuming.
The activity was very engaging.
The activity was pleasurable.
Interaction (0.913)
Interacting with other students helped me complete the activity.
I learned new concepts/skills by interacting with other students.
The activity encouraged me to ask questions to others.
Competency (0.759)
The activity helped me improved my problem solving skills.
The activity improved my technical skills and competency in the subject area.
I felt a sense of accomplishment after completing the activity.
I will be able to use what I learned in the activity in other courses or the future.
Interest (0.806)
The activity increased my curiosity and interest in this area.
The activity encouraged me to learn more about this topic.
I was very motivated for completing the activity.
Reflection (0.751)
The review questions were helpful to reinforce what was performed in the activity.
The activity provided opportunities to reflect back what was learned in the activity.
The activity promoted helpful discussions about what was performed in the activity.
Challenge (0.703)
The activity was challenging.
The activity review questions were difficult and time consuming.
The activity instructions were confusing.

Interest: The interest latent variable aimed to measure the level to which students' interest in the subject matter was increased as a result of the activity. As with competency, the interest latent variable is a perceived learning outcome measure.

The internal consistencies of the latent variables were evaluated by calculating the Cronbach's alpha values, which are also provided in Table 2. The latent variables competency, interest, interaction, and usefulness had high internal consistency while the reliabilities of the latent variables challenge and reflection were close to the minimum acceptable level of 0.707 (Nunnally & Bernstein, 1994).

EXPERIMENTAL RESULTS

Comparison Of Collaborative And Individual Work

The collected data were first analyzed to investigate differences in the means and variances of the latent variables and the overall rating of the CVCLAB across the CW and IW versions. Therefore, we first compared the latent variable means of the CW and IW versions using the *t*-test. In addition, we used Levene's test to compare the variances of the latent variables across the CW and IW versions. Table 3 summarizes the results of this statistical analysis. The columns labeled Mean and Std. Dev. are the means and standard deviations of the latent variables for the CW and IW versions. The column labeled Effect Size represents Cohen's *d* value (Cohen, 1992) for the mean difference between the CW and IW versions of the activity. The column *p*-value (*t*-test) displays the significance of the *t*-test. The column *p*-value (Levene's test) displays the significance of Levene's test. If this value is greater than 0.1, it can be safely assumed that the two versions have the same variance. If the variances of the two versions were statistically different for a latent variable, the *t*-test statistic was calculated assuming different variances.

As seen in Table 3, the students rated the CW version of the activity higher than the IW version (d=0.30). They also rated their experience with the CVCLAB higher for the CW (d=0.20). However, these differences were not statistically significant in the *t*-test with (t=1.46, p=0.14) for the activity and (t=1.0, p=0.31) for the CVCLAB. Overall, the majority of students rated the activity as very good or higher. A noticeable difference between the IW and CW versions was the variability of ratings. The variances of the activity rating and the CVCLAB rating for the IW version were respectively 22% and 19% larger than ones for the CW version.

Table 3. ***Comparisons of the means and standard deviations of the latent variables and the quiz scores across the activity versions.***

Question/ Latent Variable	Version	Mean	Std. Dev.	Effect Size (Cohen'd)	*p*-value (*t*-test)	Degree of Freedom (*t*-test)	*p*-value (Levene's Test)
Overall, how would you rate the activity/exercise?	IW	2.98	1.00	0.30	0.14	95	0.27
	CW	2.71	0.78				
Overall, how would you rate your experience with the CVCLAB?	IW	2.93	1.10	0.20	0.31	95	0.18
	CW	2.73	0.89				
Challenge	IW	3.45	1.20	0.00	0.98	95	0.79
	CW	3.45	1.22				
Interaction	IW	3.49	1.62	1.36	0.00	51.88	0.00
	CW	1.90	0.57				
Reflection	IW	2.68	1.04	0.51	0.02	66.09	0.00
	CW	2.26	0.60				
Usefulness	IW	2.49	1.06	0.36	0.09	71.86	0.00
	CW	2.18	0.67				
Interest	IW	2.61	0.97	0.34	0.10	77.22	0.00
	CW	2.33	0.67				
Competency	IW	2.37	0.74	0.37	0.07	82.13	0.08
	CW	2.13	0.57				
Quiz Grade	IW	75.89	16.65	-0.99	0.00	83.64	0.06
	CW	90.66	13.22				

