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ABSTRACT

In information security education, learning experiences that involve hands-on experimentation are extremely important. However, information security topics are challenging to teach in traditional computer laboratories mainly due to restrictive information technology policies. In the literature, virtual computer laboratories have been proposed to address the challenges of providing students with hands-on learning experiences in information security. While the literature mainly focuses on technical aspects of virtual computer laboratories and related hands-on activities, pedagogical aspects of hands-on activities are overlooked. Our experiences with a virtual computer laboratory have shown that hands-on activities which are designed based on a prescriptive, step-by-step approach do not always achieve the expected learning outcomes. In this paper, we propose Kolb's Experiential Learning Cycle as a framework to design hands-on activities in virtual computer laboratories, and we argue that hands-on activities designed based on this framework enhance student learning outcomes. We illustrate how the stages of Kolb's model can be incorporated into hands-on activities and present results from two empirical studies to test the effectiveness of the proposed framework. The empirical findings in the first study suggest that hands-on activities designed based on the proposed framework are more likely to increase student interest and competency compared to step-by-step hands-on activities. In the second study, the collected data is analyzed using structural equation modeling to determine the relationships among the factors affecting student learning outcomes as a result of hands-on activities. The results of the second study show that student-to-student interaction is an important factor determining student learning experiences.

1. Introduction

Among factors that inhibit student interest in the information security fields, students consistently cite inadequate laboratories and a lack of exciting and meaningful hands-on activities (Logsdon, 2006). Teaching information security concepts requires complex hands-on activities that are both expensive and time consuming to run. This combined with the fact that colleges limit student privileges on campus computers makes it very difficult to incorporate hands-on learning into information security education. Because of these restrictions, many colleges use Virtual Computer Laboratories (VCLs) to reduce cost and set-up time. Because virtual computers have no access to campus networks, students can also be given accounts with unlimited privileges. In the literature, several examples of VCLs are reported in the context of information security (Anisetti et al., 2007; Armstrong, Jayaratna, & Dodge, 2007; Damiani, Frati, & Rebeccani, 2006; Hu & Wang, 2008; Kneale, De Horta, & Box, 2004; Nabhen & Maziero, 2006; Powell et al., 2007; Rosenberg & Hoffman, 2006; Willems & Meinel, 2009).

VCLs depend on virtualization technologies. A virtual computer is an emulation of an operating system and behaves exactly like a real computer. Using this technology, a single computer may host multiple virtual computers with different operating systems which are isolated from one another and share the resources of the host computer. On virtual computers, students can practice advanced skills and perform complex tasks which are not usually allowed on campus computers and networks. There are two major types of VCLs: local and remote. In a local VCL, the disk images of virtual computers are directly copied to the classroom computers so that students can use a

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virtualization software package to run these images. Local VCLs require minimum investment and are easy to deploy. However, they are constrained by location and are difficult to maintain. Furthermore, classroom computers may not have resources to run multiple virtual computers. In remote VCLs, virtual computer images reside on remote servers that are coupled together to create a resource pool. Students must connect to remote VCLs using either a web interface or special client software. Remote VCLs are easier to manage since accounts and virtual computer images are centrally managed. Remote VCLs also have the resources to support concurrent operations of many virtual computers. Furthermore, students can access remote VCLs at any time and from anywhere. The main disadvantage of remote VCLs is that a reliable network connection is required.

At Penn State Berks, a remote VCL, called the Collaborative Virtual Computer Laboratory (CVCLAB), has been effectively used in several information security courses. Based on the experiences of the CVCLAB, this paper presents Kolb's Experiential Learning Cycle as a framework to design hands-on activities for VCLs. The paper argues that VCLs should be supported by sound pedagogical approaches to achieve complete student learning. The motivation of the paper stems from our observations that some CVCLAB hands-on activities have failed to foster student learning and interest in the information security fields. Such CVCLAB hands-on activities as well as the majority of published and online information security laboratories follow a cookbook approach such that they only provide students with step-by-step directions followed by minimal discussion questions. Our preliminary data indicated that students demanded more challenging activities and more active experimentation of the topics covered by hands-on activities. Furthermore, first year students usually found it challenging to follow long prescriptive instructions, particularly if they performed activities individually (Wagner, Myers, & Konak, 2013). Some student comments included:

"it doesnt really make me learn…it just makes me want to get it done…i dont really get anything from it,"

"Didn't understand all of it."

"It felt pointless"

One of the objectives of the CVCLAB is to increase students' interest in information security fields through exciting hands-on activities. Because the information security field is changing rapidly as new threats emerge constantly, it is important for students to grow as autonomous learners. Information security is also a very broad area, and it is challenging to incorporate long hands-on activities demonstrating advanced topics during the class time. We have provided students with open access so that they could independently use some of the advanced activities to develop their skills. However, some of CVCLAB activities did not motivate students as much as we anticipated. In addition, we have realized that some students go through the activity instructions without fully grasping the underlying concepts. The same concern is also raised by others in engineering laboratories (Abdulwahed & Nagy, 2009, 2011; David, Wyrick, & Hilsen, 2002).

The effectiveness of hands-on laboratories are discussed particularly in science education as reviewed in the two survey papers by Hofstein and Lunetta (Hofstein & Lunetta, 1982, 2004). Although the science education community agrees on the benefits and the distinctive role of hands-on experiences in science education, the relationships between laboratory experiences and student learning are not well understood (Hofstein & Mamlok-Naaman, 2007). Several papers address the factors reducing effectiveness of hands-on laboratory sessions. For example, Hodson (Hodson, 1993) states that hands-on experience in science education can be unproductive and confusing if the learning objectives are not aligned with what students are actually doing in the laboratory. Gunstone (Gunstone, 1991) notes that students are usually so involved in technical details of a laboratory session that they may have limited time to engage in metacognitive activities such as reflecting and interpreting the central ideas of the laboratory. Gardner and Gauld (Gardner & Gauld, 1990) argue that participating in hands-on activities does not itself ensure students' learning of scientific principles. Based on a study conducted at five US universities, Russell and Weaver (Russell & Weaver, 2011) report that students do not improve their understanding of the scientific process in the traditional laboratory curriculum where they follow tasks described in a laboratory manual and verify experiments results. They recommend research-based laboratories which emphasize active experimentation. According to Gunstone and Champagne (Gunstone & Champagne, 1990), in order to achieve comprehensive learning, hands-on laboratory sessions should encourage students to ask questions, reflect back on their learning, develop new hypotheses, and design experiments to test them. Several researchers discuss the impact of hands-on activities on students' interest and motivation. Holstermann et al. (Holstermann, Grube, & Bögeholz, 2010) report a significant positive relationship between the quality of hands-on activities and the student interest in biology topics. Guthrie et al. (Guthrie et al., 2006) indicate that stimulating activities are more likely to improve students' reading motivation and comprehension.

