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Synchronized Pair Configuration in Virtualization-Based Lab for Learning Computer Networks

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ABSTRACT

More studies are concentrating on using virtualization-based labs to facilitate computer or network learning concepts. Some benefits are lower hardware costs and greater flexibility in reconfiguring computer and network environments. However, few studies have investigated effective mechanisms for using virtualization fully for collaboration. Therefore, this study proposed one effective collaboration mechanism—synchronized pair configuration—in a virtualization-based lab and aimed to enhance interaction and collaboration between paired students to help them accomplish networks or systems configuration through one shared, synchronized terminal, which allows them to input commands simultaneously from two computers to accomplish tasks. Meanwhile, they can communicate through a chat window. In the experiment, university students were divided into an experimental group, using a synchronized pair configuration for lab assignments, and a control group, with students completing lab assignments individually. Results indicated that the experimental group significantly outperformed the control group in learning achievement and had more confidence in their work; furthermore, the instructor's workload was reduced. Finally, findings of interviews and questionnaires revealed that the experimental group considerably enjoyed the proposed mechanism and system and had high motivation to use them. Therefore, synchronized pair configuration in a virtualization-based lab is suitable for learning computer networks.

Keywords

Synchronized pair configuration, Pair programming, Virtualization, Distributed cognition, Learning computer networks

Introduction

Recently, practice labs in computer network courses have become essential for enhancing students' learning since they can enable students to apply, practice, and verify network concepts in real contexts. In general, network configuration is usually an individual task and is similar to tasks of famous networking certification examinations such as the Cisco Certified Network Associate and the Linux Professional Institute Certification. Each examinee must individually configure a network on these tests. However, implementation of a physical network lab on campus has limitations in terms of the amount of available hardware since hardware requires rapid upgrades, and the number of instructors seems insufficient to assist all students (Williams, 2010; Xu, Huang, & Tsai, 2014). Meanwhile, some studies have revealed other limitations when students work individually to solve problems in computer science; for instance, solo students had less self-confidence in doing assignments (Williams & Kessler, 2002), made more syntax and typing errors while programming (Lui & Chan, 2006), and required more assistance from instructors (Braught, Wahls, & Eby, 2011), thereby spending more time solving their problems (Williams, Wiebe, Yang, Ferzli, & Miller, 2002). In contrast, previous studies found that pairs outperformed individuals in the number of interactions (Williams, Wiebe, Yang, Ferzli, & Miller, 2002) and learning outcomes in computer programming (Layman, Williams, Slaten, Berenson, & Vouk, 2008). In computer network learning, as experienced teachers in computer networks (with more than 10 years teaching experience), we found insufficient networking hardware and a heavy teaching load when students were assigned to perform lab practices individually. Therefore, in our previous study, stand-alone desktop virtual machines (e.g., VMware and Oracle Virtual box) (Dobrilović & Stojanov, 2006; Chen & Tao, 2012) were enhanced, and one distributed virtual machine (e.g., KVM cloud platform) (Hwang, Kongcharoen, & Ghinea, 2014) was proposed for solving the hardware limitation. However, after deep investigation, we found that some students still did not pay attention in lab practices even though they could observe and learn from their peers or group mates; moreover, they did not ask for much help from instructors. Therefore, we tried to discover an effective collaboration mechanism that would strengthen their collaborations in a lab class and thereby reduce the instructors' load. This study proposed one synchronized mechanism to help paired students to practice learning computer networks in the virtualization system to reduce class teaching effort and to facilitate sufficient networking lab installation.