There was no statistical difference between the perceived challenge of the activity across both versions (t=-0.015, p=0.98). This result may indicate that both groups might have had similar technical backgrounds prior to completing the activity. Students rated their perceived interaction much higher for the CW version than the IW version (d=1.36, t=6.64, p =0.00). Furthermore, the variance of the interaction latent variable was significantly larger for the IW version compared to the CW version as seen Table 3. These results should be expected because the CW version provided a structure for student-to-student interactions while students interacted with their peers on a voluntary ad hoc fashion in the IW version. Although both versions of the activity included the same set of reflection questions, the students in the CW version indicated a higher level of reflection than ones in the IW version (d=0.51, t=2.37, p=0.02). Three other findings are that the CW group found the activity more useful, indicated that their interest increased more, and felt a greater gain in competency when compared to the IW group. The differences in the usefulness (*d*=0.36, *t*=1.70, *p*=0.09), interest (*d*=0.34, *t*=1.62, *p*=0.10), and competency (*d*=0.37, *t*=1.78, *p*=0.07) latent variables were statically significant only at the level of α=0.1. Another interesting observation about the usefulness, interest, and competency latent variables is that the variances of these variables were significantly larger for the IW version than for the CW version (Levene's test *p*-values were all less than 0.1). The large variability observed in the ratings of the latent variables usefulness, interest, and competency for the IW version can be explained by the variability in students' individual skills and capabilities to perform the rigorous tasks of the activity. In the CW version, such differences could be smoothed by peer-to-peer interactions. In other words, the CW version not only led to higher ratings, but also more predictable ones. We also observed that peer scaffolding was taking place in the CW version. This observation was verified by the text analysis of the open-ended questions as described in the following section. Specifically, many students in the CW version commended the group work aspect of the activity. Because the interdependent nature of the CW version, students called attention to the most salient steps of the activity, troubleshot one another's mistakes, and motivated one another to focus on the tasks of the activity. In other words, team members might have filled gaps in motivation and skills for one another. Therefore, the students in the CW version might have rated the latent variables interest, usefulness, and competency not only higher, but also more consistently than the students in the IW version.

The results summarized above support our main research hypothesis that collaborative hands-on work leads to higher student perceived learning than individual hands-on work in VCLs. However, the latent variables measured by the questionnaire are subjective perceptions of the students. As seen in Table 3, the average quiz score was about 19% percent higher in the CW group than the IW group. Furthermore, a significantly large variability was observed in the quiz scores of the IW group. Both mean and variance differences of the quiz score across the activity versions were statistically significant as seen in Table 3. These quiz results also support the notion that collaborative learning enabled students to achieve a higher level of learning outcomes as a result of the activity. It should be reiterated that the post-activity quiz questions were derived from the activity review questions encountered during the performance of the activity. These review questions emphasized the construction of new knowledge through hands-on experimentation and reflection. Hence, the higher quiz score of the CW group was an indicator that the CW group developed a greater level of learning than the IW group.

Relationships Between The Latent Variables

The analysis based on comparing the latent variable means showed that collaborative work in the CVCLAB had a positive impact on students' perceived learning outcomes, such as interest and competency, and the learning outcome as measured by the post-activity quiz. We also investigated the relationships between the latent variables to better understand why the students in the CW group might have felt stronger about their learning. Tables 4 and 5 summarize the correlations among the latent variables for the IW and CW versions, respectively. The correlations among the latent variables were statically significant, excluding the relationship between challenge and the others. A noticeable exception was the negative correlation between challenge and interaction (r=-0.302, p <0.05) in Table 4. This negative correlation between challenge and interaction for the IW version indicated that the more students found the activity challenging, the more they interacted with other students on their own in an ad hoc fashion (note that the challenge questions were coded in reverse). On the other hand, interaction was built-in with the CW version (this group of students rated their interactions very high); hence, this relationship was not observed. In both versions, the more students engaged in interaction and reflection, the higher they rated usefulness of the activity. In addition, their interest level and their competency also increased. The correlations between interaction and the three latent variables, usefulness, interest, and competency were particularly high for the CW version. Additionally, the correlation between the latent variables reflection and interaction was very high for the CW version.