As discussed above, the research on hands-on learning mainly addresses problems in science and engineering laboratory sessions and makes recommendations to improve their effectiveness. Although the focus of this paper is on relatively short, hands-on activities in VCLs, the factors that reduce the effectiveness of laboratory sessions, such as lack of metacognitive components, can also be generalized to explain poor learning outcomes of some CVCLAB hands-on activities. Despite the important role of hands-on learning in information security education, the related literature mainly addresses the technical aspects of hands-on activities but not their pedagogical effectiveness. Therefore, most hands-on activities for information security are usually organized as step-by-step instructions to demonstrate various technical skills. In this paper, it is hypothesized that if hands-on activities for VCLs are designed based on Kolb's Experiential Learning Cycle (ELC), more comprehensive student learning can be achieved. In this paper, we first discuss possible strategies to incorporate the stages of Kolb's ELC into hands-on activities using an illustrative example from information security. Secondly, we report results from an empirical study that compared student learning outcomes and experiences to test the main research hypothesis of the paper, i.e., if a hands-on activity includes all stages of Kolb's ELC, students can achieve a higher level of learning. Thirdly, we investigate the relationships among the factors that impact student learning outcomes and experiences using a confirmatory factor analysis. The results of the confirmatory factor analysis support our assertion that group work is an effective strategy to promote meaningful reflection and conceptualization while students perform hands-on activities in a virtual computer laboratory.

The paper is organized as follows: Section 2 briefly introduces Kolb's ELC, summarizes relevant previous research, and demonstrates an example for the proposed framework. Section 3 presents the experimental design and data collection. Sections 4 and 5 summarize the statistical analysis and results. Finally, Section 6 discusses the findings and shortcomings of the research.

2. Kolb's Experiential Learning Cycle and its application to the CVCLAB activities

2.1. Kolb's Experiential Learning Cycle for hands-on activities

According to Kolb (Kolb, 1984), knowledge results from the interaction between theory and experience: "Learning is the process whereby knowledge is created through the transformation of experience" (Dunlap, Dobrovolny, & Young, 2008). This direct experiential encounter with a learning event requires active engagement of the student as opposed to passive engagement commonly associated with teacher-directed instruction (Clark, Threeton, & Ewing, 2010). In Kolb's ELC (Kolb, 1984), learning takes place in four stages as shown in Fig. 1.

Kolb suggests that for a complete learning experience, students must go through all four stages of the learning cycle as shown in Fig. 1. Not only do these four stages allow students to comprehensively investigate a topic through different activities and views, they also allow for the accommodation of different learning styles. According to Kolb, these learning styles are a product of two pairs of variables, doing vs. watching, and thinking vs. feeling. Each stage of Kolb's ELC can be mapped to these variables (Fig. 1). Each individual has a preferred learning style, but everyone responds to, and needs the stimulus of, all types of learning styles to one extent or another (Smith & Kolb, 1986). Kolb's ELC provides the opportunity to complete activities for each learning style, with one particular stage perhaps matching a person's learning style preferences (McLeod, 2010).

Some of the criticisms of the Kolb model are that: learning does not typically take place in sequential, ordered steps, but rather that the steps overlap (Forrest, 2004); or that it does not integrate social, historical, and cultural aspects of learning (Beard & Wilson, 2006). However, none of those criticisms are strong enough to preclude the benefits that the model provides as applied to designing hands-on activities in information security. Furthermore, as explained in the following section, Kolb's ELC has not been applied in a sequential manner to structure hands-on activities in the approach proposed in this paper.

In the literature, Kolb's ELC is frequently used to analyze differences in the learning styles of various student groups (Kulturel-Konak, D'Allegro, & Dickinson, 2011). Applications of Kolb's ELC to improve student learning are usually discussed in the context of field studies or training projects that require several weeks to complete (Clark et al., 2010; Raschick, Maypole, & Day, 1998). Only limited numbers of authors suggest the use of Kolb's ELC to enhance classroom activities. Svinicki and Dixon (1987) recommend Kolb's ELC as a framework for designing classroom activities, and they also provide examples of instructional activities that could support different stages of the ELC in a broad range of fields. Stice (1987) also list examples of active learning strategies that incorporate all four stages of Kolb's ELC to improve the learning process for chemical engineering students. Concerned with the problem of poor learning outcomes from engineering laboratories, Abdulwahed and Nagy (2009) use Kolb's ELC to apply a combination of in-class remote, virtual pre-lab, and hands-on laboratory sessions. Their activities focus on the prehension, or knowledge-grasping dimension, of Kolb's ELC, in which knowledge can be grasped through concrete experience, abstract conceptualization, or a combination of the two. Abdulwahed and Nagy (2009) claim that the poor knowledge retention from engineering laboratory sessions can be explained by the inefficient activation of the prehension dimension. It is important for this dimension to be covered, that is for information to be grasped or depicted, before the next phase of transformation (i.e., constructing new knowledge through experimentation) can occur. In their study, Abdulwahed and Nagy (2009) report that including a virtual pre-lab session focusing on the prehension dimension of the Kolb model improves student learning outcomes. In a recent study, Abdulwahed and Nagy (2011) provide additional empirical evidence for the benefits of designing engineering laboratory activities based on Kolb's ELC. David et al. (2002) also report that providing balanced learning experiences, which included all four stages of Kolb's ELC, to industrial engineering students had led to deeper learning and longer retention of information.

