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An Exploratory Factor Analysis of Student Learning in a Collaborative Virtual Computer Laboratory

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ABSTRACT

Information security is a growing part of the information technology function in an organization. Higher learning institutions generally do not provide much “hands-on” exposure to information security concepts due to costs, internal information security concerns, and a lack of worthwhile exercises that cater to students. We have created a collaborative virtual computer laboratory (CVCLAB) that seeks to leverage a large group of virtual computers together with specially designed laboratory exercises in order to create a learning environment for information security. We studied the impact of collaborative work on student learning using controlled experiments in the CVCLAB. In this paper, we are investigating how to best utilize the virtual computers for teaching information security debating such issues as whether learning is greater when exercises are conducted in groups or as individuals. We developed a research model based on Kolb’s Experiential Learning Theory and used an exploratory factor analysis to answer the research questions.

Keywords

Collaborative learning, Virtual computing, Information security.

INTRODUCTION

Learning experiences that involve hands-on experimentation are extremely important in information security education. Providing students with an exposure to a broad range of practical experiences in information security is a costly and complex operation. Therefore, significant gaps exist between well funded programs that cater to mostly higher income students and those lacking the necessary resources that serve mostly minority communities. These categories of programs differ in terms of their capacity to develop and offer such practical experiences to students (Varma, 2002; Ross and Thomas, 2008). Most small colleges, vocational schools, and secondary education institutions do not have adequate financial and personnel resources to create and maintain specialized computer labs. Many colleges have IT policies that restrict student privileges on campus computers, thereby limiting their ability to learn anything meaningful about information security. Students consistently cite inadequate laboratories, limited opportunities for professional development and growth, and a lack of exciting and meaningful tasks (Logsdon, 2006). In order to incorporate pedagogical approaches, such as active, collaborative, and problem-based learning, into information security courses, specialized equipment or computer laboratories are needed. In recent years, Virtual Computer Laboratories (VCLs) based on various hardware virtualizations have become a possible way to address these challenges (Kneale et al., 2004; Chao, 2006; Damiani et al.; Nabhen and Maziero, 2006; Rosenberg and Hoffman, 2006; Anisetti et al., 2007; Armstrong et al., 2007; Powell et al., 2007; Hu and Wang, 2008; Luthon et al., 2009; Willems and Meinel, 2009; Wrubel et al., 2009).

This paper puts forward a VCL model, called the Collaborative Virtual Computer Laboratory (CVCLAB), and presents the preliminary results on how student learning can be enhanced through collaborative hands-on learning in a VCL. We hypothesize that students get greater benefit from a VCL when collaborative learning is supported. Research suggests that collaborative and cooperative learning environments have positive impacts on student learning. Several studies have shown that students who work in groups learn more and retain their learning longer than those who work alone (Cooper, 1990; Dillenbourg, 1999; Heffler, 2001; Kirk and Zander, 2002; Clark and Mayer, 2003). There is also evidence that collaborations among students improve learning in online courses (Kuljis and Lees, 2002; Hamada, 2008; Shuang, 2010). However, most

VCL architectures for information security education and training do not support teamwork. In the literature, a few studies address collaborative learning in VCLs in the context of computer networking or information security (Kneale et al., 2004; Anisetti et al., 2007; Hu and Wang, 2008). To promote collaborative learning strategies, VCLs should be designed as open and flexible systems. As briefly introduced in the next section, the CVCLAB was designed to maximize collaborative learning opportunities for students.

An important factor that supports collaborative learning is the structure of hands-on activities that students are expected to perform in a VCL. A hands-on activity should be designed in a way that students depend on one another for a successful completion of the activity. Thereby, the hands-on activity may lead to student-to-student knowledge and experience exchanges. A hands-on activity should also encourage students to reflect back on the concepts that they are experimenting with in a VCL. According to Kolb's Theory of Experiential Learning Cycle (Kolb, 1984), which is applicable to hands-on learning in a VCL, learning takes place in four stages: (i) Experience: the learner actively experiments with a concept, (ii) Critical Reflection: the learner consciously reflects back on that experience, (iii) Conceptualization: the learner attempts to generalize a model of what is experienced, and finally (iv) Advance Experimentation: the learner applies the model to a new experiment. In the context of information security, a VCL is a tool for stage (i) in Kolb's Experimental Learning Cycle, i.e. it provides students with an environment to experiment with high-risk and complex tasks. Educators should ensure that VCLs and hands-on activities support the other stages to complete the learning cycle.