Table 4. ***Pearson correlations (r) among the latent variables for the IW version***

	Challenge	Interaction	Reflection	Usefulness	Interest	Competency
Challenge	1	-0.302*	0.126	0.246	0.209	-0.023
Interaction		1	0.397**	0.354*	0.397**	0.399**
Reflection			1	0.446**	0.490**	0.518**
Usefulness				1	0.686**	0.548**
Interest					1	0.638**
Competency						1

* Correlation significant is significant at the 0.05 level
**Correlation significant is significant at the 0.01 level

Table 5. ***Pearson correlations (r) among the latent variables for the CW version***

	Challenge	Interaction	Reflection	Usefulness	Interest	Competency
Challenge	1	0.142	0.043	0.221	-0.050	-0.076
Interaction		1	.647**	0.496**	0.488**	0.528**
Reflection			1	0.464**	0.503**	0.533**
Usefulness				1	0.611**	0.451**
Interest					1	0.540**
Competency						1

* Correlation significant is significant at the 0.05 level

**Correlation significant is significant at the 0.01 level

Text Analysis of the Open-ended Questions

We also analyzed student responses to two open-ended questions: (*i*) "What did you like the most about the activity?" and (*ii*) "What did you like the least about the activity?" First, we extracted terms and pattern types that identify concepts in the student responses using the SPSS Text Survey Analysis tool with the sentiment linguistic resource library. Based on the extracted pattern types, we created the categories and assigned student responses into the categories. Table 6 and Table 7 present the identified categories, a sample student response in each category, and the percent of responses in each category for open-ended questions (*i*) and (*ii*), respectively. Some students did not respond to the open-ended questions, and the percent values in the tables were calculated based the number of the responses given to the related question. The numbers of CW and IW responses, respectively, were 44 and 31 to question (*i*) and were 34 and 31 to question (*ii*). We should also note that the total percent can be higher than 100% under the CW and IW columns because several responses were assigned to multiple categories.

In both CW and IW versions, the students appreciated that the activity was very hands-on and that they were learning important skills that applicable to the workplace. As seen in Table 6, the major positive themes about the activity were related to its being hands-on and the skills and knowledge gained (the competency/skills category). About 31.8% of the students in the CW version made specific comments regarding their appreciation of being allowed to work on the activity in groups, and none of the students commented that they did not like the collaborative aspect of the experience. Several students in the CW version also indicated that they felt that the results of the activity were of better quality because other students tested and used their database configurations remotely. A few students particularly appreciated learning how to access databases remotely. For example, one student commented, "[It] was interesting connecting between two computers to test all the databases." In other words, the students in the CW version considered the activity more relevant to the real world. The fact that the students explicitly commended the collaborative work aspect of the hands-on activity is important for supporting one of the main results of this work.

Table 6. ***The identified categories, a sample student response in each category, and the percent of the responses in each category for the open-ended question "What did you like the most about the activity?"***

Category	Sample Student Comments	CW	IW
Competency and Skills Gained	The activity improved my technical skills and competency in the subject area.	36.3%	32.2%
Teamwork/ Interactive	I enjoyed the team part of this activity. It allowed me to ask any questions that I had to my teammate or another person in a different team. It was also an interesting activity because we had created our own database.	31.8%	3.2%
Enjoyable/Fun	It was fun and interesting. Always nice to learn new things.	22.7%	22.5%
Hands-on	It was very hands on.	22.7%	22.5%
Interesting	It was more interesting than challenging	13.6%	25.8%
Virtualization	I liked working with the virtual machines and being able to create and manage databases.	12.9%	11.3%
Instructions	The instructions were clear and the activity had a great purpose and was easy to learn…	9%	9.6%
Negative	I did not like much of the activity	0%	6.4%