Kolb's ELC has similarities with other active learning approaches (see (Conole, Dyke, Oliver, & Seale, 2004) for a comparison of active learning approaches). The main difference between Kolb's ELC and the other active learning approaches is that Kolb's ELC considers experience as the foundation of learning. This difference is also the main justification for using it as a framework to design hands-on activities in this paper. Among the active learning approaches, Lab-centric Instruction (Titterton, Lewis, & Clancy, 2010) and Process Oriented Guided Inquiry Learning (POGIL) (Moog & Spencer, 2008) are closely related to Kolb's ELC. In both of these approaches, a group of students are expected to work on scripted activities designed to encourage them to construct their own knowledge rather than to attain it through instructor led lectures. To achieve this goal, lab-centric instruction depends on structured and unstructured lab sessions supported by quizzes, discussion and reflection sessions, projects, and self-assessment. POGIL uses inquiry activities, which are usually designed based on the process of research. POGIL activities are designed around three phases: (*i*) exploration phase where students analyze the available data and propose hypotheses, (*ii*) concept invention phase where students create new concepts, and (*iii*) application phase where students apply

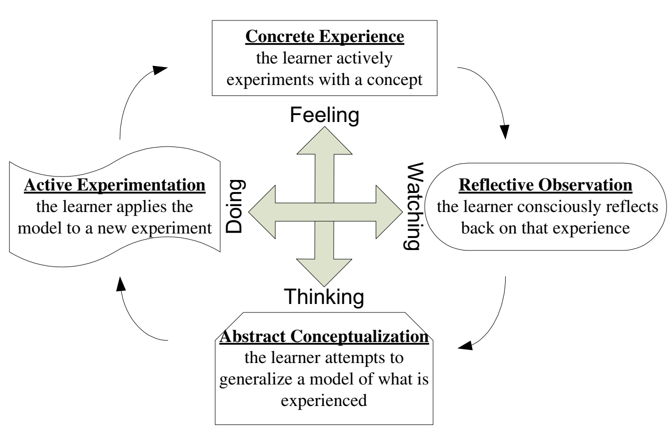

Fig. 1. Four stages of the Kolb's Experiential Learning Cycle.

the concepts to new problems. POGIL has been successfully used in science education to design class activities, and it has been also applied in the context of information sciences (Kussmaul, 2011). However, further research is needed to refine POGIL for skill-based activities which are frequently used in introductory level information security classes. The proposed framework in this paper can be used to enhance student learning outcomes in such activities whose objective is to improve students' technical abilities. The proposed framework can also be used for individual or group work, whereas lab-centric instruction and POGIL have been designed for group work only.

2.2. *Using Kolb's Experiential Learning Cycle to improve the CVCLAB activities*

To support learning in the CVCLAB, we created a library of hands-on activities and collected data to ascertain their effectiveness in increasing students' interest and learning outcomes. Although student feedback was overwhelmingly positive, our classroom observations, as well as some isolated student feedback, indicated that some activities failed to achieve their expected learning outcomes. We realized that at times students executed the activity instructions without always fully grasping the underlying concepts. As Abdulwahed and Nagy (Abdulwahed & Nagy, 2009) note in regards to engineering laboratory activities, hands-on activity sessions can turn into an algorithmic following of the laboratory manual instead of an active construction of meaningful knowledge out of an activity. For the CVCLAB, the activities were initially organized as step-by-step instructions that guided students through challenging tasks, and in doing so perhaps functioned more as how-to guides for technical skills. In terms of Kolb's ELC, these activities were initially based on stage (*i*)-Concrete Experience. As an example, for one activity, students learned about sharing files and folders between computers. Initially, students followed step-by-step instructions to create a folder and configure the file sharing parameters so that their partner could connect to the folder. Next, their partners accessed the shared folder. Some learning can take place with the steps in stage (*i*), as students actively experience sharing a folder. However, it is questionable whether they fully understand what they have done or whether they are able to extend what they have learned to different situations.

By constructing learning sequences that lead students through the full cycle of Kolb's model, instructors should be able to foster more comprehensive learning than can be gained from a single perspective (Svinicki & Dixon, 1987). Because of this potential of Kolb's ELC, we decided to apply the Kolb model to the hands-on activities of the CVCLAB. A set of pilot activities were enhanced by including all stages of Kolb's ELC. One of the challenges in this process was to incorporate meaningful tasks that support all four stages of Kolb's ELC into 30–90 min activities. We utilized collaborative learning and designed our activities as group work in particular to achieve the reflective observation and abstract conceptualization stages. Additionally, in our choice of activities, we considered learning activities as described by Svinicki and Dixon (1987) in their modification of Kolb's ELC for classroom activities. Fig. 2 summarizes an example that illustrates how all stages of Kolb's ELC can be incorporated into a hand-on activity for asymmetric encryption. Next, we summarize our approach using the example in Fig. 2.

2.2.1. *Concrete experience*

Concrete experience means direct practical experience by performing a new task. In our activities, concrete experience corresponds to a set of step-by-step instructions demonstrating a new subject or concept. Originally, all activities in the CVCLAB were designed based on this approach. In the illustrative example, students follow step-by-step instructions to learn about asymmetric encryption. The activity instructions are written for novice users and are very descriptive so that students can complete the activity even though they have no previous experience in cryptography (note that each summarized step in Fig. 2 involves several detailed instructions in the actual activity).

2.2.2. *Reflective observation*

Reflective observation includes activities such as discussion and reflective questions that require students to reflect on their hands-on experiences. Our strategy is to divide an activity into smaller sections and include reflective activities for each section. This strategy also helps the instructor phase the activity across multiple groups. In the illustrative example, after completing the first section, students are asked to analyze the components of their digital certificate and discuss questions such as why they have to export their private keys. Reflective observation activities should foster student-to-student interaction in order to achieve a higher level of reflection. Group work is a particularly effective strategy to promote meaningful reflection in short classroom activities. For example, instead of asking students to analyze their own digital certificate individually, asking them to compare their certificates with their teammates and list similarities and differences may lead to a higher level of reflection.

2.2.3. *Abstract conceptualization*

Through abstract conceptualization, learners are expected to create a theoretical model and a generalization of what was performed. Generally, this stage could be difficult to achieve in short hands-on activities. Class or peer-to-peer discussions are helpful to connect the learning experience to the overall theory. At this stage, instructor intervention is important. In the illustrative example, students are asked to create a diagram of asymmetric encryption based on the steps that they perform. After this question, a class discussion led by the instructor may help students solidify a mental picture of asymmetric encryption. Another useful strategy is the utilization of generalization questions. For example, in the illustrative example students are asked to compare what they performed in an earlier activity about symmetric encryption and to list the advantages and disadvantages of asymmetric algorithms. Such generalization questions can be combined with the next stage of active experimentation.

2.2.4. *Active experimentation*

At this stage, the learner is ready to plan and try out another concrete experience. We use two strategies in this stage. The first strategy is to give students a new task, albeit similar to what was performed in the Concrete Experience stage, but without providing step-by-step instructions. For example, students are asked to send encrypted messages to students other than their teammates. By this time, they should be able to achieve this task without detailed instructions. The second strategy is to combine a few related topics in the same activity such that the later topics build on the former ones.