VIRTUAL COMPUTER LABS AND THE CVCLAB

A VCL consists of several virtual machines (VMs). A VM is a software emulation of a computer that runs exactly like a real computer. Using this technology, a single computer can host multiple VMs with different operating systems, which are isolated from one another and share the resources of the host computer. VMs can also be connected through virtual networks within the host computer. Using VMs, students can test advanced skills and perform complex tasks which are not usually allowed on campus computers and networks. For example, students can study the vulnerabilities of different operating systems, attempt to compromise the security of various computer systems, and take measures to defend against attacks without any concern that their actions may affect other physical computers, production systems, or students. Furthermore, being software emulations, VMs are literally unbreakable. Students can experiment with complex and high risk operations without any hesitation because the original state of a VM can be restored at anytime.

The easiest way to create a VCL is to install a virtualization system on campus computers so that students can run multiple operating systems. This model was adopted by many institutions in networking and information security courses (e.g., (Nabhen and Maziero, 2006; Rosenberg and Hoffman, 2006)). Although this model overcomes some of the problems associated with providing students with a hands-on learning environment, it does not address all needs of commuter, non-traditional, and distance learning students because these computer laboratories are physically bounded and cannot be shared by multiple institutions. Recently, many universities have started providing their students with access to campus computers via remote login or virtual computers. In the literature, several VCLs are also reported (Kneale et al., 2004; Chao, 2006; Damiani et al.; Nabhen and Maziero, 2006; Anisetti et al., 2007; Armstrong et al., 2007; Powell et al., 2007; Hu and Wang, 2008; Luthon et al., 2009; Willems and Meinel, 2009; Wrubel et al., 2009) with promising results.

The CVCLAB aims to provide students with an *open learning environment* in which they can experiment with complex and high risk operations without any concern. The physical and logical architectures of the CVCLAB are shown in Figure 1. The fundamental computing base of the CVCLAB is called a VM team which consists of four VMs with various operating systems. All computers in a VM team are networked, but VM teams are not connected together by default. If needed, VM teams can also easily be networked together. Each VM team is assigned to a team of two or three students depending on the exercise type. Students are granted full access and administrative privileges on their team VMs, but they cannot access other teams' VMs. All VMs are loaded 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. In addition, the CVCLAB includes VMs dedicated for instructor use (S-VMs and T-VMs in Figure 1). S-VMs provide network services such as DHCP, DNS, file server, routing etc., and T-VMs are used by the instructors to simulate real-life scenarios. For example, instructors may set up T-VMs to simulate numerous operating system vulnerabilities and ask students to detect them using security tools available in C-VMs. For security precautions, all VMs have non-persistent disks (i.e., all configuration changes during a lab session are automatically deleted when students log-off), and VMs are confined in the virtual environment and independent from the campus network.

The CVCLAB also include sandboxes. A sandbox is a group of VMs dedicated to the exclusive use of a student team (e.g., a senior design project team) for inquiry based learning or undergraduate research activities over extended time periods. Sandbox VMs have persistent storage; therefore students can build on their work throughout a semester.