The virtualization system is a group of virtual machines (VMs) deployed on one server, and the VMs contain operating systems (OSs) for operating as networking equipment, such as hubs, networking switches, and routers. The synchronized mechanism is a group assignment, and it requires a pair of users to work simultaneously. Thus each user works in a pair and pays the same level of attention as his/her partner. The mechanism mentioned above is called synchronized pair configuration (SPC) in this study. Through SPC, paired students can input commands simultaneously from two computers to one terminal. SPC enables a pair of students to work simultaneously and reduces instructor effort. In addition, paired students can share ideas and knowledge during lab assignments without much help from instructors. Due to SPC, this study established a virtualization-based lab (VBLab) that allows conduction of labs in the virtualization system. This VBLab's design is improved from our previous version (Hwang et al., 2014), with a new feature for a web terminal that allows students simultaneously or separately to input commands to VMs. In addition to experiment procedures, university students were divided into two groups, as pairs and as individuals, and each pair accomplished network lab practices together using SPC while each individual accomplished them alone. Consequently, this study compared pair and individual learning and studied differences in student interaction among lab practices and their effects on learning achievement. Furthermore, students' perceptions of using our proposed system are also investigated.

Literature review

This experiment was undertaken with three well known techniques: pair programming and synchronized programming, a virtualization-based lab, and distributed cognition theory. Details regarding theory and technique are as follows:

Pair programming and synchronized programming

Canfora, Cimitile, Garcia, Piattini, and Visaggio (2007) and Williams, Kessler, Cunningham, and Jeffries (2000) originally introduced pair programming in the industry. The concept of pair programming consists of two programmers working collaboratively to develop software. One programmer (the driver) has responsibility to generate code, while the other programmer (the navigator) monitors the driver's work to safeguard against defects and offers suggestions to the driver regarding various components of the overall software process such as design, coding, and testing. The driver and navigator can swap roles, thus balancing the workload. Various studies applied pair programming in programming labs and reported that it has more beneficial effects on performance than solo programming.

Synchronized programming (SP) has been used in computer science labs to enable students to code together at the same time in both distance and face-to-face classroom settings (Boyer, Dwight, Fondren, Vouk, & Lester, 2008; Schümmer & Lukosch, 2009). SP uses a plug-in with an IDE editor (Vandeventer & Barbour, 2012) to facilitate the program development pane for coding and compiling and the chat pane for online chatting. The SP system is a synchronized tasks system. When one user creates a task, that task generates an action transmitted to the other user. Synchronized actions consist of file operations (e.g., creating, saving, and removing files), editor operations (e.g., coding, code checking, and code integrating), and program running (i.e., execution and debugging).

Virtualization-based lab

Anisetti et al. (2007), Border (2007), and Wannous and Nakano (2010) introduced virtualization-based technology as a new way of installing a group of VMs on one server and running OSs on the VMs. Moreover, labs that implement virtualization-based technology allow learners to conduct experiments like real lab devices with flexible and portable features that have been successfully tested and verified for learning purposes.

Xu et al. (2014) have reported that there are few existing virtualization studies, and this research also found limited information about virtualization in existing studies, as shown in Table 1. We classified existing studies into four categories based on research variables; in reference to existing studies' variables, this study's subject is a course, and activities (i.e., individual, pair, or group tasks) are lab tasks assigned to students in its experiment. Table 1 demonstrates that the current study extends previous research, which focused only on students' achievement and perception by including the instructor's activity as a research variable and investigating how synchronized mechanisms of paired students can benefit learning of computer networks. Furthermore, this study conducted further comparison analysis, such as the *t*-test and ACOVA.

Table 1. Virtualization lab feature comparison

Existing study	Variable	Subject	Activity
Ros, Robles-Gomez, Hernandez, Caminero and Pastor (2012)	• Student's perception	• Networks configuration	• Individual/Group Tasks
Anisetti et al. (2007)	• Learning achievement	• Computer Networks	• Individual/Group Tasks
Chen and Tao (2012)	• Learning achievement	• Web security	• Individual Tasks
Wannous and Nakano (2010)	• Learning achievement • Student's perception	• Computer networks	• Individual Tasks
Marsa-Maestre, de la Hoz, Manuel Gimenez-Guzman and Lopez-Carmona (2013)	• Learning achievement* • Student's perception	• Networking security	• Individual/Group Tasks
Ruiz-Martinez, Pereniguez-Garcia, Marin-Lopez, Ruiz-Martinez and Skarmeta-Gomez (2013)	• Learning achievement • Student's perception	• Computer networks	• Individual/Group Tasks
Xu et al. (2014)	• Learning achievement • Student's perception	• Computer networks	• Individual/Group Tasks
Hwang et al. (2014)	• Learning achievement* • Student's activity* • Student's perception*	• Computer networks	• Individual/Group Tasks
The current study (SPC in VBLab)	• Learning achievement** • Student's activity* • Instructor's activity* • Student's perception*	• Computer networks	• Individual/Pair/Group Tasks

Note. *Group comparison with *t*-test, **Group comparison with analysis of covariance.