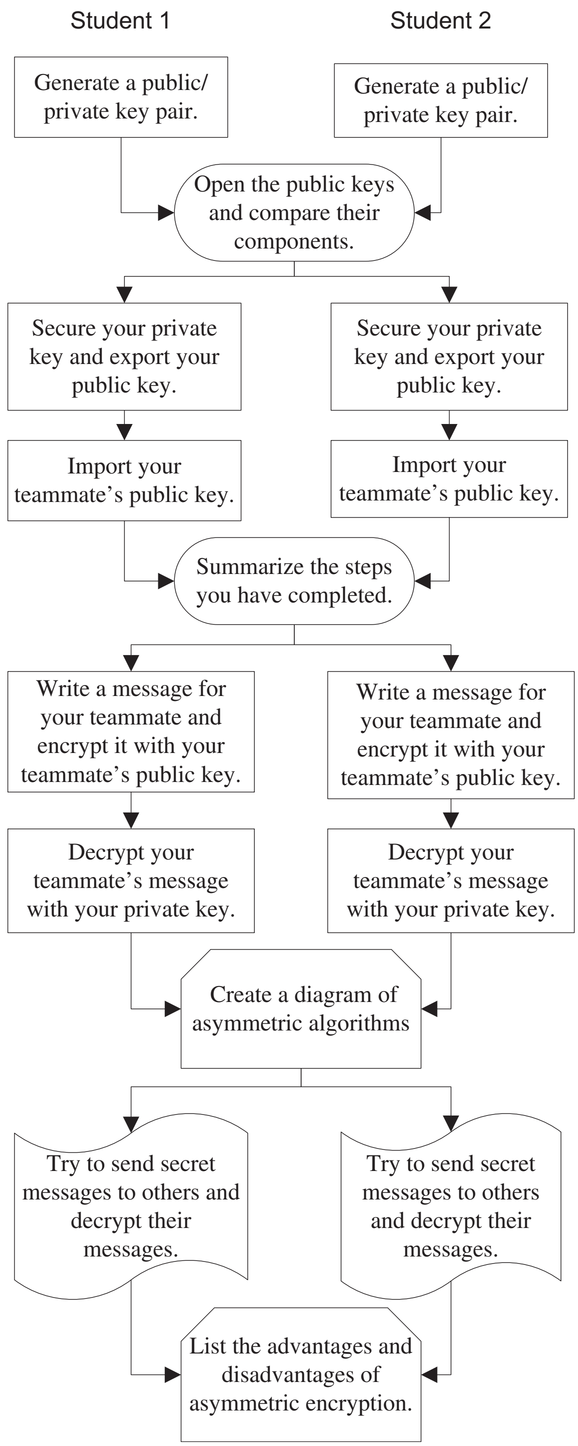

Fig. 2. Asymmetric encryption algorithm hand-on activity designed based Kolb's Experiential Learning Cycle (Refer to Fig. 1 for the meaning of the symbols).

3. Experimental design and data collection

3.1. Participants and data collection

To evaluate the impact of hands-on activities designed based on Kolb's ELC on student learning, data was collected from five hands-on activities in several first and second year classes in the Information Sciences and Technology and Security and Risk Analysis programs at Penn State Berks. The activities were performed in the CVCLAB during regular class time, and all students were expected to participate. After completing an activity, students were asked to complete a short questionnaire evaluating the activity as well as providing feedback about their learning experiences. The completion of the questionnaire was voluntary with an informed consent (about 80% of the participants completed the questionnaire). The questionnaire included two groups of statements operationalized with a five-point Likert scale, ranging from "Strongly Agree" (1) to "Strongly Disagree" (5). The first group included statements about students' experiences during the activity such as their perceived challenge, their engagement, and the level of interactions with other students. The second group intended to measure students' perceptions about how much their competency and interest in the subject area were improved as a result of the activity. In addition, students were asked to provide feedback about what they liked most and least about the activity. Collected responses were first visually screened and cases with many unanswered questions were eliminated. Then, cases for each activity were analyzed by the SPSS anomaly detection procedure, and unusual cases were removed. Finally, a preliminary factor analysis was performed, and the cases which turned out to be outliers with respect to all extracted factors were considered as outliers. As a result of this data cleaning process, 24 cases were not considered in the final statistical analysis. The final number of cases used in the statistical analysis is given in Table 1.

We conducted two field studies. The objective of the first study was to test the main research hypothesis of the paper, i.e., if a hands-on activity includes all stages of Kolb's ELC, it will enable students to achieve a higher level of learning. To test this hypothesis, we designed a stripped-down version (control) of a basic networking activity which was originally structured according to Kolb's model (treatment). Fig. 3 illustrates the main steps of this activity and the differences between the control and treatment versions. The control version represents a step-by-step "cookbook" approach where students follow a sequence of directions without much reflection and conceptualization. In both versions, students are expected to work in groups of two to complete tasks such as testing the connection between their computers and sharing folders. In the treatment version, however, students are guided through additional activities to reflect upon their learning and to interact with their partners as seen in Fig. 3. For example, students are asked to experiment with the "ipconfig" command to investigate its functions in both groups, but in the treatment group, students are also expected to discuss three of these functions with their partners (reflective observation). In other words, student-to-student interactions are used as the main strategy to achieve reflective observation as discussed in Section 2.2. Furthermore, students are faced with new problems (active experimentation) in the treatment version. For example, students are asked to change the permissions of their shared folder without providing them with the step-by-step instructions to do so. Finally, the treatment version includes review questions to generalize the concepts learned throughout the activity (conceptualization). This activity was performed in an introductory information technology class with four sections. Two of the sections were randomly selected as the control group and the other two sections as the treatment group. A total of 94 responses, 44 of the treatment and 50 of the control groups, were collected. This data set is referred to as Data Set A in the following sections of the paper. Section 4.1 summarizes the results of this controlled field experiment.

The second study involved four additional activities listed in Table 1, all of which are based on Kolb's ELC. The objective of this study was to better understand the interplay among the factors that affect student learning experiences and outcomes. As stated earlier, another objective of this paper is to investigate how hands-on activities designed by incorporating steps that support different stages of Kolb's ELC impact learning outcomes. Section 4.2 introduces the research model and the outcomes of a confirmatory factor analysis based on the research model. The second study included 119 cases (44 treatment cases of the basic computer networking activity in addition to the cases of other activities), and is referred to as Data Set B in the subsequent sections of the paper.