As seen in Table 7, many students in the IW version made negative comments regarding the slowness of virtual machines. In fact, this was the main concern in the IW version. In the CW version, the students made similar comments about the response time of virtual computers, albeit the percent was much lower (14.7% in the IW version versus 29% in CW version). In the CW version, the main concern was the long duration of the activity. Because the students in the CW version had group discussions, the CW version took a longer time to complete than the IW version. In addition, the students had to coordinate the tasks in the CW version, which increased possibility of mistakes as stated by one of the student comments in Table 7. Therefore, the students found the CW version to be more tedious (14.7% in the CW versus 3.2% in the IW version). About 20% of the students in both groups explicitly stated that they had no negative experience about the activity. However, some students mentioned that they did not fully understand concepts in the activity (8.8% in the CW version versus 19.3% in the IW version).

The difference between the two groups in terms of the conceptual difficulty category is parallel to the differences observed in the usefulness and competency latent variables, but the sample size is not large enough to make statistical inferences based on the text analysis.

Table 7. ***The identified categories, a sample student response in each category, and the percent of responses in each category for the open-ended question "What did you like the least about the activity?"***

Category	Sample Student Comments	CW	IW
Time Consuming	Took a little bit longer than I was hoping.	38.2%	22.5%
Nothing	I did not really dislike anything about the activity	20.5%	19.3%
Slow Virtual Machines	The virtual machines seemed to be overloading the server that they run on... it was slow and laggy much of the time.	14.7%	29.0%
Tedious	There are many ways to get confused and maybe ruin connection between other students.	14.7%	3.2%
Conceptual Difficulty	I may not know or understand all the terms involved and displayed in the activity.	8.8%	19.3%
Instructions	Confusing to follow at some points.	8.8%	6.4%
Repetitive	Became slightly repetitive after awhile	5.6%	0%
Review Questions	Some of the questions were not relevant.	2.9%	6.4%

DISCUSSIONS OF THE EXPERIMENTAL RESULTS

With respect to research question I, both CW and IW student groups were satisfied with the activity and the CVCLAB at the same level based on their questionnaire ratings. Both groups were appreciative of learning database administration and security concepts through a rigorous hands-on activity. However, the text analysis of the open-ended questions and the usefulness latent variable suggest that the CW group had a slightly higher-level satisfaction with the activity than the IW group. With respect to research question II, we observed that the CW version of the activity led to the higher and more consistent levels of competency and interest development as well as post-test scores than the IW version. The correlation analysis suggests that the interaction and reflection latent variables were strongly correlated with the competency and interest latent variables. These results have important practical implications for the design of VCLs and hand-on activities as discussed below.

Practical Implications Of The Research

The literature suggests that learning most naturally occurs by a group of students working together to solve problems (Jonassen & Rohrer-Murphy, 1999) and collaborative learning leads to deeper level learning (Johnson & Johnson, 1987; Johnson, Johnson, & Stanne, 2000). Unfortunately, the VCLs literature has not focused on the benefits of collaborative learning to this point in time. Based on the findings in this paper, we recommend that VCLs should be designed and utilized taking into consideration the benefits of collaborative learning. Rather than being only a technology solution for providing students with hands-on experimentation, VCLs should be planned as a learning environment that allows students to construct knowledge and skills through a social process. We provide the CVCLAB description in this work as a design template for such a hands-on virtual computer learning environment. The empirical results in this paper also support the importance of social processes involved hands-on learning in a VCL. Because of their flexibility and technological advantages, VCLs can effectively support collaborative hands-on activities which are difficult to conduct in traditional computer laboratories. A technical requirement to achieve this objective is to ensure that VMs are interconnected. Setting up VM access permissions as team-based in nature also facilitates interaction, and allows team members to exercise some control with respect to the other team member. These technical recommendations are relativity straightforward to implement.