Distributed cognition theory

The distributed cognition concept explains interactions between people and technologies. Distributed cognition especially focuses on the study of teamwork, information transformation in the team, and problem solving by teammates (Flor & Hutchins, 1991; Hutchins, 1990).

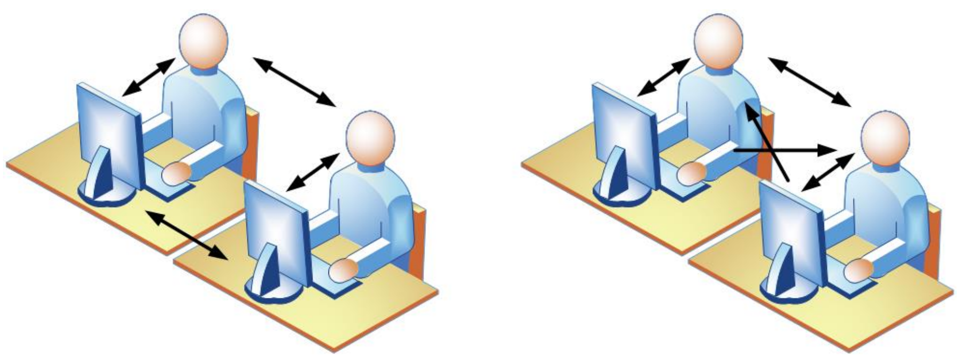

Figure 1. (a: Left side**)** the modified proposed distributed cognition system. (b: Right side**)** the original distributed cognition system (Flor & Hutchins, 1991, p. 41).

In the 1990s, Hutchins conducted research in software engineering; his study introduced distributed cognition to explain collaborative activities and analyzed a pair of programmers performing a perfective software maintenance task by analyzing a complex cognitive system. This study reported that successful software development is viewed as a consequence not of any single programmer's cognition but of an interaction of programmers and development artifacts in a system of distributed cognition (Flor & Hutchins, 1991).

Based on this theory, the current study designs a proposed distributed cognition system (see Figure 1a), in which the pair works only on their own monitor while they communicate with their partner through three ways: face-to-face, online discussion, or synchronized terminal. This protocol differs from the original distributed cognition system as shown in Figure 1b in which the pair works on two separate terminals using only face-to-face communication. In Figure 1, arrows represent the direction of communication. The bidirectional line between paired students is a face-to-face communication, the bidirectional line between students and terminals refers to students obtaining information from terminals and inputting data into terminals, and the bidirectional line between two terminals represents communication between paired students via chat window. The unidirectional line refers to paired students obtaining information from the partner's terminal.

System framework

Based on the literature mentioned above, this study's system framework in Figure 2 consists of three main elements: Pair users, SPC, and VBLab. SPC is a mechanism that requires a pair of users to work synchronously to complete their tasks. The VBLab is a networking infrastructure that can facilitate synchronized Web GUI for a pair of users to work together in the VM. The Web GUI and VMs components belong to VBLab. The Web GUI is a synchronized web-based interface developed based on the synchronized IDE editor (Vandeventer & Barbour, 2012). However, our synchronized web-based interface is more flexible than the original synchronized IDE editor because it can be used anywhere on the Internet without program installation and is easy to integrate with other web-based components. VMs are running OSs that operate as networking equipment. In summary, Figure 2 shows that users can work synchronously with their partners to complete work in VMs by following the concept of SPC with Web GUI.