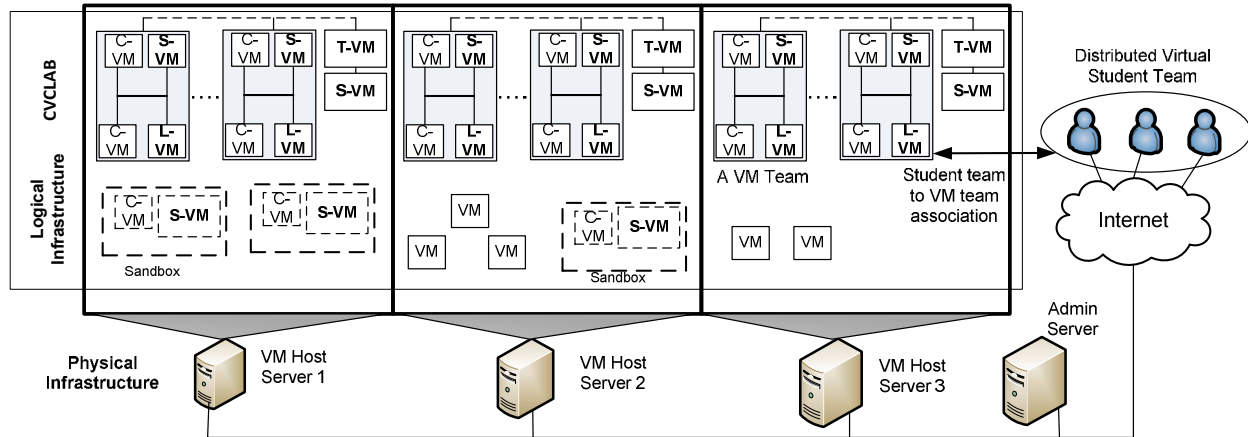


Figure 1. Current physical and logical infrastructure of CVCLAB and NPOL. (C-VM: Windows XP Client; S-VM: Windows-based server; L-VM: Linux based VM; T-VM: test VMs)

RESEARCH OBJECTIVES AND METHODOLOGY

There is significant evidence in the literature that VCLs enhance student learning (Kneale et al., 2004; Bullers et al., 2006; Damiani et al., 2006; Anisetti et al., 2007; Powell et al., 2007). However, research has not focused on collaborative learning in VCLs. This paper argues that VCLs should be designed considering collaborative learning strategies to enhance student learning further. The overall research hypothesis is: “collaborative learning has a positive impact on student learning in VCLs.” To investigate the effect of collaborative work on student learning in VCLs, we conducted an experiment in the CVCLAB where two groups of students performed two versions, group work (GW) and individual work (IW), of the same activity. In both GW and IW treatments of an activity, students followed the exact same steps and were introduced to the exact same content, but students in the GW treatment had to work together for a successful completion of the activity. Then, we compared student learning experiences and outcomes using a research model based on Kolb’s Experiential Learning Theory (ELT) (Kolb, 1984). In addition, a structural equation model was used to investigate the differences between the treatment groups.

Research Model

We developed our research model based on the ELT to analyze the differences, if any exist, between the learning outcomes and perceptions of the students in the IW and GW treatments as a result of engaging in an activity in the CVCLAB. The ELT was selected as the research framework because it aims to explain how experience is transformed into learning, particularly in adult learning processes involving active experimentation. Figure 2 summarizes our research model. The research model has eight constructs mapped against the stages of Kolb’s Experiential Learning Cycle (Kolb, 1984). We were particularly interested in understanding the interplay between group work and the constructs in the research model. We used a survey instrument to measure subjective constructs Difficulty, Engagement, Usefulness, Reflection, Interaction, Competency and Exploration, and the Comprehension construct was measured by a post-test. The survey questions and their related constructs are given in Table 1. The survey had three sections. The first section included two questions to measure overall student satisfaction about the CVCLAB and the activity. The second part had several questions to measure the constructs as given in Table 1. The constructs in Table 1 were operationalized with a seven-point Likert scale, ranging from “Strongly Agree” (1) and “Strongly Disagree” (7). We evaluated internal consistency and convergent validity of the constructs by examining Cronbach’s alpha and eliminated preliminary survey items if the construct reliability values were less than 0.707 (Nunnally and Bernstein, 1994). Table 1 also provides Cronbach’s alpha values for the constructs used in the final model. In addition, the correlations between the constructs and the survey questions are also given in the table. The correlations showed that the survey items indented to measure the same construct had higher factor loadings on that construct than the others, suggesting the convergent validity of the constructs. Finally, the third section had two open-ended questions about what students liked and disliked the most about the activity. In addition to this survey instrument, students were expected to complete a post-test and return a lab report answering the review questions of the activity. The post-test included several questions to measure students’ understanding of abstract concepts in the activity as well as to measure how well students can apply the new concepts learned in the activity to more general problems. Therefore, the result of the post-test was used to measure the Comprehension construct. Note that our research model was primarily designed to investigate the impact of collaborative learning on student learning outcomes. The research model was used for exploratory factor analysis. Therefore, the constructs in a group, which is defined by dashed rectangles in Figure 2, are fully connected to all constructs in

another construct group if there is an arrow between the two construct groups. The research model assumes that perceived learning of students is affected by their perceived experience and perceived level of critical reflection. In addition, the Comprehension construct is also a predictor of the constructs Competency and Exploration.