In addition to the technical design aspects of VCLs, the design of hands-on activities is important to promote collaborative learning. Earlier research on computer-based problem solving overwhelmingly reports that the benefits of group work as compared to individual work (Barbieri & Light, 1992; Blaye et al., 1991; Jackson & Kutnick, 1996; Johnson & Johnson, 1987). Jackson and Kutnick (1996) note that benefits of collaborative work depend on the nature of the activity. Konak, Clark, and Nasereddin (2013) report that the design of hands-on activities is an important factor in order to fully realize the benefits of VCLs. Kirschner et al. (2004) note that social interactions should not be taken for granted in computer-supported collaborative learning environments, and they suggest that group cohesion and interactions should be fostered by incorporating positive interdependence in learning activities and building interactivity into the learning environments.

In this paper, interaction and reflection were identified as significant factors to determine student experience and learning outcomes in VCLs. To increase peer interactions, a hands-on activity should be designed with task interdependency in mind. The activity should be designed in a way such that each student depends on, and is accountable to, one another for the successful completion of the activity.

This should not be interpreted as dividing the activity into disjoint tasks among students. The activity should incorporate interface points where students are required to interact with one another and/or use the end results of one another's work. In Figure 2, such interface points are indicated by the diagonal arrows from one student's tasks to the other's ones. In the database activity, for example, each student is asked to test the database configurations of his/her teammate remotely. This strategy not only makes the activity more engaging, but also initiates peer-to-peer learning by encouraging skilled students to help their teammates who are not as skilled as themselves. Such interface points also facilitate the passing of control of the activity between the teammates. Note that the major difference between the CW and IW versions of the database activity used in this paper is the inclusion of these interface points. Therefore, we can claim that the interface points were successful in stimulating student interactions as shown in Table 3.

The second point in the activity design is to ensure that students have opportunities to reflect on what they are actually accomplishing during the hands-on activity. Otherwise, it is possible that students go through the steps of the hands-on activity without clearly understanding the concepts behind them. Reflection during the activity can be achieved by discussions, reviews, and rhetorical questions that challenge students to reflect on their experience. A good strategy is to break an activity into smaller modules and to incorporate reflection activities between the modules (Konak, Clark, and Nasereddin, 2013). After completing a module, instructors can provide feedback through class discussion or explanations to reinforce student learning. In the database activity, a reflection component was included after each major task group, such as installing the database management system, creating access controls, etc. Although both versions of the activity included identical reflection components, students' perceived reflection was significantly higher in the CW version. Furthermore, the relationship between interaction and reflection was clearly stronger in the CW than in the IW version of the activity as shown in Tables 5 and 4 (r= 0.647 versus r=0.397, respectively). Collaborative reflection requires a different, more rigorous cognitive process than self-reflection (Webb, 1989). Webb (1989) argues that explaining concepts to others involves more learning opportunities than trying to understand it by yourself. In collaborative reflection, students are expected first to understand their teammate's point of view, express their own understandings, and then negotiate a common solution. Through this process, they can correct their misconceptions and gain deeper knowledge about the activity. Jonassen (1994) points out the importance of reflection and articulation in constructivist learning environments. Note that in this study, the post-quiz included questions from the reflection component of the activity. Therefore, the quiz scores implicitly represent the common understanding of two students for the CW version (even though students took the quiz individually) and the individual understanding for the IW version. As seen Table 3 that the CW group performed significantly higher and more consistent than the IW group did in the post-quiz. Based on these observations, we recommend that collaborative hands-on activities should include collaborative reflection strategies to enhance student learning.

CONCLUSIONS

This work explored the benefits of collaborative learning in virtual computer laboratories. Obviously tour findings were limited in scope to a single institution and subset of students studying information technology and information security, but we feel that the results are transferable to other institutions. Through the nature of the laboratory activities designed and conducted in this work, the notion that students may construct a higher level of knowledge as a result of a collaborative hands-on activity than an individual hands-on activity in virtual computer laboratories is supported. Students engaged in collaborative learning felt more competent about their learning and demonstrated a higher level of interest in subject matter. In addition, we observed a lower level of variability in the perceived learning outcomes of the students who completed the collaborative version of the activity. Therefore, collaborative learning strategies should be considered in the design of virtual computer laboratories and hands-on activities.

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