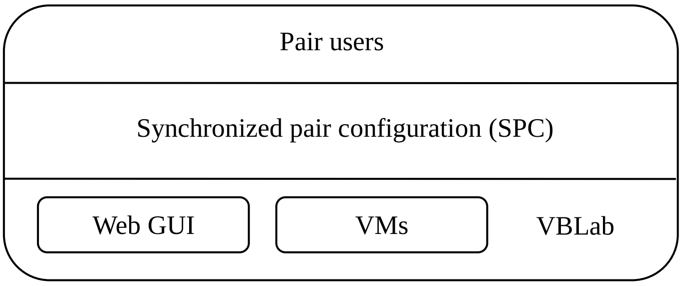

Figure 2. System framework

Research questions

This study's purpose was to assess how beneficial SPC and VBLab are for students' learning and to answer the following research questions:

- When SPC is applied in VBLab, do students complete their assignments (homework and post-test objectives) better than those working solo in VBLab? Does SPC in VBLab reduce the instructor's efforts to help students?
- What are students' perceptions and behavioral intentions when using VBLab in the two groups?
- What are the differences in students' behaviors and benefits from solo and synchronized pair mechanisms, as deduced from the interviews?

Method

Participants and procedures

The experiment was conducted during the summer semester (March–May 2014) at a university in Thailand. Participants consisted of 61 undergraduate students enrolled in two sections of a computer networks course. One section, with 32 students, was assigned as the control group, while the other section, with 29 students (13 pairs and 1 three-member group), was assigned as the experimental group.

Procedures of the experiment were based on four overall steps, as shown in Figure 3. The experiment was administered twice a week in three-hour increments. The same teacher lectured both groups with the same lab topics (see Appendix 2), which consisted of two parts: Basic Labs (Labs 1–3) and Advanced Labs (Labs 4–6). In the lab class, both groups did their lab assignments using the VBLab. The experimental group conducted their lab assignments using the SPC mechanism, whereas the control group members worked individually.

Learning activity designs

In this experiment, learning activities consisted of Basic Labs assignments, Advanced Labs assignments, and homework. Before the lab started, experimental and control students were further divided into groups of four pairs and groups of four students, respectively. Details regarding the designed lab class and the homework assignments are as follows.

Basic Labs assignments

Basic Labs were individual assignments and consisted of Labs 1–3. Instructors prepared lab materials and assignments for both student groups. At the beginning of class, the teacher briefed students on the objective and contents of the experiment and gave them assignments to be completed by the end of the three-hour class period. Completed assignments were then presented to instructors for evaluation. In addition, students had both face-to-face and online synchronous discussion (OSD) with class members (e.g., group members, teaching assistants, and instructors).

Advanced Labs assignments

Advanced Labs were group assignments and comprised Labs 4–6. Students in both experimental and control groups were asked to collaborate with their fellow group members to complete lab assignments within the class period. Again, students had both face-to-face and OSD with class members. In Lab 4 (see Appendix 3), each student and each pair configured a file server, web server, database server, and FTP server. At the beginning of the assignment, one student or one pair configured one type of server and then explained how to do so to other group members. In Labs 5 and 6 (see Appendix 4), each student and each pair managed and configured one of the four routers. In Lab 5, students configured static routing to route four routers to communicate with each other. In Lab 6, students configured dynamic routing (i.e., routing information protocol: RIP) to route four routers to communicate with each other.

Homework

For control and experimental groups, the teacher prepared the same homework assignments, which consisted of a post-lab question aimed at improving students' understanding of the lab contents. Students were allowed to use the VBLab to determine answers from the command search window and to redo assignments to confirm their answers.

Research variables

In this experiment, the following variables were defined and compared with each other as well as with overall learning achievement.