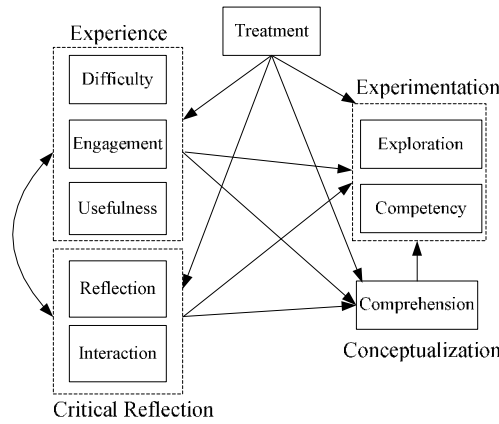


Figure 2. The research model

Constructs (Cronbach's alpha) and Related Survey Questions	EX1	EX2	EX3	CR1	CR2	EP1	EP2
EX1: Difficulty (0.818)	1.00	0.73	0.64	0.62	0.75	0.58	0.76
The activity was challenging.	0.91	0.66	0.55	0.64	0.64	0.68	0.72
The activity review questions were difficult and time consuming.	0.90	0.65	0.61	0.48	0.72	0.36	0.66
EX2: Usefulness (0.848)	0.73	1.00	0.77	0.66	0.77	0.53	0.66
I would like to do more of similar activities, even if it is time consuming.	0.65	0.86	0.65	0.69	0.64	0.45	0.65
The time I spent for the activity was worthwhile.	0.63	0.87	0.68	0.60	0.66	0.52	0.57
I found the activity useful to me.	0.63	0.91	0.70	0.44	0.74	0.44	0.53
EX3: Engagement (0.877)	0.64	0.77	1.00	0.53	0.81	0.57	0.57
The activity was very engaging.	0.53	0.69	0.94	0.37	0.68	0.48	0.44
The activity was pleasurable.	0.67	0.74	0.93	0.63	0.83	0.59	0.62
CR1: Interaction (.825)	0.62	0.66	0.53	1.00	0.61	0.57	0.76
I learned new concepts/skills by interacting with other students.	0.45	0.55	0.41	0.81	0.42	0.50	0.62
Interacting with other students helped me complete the activity.	0.67	0.64	0.51	0.86	0.65	0.46	0.72
The activity encouraged me to ask questions to others.	0.47	0.50	0.44	0.88	0.50	0.50	0.61
CR2: Reflection (0.852)	0.75	0.77	0.81	0.61	1.00	0.60	0.69
Review questions were helpful to reinforce what was performed in the activity.	0.72	0.69	0.78	0.55	0.89	0.54	0.61
Provided opportunities to reflect back what was learned in the activity.	0.61	0.76	0.76	0.55	0.88	0.47	0.64
Promoted helpful discussions about what was performed in the activity.	0.61	0.56	0.57	0.48	0.82	0.53	0.56
EP1: Competency (0.915)	0.58	0.53	0.57	0.57	0.60	1.00	0.57
The activity helped me improved my problem solving skills.	0.63	0.57	0.62	0.68	0.66	0.92	0.62
The activity improved my technical skills and competency in the subject area.	0.44	0.40	0.45	0.45	0.45	0.93	0.42
I felt a sense of accomplishment after completing the activity.	0.54	0.51	0.52	0.46	0.55	0.92	0.55
EP2: Exploration (0.893)	0.76	0.66	0.57	0.76	0.69	0.57	1.00
I will be able to use what I learned in the activity in other courses or the future.	0.59	0.55	0.38	0.68	0.56	0.38	0.87
The activity increased my curiosity and interest in this area.	0.71	0.62	0.56	0.64	0.69	0.51	0.91
The activity encouraged me to learn more about this topic.	0.73	0.59	0.57	0.71	0.61	0.62	0.89

Table 1. Survey questions for each construct and correlations between them

Experimental Setup and Data Collection

To test our main research hypothesis, we conducted experiments and collect data using two hands-on activities, a computer networking activity (NT) and a database administration activity (DB). Both activities were performed in the CVCLAB during regular class time. We created two versions of the activities, Group Work (GW) and Individual Work (IW). As explained below, the GW version of an activity was designed in a way that two students, A and B, had to depend on one another to complete the activity. Although the students in the IW treatment did not have to work together, they were allowed to interact with one another without any restriction.