3.2. Factor analysis

An exploratory factor analysis was performed to validate the questionnaire items by measuring the extent to which the individual items loaded onto their expected latent constructs. This analysis further served as a means to determine factors affecting students' learning experiences and outcomes when they were performing hands-on activities in the CVCLAB. First, a preliminary exploratory factor analysis was run for the entire data set to investigate unreliable questionnaire items and cases. The preliminary factor analysis was used to investigate whether the extracted factors would match with the anticipated latent variables. The factorization was converged after determining five factors. After verifying the factors, two factor analyses were run independently: for Data Set A to compare the control and treatment groups, and for Data Set B to build a structural equation model. In both the preliminary and final factor analyses, the Maximum Likelihood extraction method with the Promax with Kaiser Normalization rotation method was utilized. Table 2 presents the final factor loadings higher than .65 for both data sets (a factor loading greater than .63 can be considered as very good (Comrey & Lee, 1992)). As seen in the table, the questionnaire items were clustered under the extracted factors, suggesting the convergent validity of the constructs. In addition, Cronbach's Alpha values were computed to evaluate the internal consistency of the questionnaire items associated with each construct. All Cronbach's Alpha values are higher than .707, which is commonly accepted in the literature as the minimum acceptable reliability level for internal consistency (Nunnally & Bernstein, 1994). The constructs are defined as follows:

3.2.1. Interaction (ACT)

The interaction construct is a measure of the extent to which students interacted with one another during the activity. In all activities, students worked in groups of two and had to collaborate for successful completion of the activity. Students were also faced with scenarios that required them to solve new problems with their partners and reflect upon their learning collaboratively. In this sense, the reflection and conceptualization stages of Kolb's ELC were integrated into the activities as collaborative work. Therefore, the interaction construct is a strong indicator of how much students performed reflection and conceptualization during the activity.

Table 1
Number of cases used in the final statistical analysis.

Activity	Data set A cases		Data set B cases
	Control	Treatment	
Basic Computer Networking	50	44	44
File Permissions			32
Traditional Ciphers			14
Symmetric Ciphers			13
Public Cryptography			16
Total	**94**		**119**

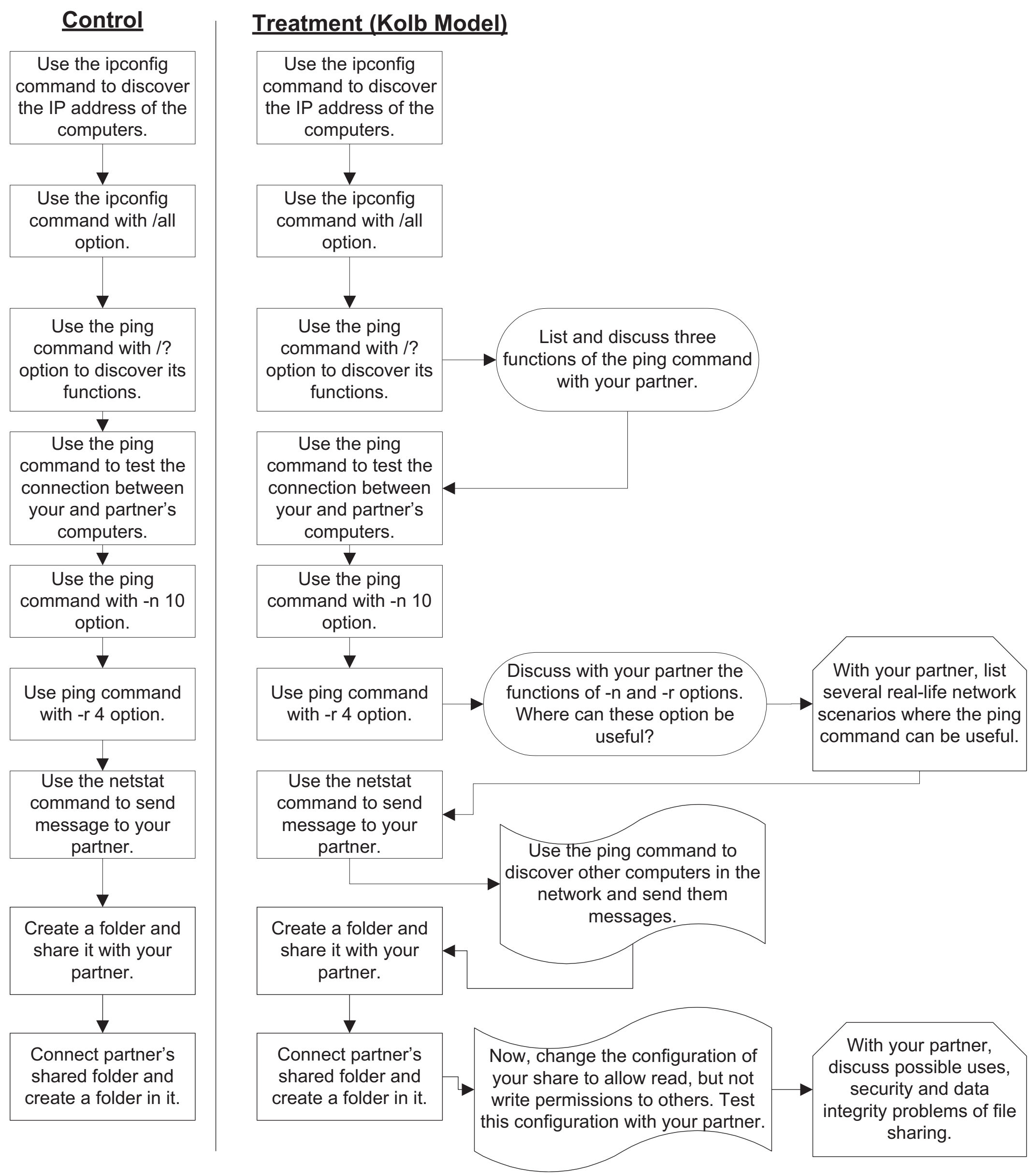

Fig. 3. The control and treatment versions of the computer networking activity to collect data for Data Set A (Refer to Fig. 1 for the meaning of the symbols).

Table 2
Factor loadings (values ≥ .65) and Cronbach's alpha values (Data set A/Data set B).