- Command count: the total number of Linux commands coded by a student using the VBLab for Labs 2–6
- The ratio of incorrect to total commands: ratio of incorrect to total Linux commands coded by a student using the VBLab for Labs 2–6
- Chat message count: total number of chat messages typed by a student using VBLab for Labs 2–6 relevant to the lab assignment
- Homework scores: homework scores for Labs 1–6
- Pre-test and post-test: pre-tests 1 and 2 are students' exam scores before Basic Labs and Advanced Labs, respectively. Post-test 1 is the students' midterm exam score, while Post-test 2 is the students' final exam score.
- The number of face-to-face helps: total number of students' face-to-face help meetings with instructors

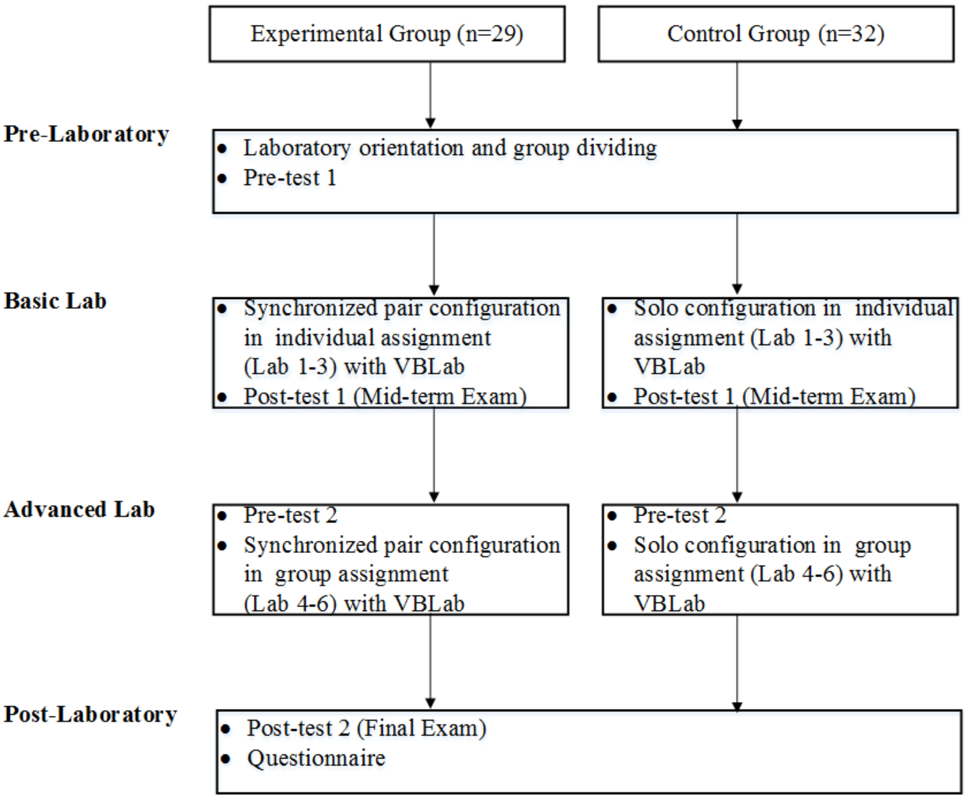

Figure 3. Flowchart for the experiment

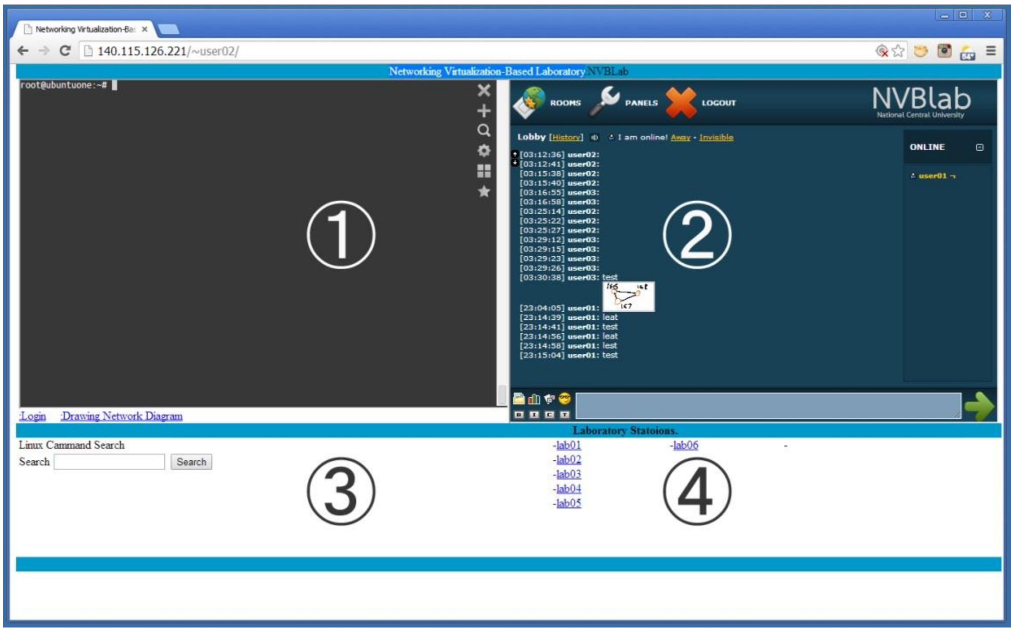

Figure 4. VBLab Web GUI: (1) Web terminal; (2) Chat window; (3) Command search window; and (4) Lab materials

The virtualization-based lab

This study used the VBLab to support lab activities, i.e., online networking lab with OSD and lab materials. The VBLab is a web-based lab (see Figure 4) and consists of four features that include the following aspects: (1) a web terminal that allows students to input command lines into the system for performing labs. This terminal synchronizes and shows input command lines from two students in the experimental condition and shows input command lines from only one student in the control condition. The web terminal is the key feature of this study. Control students input commands to the terminal individually, while the pair of experimental students help partners enter commands in synchronized web terminals. When one of the pair (the driver) inputs a command, the partner (the navigator) observes its correctness. In addition, the VBLab with a synchronized web terminal allows the pair to swap driver and navigator roles immediately, as they require; (2) a chat feature that allows students to have OSDs for discussing and sharing Linux commands with each other because all lab assignments are text-based activities, especially for the long Linux commands. Therefore, OSD is a suitable tool for communicating