The activity NT was an introductory-level networking activity where students were instructed to configure the TCP/IP settings of two VMs according to the different scenarios, and then to test connectivity between them for each scenario. During the activity, students were expected to figure out why their VMs could communicate in some settings and why they could not communicate in others. In the GW treatment, students A and B were assigned to a team of two networked VMs, each administrating a VM. Therefore, students A and B had to coordinate with one another in order to complete the activity successfully. In the IW treatment, each student was assigned to two VMs where they could configure and test the instructed configurations individually. The instructions and review questions of both treatment conditions were identical.

The activity DB involved installation and administration of a database server. In this activity, students were expected to install a database server, configure server settings, create databases and users, and test various security settings. In the IW treatment, students performed all tasks and tested them on a single VM individually. In the GW treatments, students A and B were assigned to a team of two networked VMs, and they performed the exact same steps as in the IW treatment, but they were instructed to test one another's configurations remotely. For example, when student A completed the configuration of a database, student B tested the configuration by remotely accessing Student A's database server.

The participants of the experiments were students in introductory level computer networking and database management classes at Penn State Berks. Both of the target classes had two sections. A randomly selected section of a class was exposed to the GW treatment of an activity and the other section was exposed to the IW treatment. Activities NT and DB were parts of the regular course content in their respective courses. Therefore, all students were required to complete the activities. After completing the activities, students were asked to complete the survey and take a short quiz. Students were asked for a signed-consent to participate the experiment, and if they did not give consent, they were not expected to complete the survey and their test scores were excluded in the study. Table 2 summarizes the number participants in each treatment condition, partitioned by the activity.

	Treatment IW	Treatment GW
Activity NT	13	16
Activity DB	22	24
Total	35	40

Table 2. The distribution of the participants over the treatments

ANALYSIS AND RESULTS

Construct Mean Comparisons

To investigate the differences between the construct means and overall rating of the CVCLAB and the activities across the treatment conditions, we used a t-test. The construct means and the overall ratings of the CVCLAB and the activities are summarized in Table 3. The t-test showed that students' perceptions of the constructs Difficulty, Engagement, Usefulness, Interactions, and Reflection were not different across the treatment conditions for both activities. Interestingly, students in the IW group also indicated that the activity encouraged them to interact with other students and ask questions (Interaction). Both treatment groups indicated that the activity provided ample opportunities to reflect back on tasks (Reflection). These results can be interpreted that the students in both treatments appraised the hands-on learning experience in the CVCLAB as equally valuable. This observation was also supported by the overall rating of the CVCLAB and the activities across the treatments. However, two treatment groups were significantly different in the Competency construct, which measured perceived gained skills and knowledge. In both activities, the students in the GW treatment felt more confident about their learning and skills gained than the students in the IW treatment, and the difference was statistically significant as seen in the Table 3. Supporting this observation for Activity DB, the students in the GW treatment performed significantly better in the post-test (Comprehension) than the students in the IW treatment. In summary, the students in the GW treatment believed that they were achieving more although their overall learning experience about the activities and the CVCLAB were statistically not different.

Construct	Activity DB			Activity NT		
	IW	GW	<i>p</i> -value	IW	GW	<i>p</i> -value
Difficulty	2.90	2.91	0.95	4.29	3.50	0.07
Engagement	2.30	2.52	0.54	3.50	3.00	0.29
Usefulness	2.14	2.48	0.19	3.14	2.79	0.46
Interaction	2.18	2.36	0.46	3.18	3.00	0.69
Reflection	2.55	2.33	0.45	3.67	3.09	0.23
Comprehension	76.91	90.47	0.00	35.00	42.50	0.46
Competency	2.74	1.79	0.02	4.67	2.85	0.03
Exploration	2.20	2.25	0.88	3.39	3.13	0.61
Overall Activity Rating	2.85	2.91	0.80	4.58	3.75	0.08
Overall CVCLAB Rating	2.85	2.91	0.85	4.00	3.25	0.15

Table 3. Comparison of the construct means across the treatments for the two activities.