Questionnaire item	Factor loadings (Cronbach's alpha)				
	ENG (.92/.89)	ACT (.84/.86)	COMP (.85/.80)	CHA (.74/.78)	INT (.89/.71)
q1. The activity was enjoyable.	.91/.87				
q2. The activity was interesting.	.89/.87				
q3. I was engaged in the activity.	.88/.86				
q4. Asking questions to other students.		.80/.73			
q5. Observing other students.		.79/.77			
q6. Discussions with other students.		.75/.78			
q7. Interacting with other students.		.73/.88			
q8. I felt that I learned important skills.			.84/.85		
q9. I felt a sense of accomplishment after completing the activity.			.82/.71		
q10. The activity improved my competency in the subject area.			.71/.66		
q11. The activity review questions were difficult.				.82/.70	
q12. The activity was challenging.				.76/.98	
q13. The activity increased my curiosity and interest in this area.					.857/.77
q14. The activity encouraged me to learn more about this topic.					.841/.84

3.2.2. Engagement (ENG)

This construct is intended to measure students' willingness to participate and complete the activity.

3.2.3. Challenge (CHA)

This construct is intended to measure students' perceived difficulty in completing the activity.

3.2.4. Competency (CMP)

This construct measures students' perceived learning outcomes as a result of the activity. The competency construct is different than the former three constructs in the sense that the objective is to measure an *outcome* of performing the activity whereas the former ones are intended to measure student experiences during the activity.

3.2.5. Interest (INT)

The interest construct aims to measure the level to which students' interest and curiosity has been increased as a result of the activity. Like the competency construct, the interest construct is a learning outcome measure.

4. Analysis of results

4.1. Comparisons of the treatment and control groups

After establishing the internal consistency and convergent validity of the constructs for Data Set A, the coarse score of each construct was computed as the unweighted sum of the scores of the associated questionnaire items. Table 3 presents the means and standard deviations of the construct scores for the treatment and control groups. The mean values of the two groups were compared using the two-sided t-test assuming equal variances to test the main hypothesis of the paper: Hands-on activities that include all stages of Kolb's ELC lead to a higher level of learning. The largest mean difference between the treatment and control groups was observed for the interaction construct. This outcome should be expected as students interacted with one another in a more structured way in the treatment group than the control group. Student interactions in the treatment group not only involved feedback and information exchange between students but also reflections about the activity steps and generalizations of the concepts learned.

The treatment group indicated a higher level of engagement, and with the difference between the groups being small and yet statistically significant only with a level of p-value = .067. The control group found the activity to be slightly more challenging. However, the difference was very small and not statistically significant (p-value = .247). In terms of the competency construct, the difference between the treatment and control groups was statistically significant (p-value = .026). The treatment group rated their perceived learning outcomes higher than the control group did.

Although the results summarized above support our main research hypothesis, the competency construct is a subjective outcome of student learning. Therefore, a quiz was also administrated a week after completing the activity to assess students' recall of the concepts learned in the activity as well as to measure how well students could apply these concepts to more general problems. The recall questions asked students about the specifics of the commands they used in the activity. For example, students were asked to describe the function of the "ping -n 10 192.168.1.1" command. In generalization questions, students were asked about applying the commands to new situations (e.g. Which of the following is the least likely scenario in which you would use the ping command?). As seen in Table 3, the average quiz score was about 9.6% percent higher in the treatment group than the control group (statistically significant with a level of p-value = .058). The quiz results, combined with the students' responses about their learning outcomes, supported the main research hypothesis of the paper.

The treatment group was more likely to state that the activity increased their curiosity and interest in the subject matter. The difference in the scores of the interest construct between the two groups was statistically significant (p-value = .011) as shown in Table 3. This outcome is particularly important because research supports that learning in a particular domain is highly affected by the learner's interest in that domain. In fact, Alexander et al. (Alexander, Jetton, & Kulikowich, 1995) have found higher correlation between learning and interest than between learning and learner's ability to acquire knowledge. VCLs are excellent tools to increase student interest in the information security fields as they allow students to perform hands-on activities which are impossible to do in traditional computer laboratories. Overall, the

Table 3
The comparison of the treatment and control groups in data set A.

Construct/Variable	Group	Mean	Std. Deviation	Difference (T−C)	Significance (2-tailed p-value)
Interaction	Treatment	6.818	2.355	−1.610	.008
	Control	8.429	3.227		
Interest	Treatment	3.023	1.045	−.617	.011
	Control	3.640	1.241		
Engagement	Treatment	4.409	1.468	−.571	.067
	Control	4.980	1.505		
Challenge	Treatment	4.791	1.521	.371	.247
	Control	4.420	1.540		
Competency	Treatment	5.256	1.575	−.723	.026
	Control	5.979	1.466		
Quiz	Treatment	68.750	23.155	9.6	.058
	Control	59.146	24.847		

significant differences between the control and treatment groups in terms of learning outcomes indicate that by designing activities based on Kolb's ELC, more comprehensive learning can be fostered in VCLs than can be achieved by a single perspective.

4.2. Confirmatory factor analysis

A better understanding of the interplay among these factors affecting student learning outcomes is important for better design of hands-on activities that achieve the targeted learning objectives. Although Kolb's ELC has been previously recommended as a framework for structuring hands-on activities, the literature lacks analytical research models that explain the relationship among factors affecting student learning outcomes as a result of performing activities designed based on Kolb's ELC. We used structure equation modeling (SEM) to investigate how the engagement, interaction, challenge, interest, and competency constructs are related to one another. Our primary objective in using SEM was to understand which of the factors had the most impact on the interest and competency constructs. For example, the treatment group indicated a higher level of perceived interest than the control group, and then the next relevant step was investigating the main cause of this observation (i.e., What was the main reason that the treatment group scored higher: whether it was because of their perceived difference in the challenge of the activity, engagement, interaction, or competency). We could not answer such questions solely based on Data Set A, which only showed that the treatment group performed better than the control group. Further data and analyses were needed to answer the question of "Why?" To do so, we collected additional data (Data Set B) and created various structural models and used SEM to determine which model fitted the collected data the best.

SEM is a powerful statistical technique for testing relationships among several factors. SEM assumes that the relationships between the factors are linear and the residuals are normally distributed (Kline, 2011). It is also assumed that the modeler has a basic understanding of the relationships between the factors. An advantage of SEM is that it allows the modeler to define latent variables which are derived from measured variables. SEM considers the measurement error due to latent variables in addition to the error due to the model structure. Therefore, SEM is well suited to compare complex alternative models where the variables of the model are estimated from multiple measurements (i.e., the questionnaire items in this paper). Among the disadvantages of SEM are difficulty of assessing goodness-of-fit of a model and a relatively large sample size requirement (Kline, 2011).

In this study, Data Set B was used. Several plausible structural models were developed by adding and removing the following hypotheses into the models, and only four of these models, the best model and its related ones, are presented in this paper.