Analysis with Structural Equation Modeling

Our analysis based on the construct means showed that the group work in the CVCLAB had a positive impact on student learning in terms of both a subjective measure (Competency) and an objective measure (Comprehension). However, this assertion could not be explained by the t-test results. We used structural equation modeling to better understand why the students in the GW treatment felt stronger about their learning. A structural model was developed in AMOS 20 based on the research model given in Figure 2. We performed a multi-group analysis and evaluated the structural model fit for both GW and IW treatments. An unconstrained model was used because our objective was to investigate the differences in the structural model regression coefficients for the GW and IW treatments. We did not partition the data set in terms of the activity. The final fitted model had $\chi^2/d.f.$ value of 4.2 and the comparative fit index (CFI) of 0.981, both indicating a good fit.

Table 4 summarizes the fitted regression weights of the structural model for the relationships which turned out to be significant with *p*-values < 0.05. These results reveal several interesting points about the impact of collaborative work on student learning outcomes. Firstly in the GW treatment, the Interaction construct was a significant factor for the Comprehension, Competency, and Exploration constructs which were used to measure student learning in this study. In other words, the students who tended to perceive higher interaction also felt stronger about their perceived learning. They were more likely to indicate that their competency increased as a result of the activity (Competency), and they were more encouraged to apply their gained skills to new problems (Exploration). Furthermore, they were more likely to perform better in the post-test (note that the negative coefficient indicates the higher test scores for a lower rating of the construct).

In the IW treatment, the Interaction construct had a positive impact on the Exploration construct, but it did not appear as a significant factor for other constructs measuring student learning. The students in IW treatment did not perceive that their competency was improved as much as the students in the GW treatment did. For this group, a major factor was the perceived difficulty of the activity. When we analyzed student responses to the open-ended questions, we realized that many of the students in IW treatment made negative comments regarding the tediousness and the time it took them to complete the activity. On the contrary, a few students in the GW treatment 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 group work aspect of the experience. Several students in the GW treatment also indicated that they felt accomplished by other students' testing their configurations from remote computers. In other words, the students in the GW treatment considered the activities to be more relevant to the real-world. This observation could explain why students in the GW treatment were more likely to associate collaboration with their increased competency and learning. This assertion was also supported by the high correlation between the Interaction and Comprehension constructs observed in the GW treatment.

GW Treatment			IW Treatment		
Structural Model Connection	Coefficient	p-value	Structural Model Connection	Coefficient	p-value
Exploration<- Interaction	0.438	0.007	Exploration<- Interaction	0.584	0.000
Competency<- Interaction	0.424	0.009	Comprehension<- Difficulty	-15.908	0.008
Exploration<- Difficulty	0.428	0.014	Comprehension<- Usefulness	14.758	0.033
Comprehension<- Interaction	-14.92	0.020	Exploration<- Difficulty	0.379	0.045
Competency<- Comprehension	-0.007	0.056	Exploration<- Reflection	0.383	0.061

Table 4. Significant regression coefficients in the exploratory factor analysis.

CONCLUSIONS

This paper hypothesized that student learning can be improved by incorporating collaborative learning strategies in VCLs. This conclusion has several implications in the design of virtual computer labs. The VCL should not only provide students with an environment in which they can test critical skills in isolation but also opportunities to collaborate and interact with other students. Our experiments have shown that students engaged in collaborative learning felt more competent about their learning and more confident about applying their skills to other areas. After this limited set of experiments, the final conclusion is that group work at least creates more student satisfaction which hopefully will lead to greater overall learning through a succession of laboratories. In other words, a single exposure to the use of the virtual computer laboratory sets the stage for the future and possibly more successful overall learning by individual students. This encourages the development and use of exercises that students will more readily welcome and participate in if they are allowed to work in groups.

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