Hypothesis 1 (H1): Interaction is positively related to students' perceived competency.

Hypothesis 2 (H2): Interaction is positively related to students' interest.

H1 and H2 are based on Kolb's ELC which states that learners transfer concrete experiences into learning through reflection and conceptualization, which in turn lead to new active experimentation. We embedded the reflection and conceptualization stages into activities as group work where students are expected to collaboratively reflect back on steps performed and to generalize the concepts learned. In this study, therefore, student-to-student interaction is an indicator of the level at which students immersed themselves in reflection and conceptualization during the activity. As a result, it is hypothesized that higher levels of student-to-student interaction lead to higher student learning outcomes.

Hypothesis 3 (H3): Engagement is positively related to students' perceived competency.

Hypothesis 4 (H4): Engagement is positively related to students' interest.

H3 and H4 are not directly grounded on Kolb's ELC. Nonetheless, student engagement is considered to be among the better predictors of student learning (Carini, Kuh, & Klein, 2006).

Hypothesis 5 (H5): Challenge is negatively related to students' interest.

Hypothesis 6 (H6): Challenge is positively related to students' perceived competency.

H5 and H6 can be thought of in terms of finding the optimal level of challenge for an activity (Csikszentmihalyi, 1988). If an activity is too challenging, students will become frustrated, which will subsequently decrease their interest even to the point of giving up. However, for H6, students also need a certain level of challenge to feel that they have learned something. This idea is implemented in learning games (Lopes & Bidarra, 2011) and web activities (Chen, Wigand, & Nilan, 1999) that adapt to provide the right level of challenge at the right time.

Hypothesis 7 (H7): Students' perceived competency is positively related to students' interest.

H7 maps onto the last stage of Kolb's ELC where learners plan to test and apply their newly acquired skills on new problems. To reiterate, the interest construct aims to measure the extent to which students are interested in investigating the activity topic further. Mastering information security skills usually requires long hours of practice, which is impossible to achieve in the classroom. One of the objectives of the CVCLAB activities, particularly in introductory level courses, is to instill an academic curiosity into students along with basic technical skills so that students can independently explore subject matters in depth.

Hypothesis 8 (H8): Interaction and engagement are positively correlated.

By structuring activities as group work, we intended to increase student engagement. Therefore, the more students interact with one another, the higher level of engagement should be observed. At the same time however, student interactions may be also affected by their engagement in the activity because of other factors, such as their personal interest in the topic. H8 represents this relationship between the engagement and interaction constructs.

Confirmatory factor analyses (CFAs) were carried out in AMOS 20 software to compare the alterative models based on their goodness of fit (i.e., at what level the models fit to the collected data). Table 4 presents the summary of the models and their goodness of fit statistics, as well as the fitted unstandardized regression weights and correlations. In the literature, most frequently used goodness of fit statistics for CFA and their acceptable levels indicating a good fit are as follows (Brown, 2006): Comparative fit index (CFI) $>$ .90, Root mean square error of Approximation (RMSEA) $\leq$ .5, the Tucker Lewis coefficient (TLI) $>$ .90, and χ^2/df $<$ 2.5. The χ^2 statistics depends on sample size, thereby it has some limitations in assessing the goodness of fit. However, low p-values of the χ^2 statistic indicate a poor fit of the data to the hypothesized model.

As illustrated in Fig. 4, all hypotheses given above were included in Model A. Model B was derived from Model A by removing the challenge construct, which was deemed to be detrimental to the goodness of fit. Model C was derived from Model B by removing the relationship between the competency and interest constructs.

Table 4
Structure equation models and goodness of fit summary of confirmatory factor analysis.

Hypotheses	Model connections			Model A	Model B	Model C	Model D	Benchmark values for a good model fit
				Regression weight estimates (unstandardized) and correlations				
H1	CMP	←	ACT	.267**	.093*	.100**	.091*	
H3	CMP	←	ENG	.888**	.305**	.314**	.324**	
H5	CMP	←	CHA	.137*	–	–	–	
H4	INT	←	ENG	.258	.237	.577**	–	
H2	INT	←	ACT	.160*	.169*	.271**	.148#	
H7	INT	←	CMP	.524**	1.034*	–	1.472*	
H6	INT	←	CHA	−.041	–	–	–	
H8	ACT	↔	ENG	.647*	.348*	.348*	.348*	
	CHA	↔	ENG	.345*	–	–	–	
	CHA	↔	ACT	.298*	–	–	–	
Goodness of fit statistics				**Model A**	**Model B**	**Model C**	**Model D**	
			χ^2	289.306	57.101	68.675	59.900	
			df	77	48	49	49	
			χ^2/df	3.757	1.190	1.402	1.222	<2.5
			p	0	.173	.033	.137	>.1
			TFI	.688	.983	.963	.980	>.95
			CFI	.736	.987	.973	.985	>.90
			RMSEA	.53	.040	.058	.043	<.5

#: Significant with $p < 0.1$; *: significant with $p < 0.05$; **: significant with $p < 0.01$.

Although Model A supported all hypotheses, excluding H4 and H6, the CFA goodness of fit statistics did not indicate a very good model fit to the data. The analysis of the standardized residual covariance values also revealed a statistically significant discrepancy between the hypothesized model and the data, particularly due to the challenge construct. This observation is also parallel to the controlled experiment where no statistically significant difference was observed between the treatment and control groups in terms of the challenge construct. Therefore, the challenge construct was not included in Model B. The CFA goodness of fit statistics indicated a good model fit for Model B. In addition, all standardized residual covariance values were also less than 2.58, verifying the agreement between the model and the data (Brown, 2006). Hypotheses H1, H2, H3, H7, and H8 were supported by Model B whereas hypothesis H4 was not. Model C was developed to assess the significance of the relationship INT ←CMP, which turned out to be the most influential factor for the interest construct in Model B. Model D was developed to assess the significance of the relationship INT←ENG.

The results presented in Table 4 indicate that among the models discussed, Model B has the best good fit to the data, and that the relationship INT←CMP is significant because removing this relationship significantly reduced the goodness of fit of Model B. On the contrary, the weak relationship INT←ENG was also supported by Model D because removing this relationship degraded the goodness of fit of Model B at a negligible level. In this study, the observed weak relationship between the interest and the engagement construct indicated

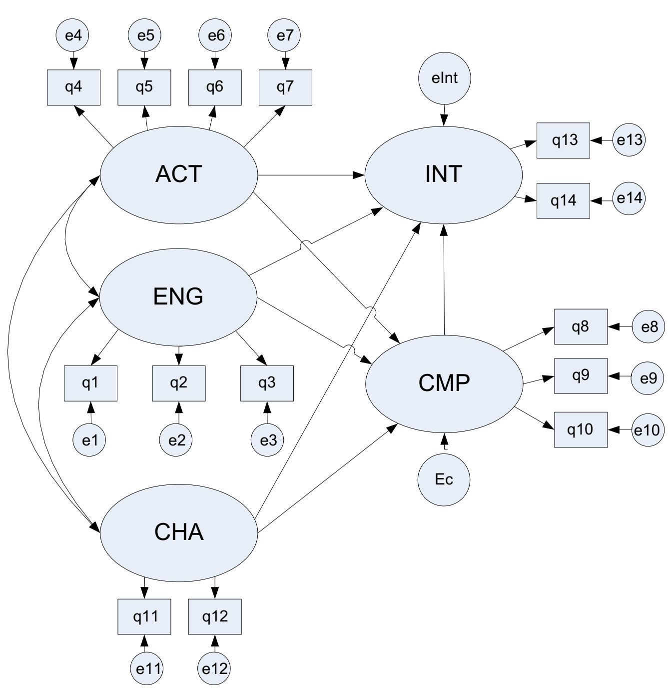

Fig. 4. The structural equations of Model A.

that increased student interest in the subject matter loosely depended on student's engagement. This outcome is in fact desirable to some extent because hands-on activities were able to increase student interest levels in a topic even though students might have not found the topic very engaging or enjoyable.

5. Discussions and limitations of the research

Hands-on activities in information security usually consist of step-by-step instructions to guide students through challenging tasks. The findings in this research suggest that more comprehensive student learning could be achieved in VCLs if hands-on activities are designed based on an inquiry-based framework rather than a cookbook approach. In the control experiments, students who performed hands-on activities whose design is based on Kolb's ELC perceived higher levels of competency development and increased interest relative to students who performed the control version of the activities. Hands-on activities designed based on Kolb's ELC can also encourage students to gain a deeper understanding of the subject matter. The confirmatory factor analysis revealed a strong positive relationship between the increased interest and perceived competency development. Compared to the engagement and interaction constructs, the competency construct turned out to be the most significant predictor of the interest construct. This outcome suggested that students' attitudes towards advancing the new skills introduced by a new hands-on activity were influenced by students' perceptions of how much they had actually learned as a result of the activity. In other words, students can complete a lengthy hands-on activity by following step-by-step instructions, but this may not be transferred into motivation for students to seek a higher mastery of the subject matter. To achieve this goal, hands-on activities should provide students with opportunities for reflection, conceptualization, and experimentation on the new concepts and skills that they are learning.

In this research, student-to-student interaction was found to have a significant positive effect on the competency development. This finding has several implications in the design of both VCLs and hands-on activities. First of all, VCLs should not only provide students with a technology solution in which they can experiment with critical information security skills in isolation but also opportunities to collaborate and interact with other students. In Section 2, group work is suggested as the main strategy to incorporate all stages of Kolb's ELC into hands-on class activities. Our findings showed that the more students were engaged in group work, the more competent they felt about their learning. Moreover, students who reported higher levels of interaction also indicated higher levels of increased interest in the subject matter. Overall, these findings suggest that collaborative and cooperative learning strategies should be an integral part of hands-on activities based on Kolb's ELC. In fact, the theoretical basis of both collaborative learning and Kolb's ELC is constructivism (Vygotsky & Cole, 1978) which states that learning is an active process of constructing knowledge rather than acquiring it. In this respect, Kolb's ELC represents the process through which students contextualize their experiences during a hands-on activity. Group work in particular can facilitate the implementation of the reflection and conceptualization stages of Kolb's ELC. In the context of information security, group work is also helpful to remedy problems due to differences in students' information technology backgrounds. In this research, although both control and treatment versions of the basic networking activity (Data Set A) required group work, the treatment group reported much higher levels of students-to-student interactions. These observations indicated that hands-on activities based on Kolb's ELC could also promote peer-to-peer learning.

One of the limitations of the research is that we did not identify which stages of Kolb's ELC had the most impact on student learning. To answer this question, data should be collected using multiple versions of hands-on activities with varying degrees of reflection and conceptualization components. One other limitation of the research is that all participants were first-year students, and all activities given in Table 1 were performed as group work. Therefore, the findings in this research should be generalized with caution. It is a further research question whether Kolb' ELC will lead to more comprehensive learning if participants are more experienced students or when the activities are performed without group work.

Another limitation of the paper is that the academic and socio-demographic backgrounds of the participants were not considered. However, to minimize the effect of student backgrounds, all participants were from the same academic standing and the control and treatments groups were randomly selected. A pre-test could be used to assess the academic background of the students in future testing.

6. Conclusions

Although the literature includes examples of virtual computer laboratories for the information security education, the majority of papers focus on their technical aspects rather than their educational impact. The research in this paper addresses how to enhance student learning outcomes by designing hands-on activities for virtual computer laboratories based on a pedagogically sound framework. It is hypothesized that step-by-step hands-on activities do not always achieve expected learning outcomes such as competency development and increased interest. Kolb's Experiential Learning Cycle is proposed as a framework to design hands-on activities for virtual computer laboratories, and an empirical study is presented to investigate the differences in learning outcomes of step-by-step activities and enriched activities based on Kolb's Experiential Learning Cycle. The research in this paper does not claim that step-by-step instructions should not be used. Frequently, the step-by-step approach is the only way to introduce new skills to students. Rather, the findings of the controlled empirical study supported that student learning outcomes could be enhanced by incorporating all stages of Kolb's Experiential Learning Cycle into hands-on activities. The findings of the confirmatory factor analysis indicated that increased student-to-student interaction led to higher perceived competency development of students. Therefore, this paper recommends collaborative learning strategies to promote reflection, conceptualization, and active experimentations in virtual computer laboratories. To achieve these goals, virtual computer laboratories should not only provide students with a technological infrastructure in which they can test critical skills in isolation but also with opportunities to collaborate and interact with one another. In other words, collaborative learning strategies should be considered in the design of virtual computers laboratories.

In terms of future research, studying how various aspects of the hands-on activities might impact learning outcomes differently based on the background and type of learners could prove informative. For example, conceptualization components of a hands-on activity may produce different outcomes for novice and experienced students. Studying the interactions between the stages of the Kolb Experiential

Learning Cycle and learner types could lead to more informed guidelines to design hands-on activities most appropriate for learners' background and expectations.

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