with the class members; (3) a command search box that enables students to find the Linux command manual for providing guideline commands, which are collected from all assignments; and (4) for Labs 1–6, lab materials, which are lab sheets that consist of lab introductions, assignments, and homework. Students can download lab materials before lab class. The VBLab is a web-based platform that has a web terminal based on an open source Gate One web terminal emulator (McDougall, 2011), and the other three features (e.g., chat window and command search box) were developed by PHP and MySQL database. The four features are integrated by PHP and HTML coding and deployed to the web server, and students can access their services.

Results and discussion

These research results and pedagogical implications are presented in relation to each of the research questions, above, in the following three sections.

Learning and activity outcomes

Analysis of pre-test, post-test results, and homework scores

The pre-test aimed to ensure that both student groups had equivalent basic knowledge required for learning in the course. According to Table 2, the mean and standard deviation of pre-tests 1 and 2 of the experimental and control groups indicated significant differences in pre-test 1 ($t = -2.095$, $p = .041$) and pre-test 2 ($t = -2.119$, $p = .038$) for the two groups. However, pre-test 1 and 2 scores for both groups were lower than 3 (out of 10); thus, the two groups of students had the same level of abilities prior to taking the course.

Table 2. Results of pre-test and post-test analysis

Assessment	Experimental group (n = 29)			Control group (n = 32)			t	p
	Mean	*SD*	*SE*	Mean	*SD*	*SE*		
Pre-test 1	1.69	0.71	0.13	2.13	0.91	0.16	−2.095	0.041^{*}
Pre-test 2	2.17	0.97	0.18	2.69	0.93	0.16	−2.119	0.038^{*}
Post-test 1	9.62	0.93	0.16	7.59	3.18	0.56	-	-
Post-test 2	10.00	3.70	0.69	5.47	2.38	0.42	-	-

Note. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Analysis of covariance (pre-test as covariate) was also used to investigate whether students in the two groups differed in their post-test performance when SPC was used or not used during a lab (see Tables 3 and 4). These analyses reveal a significant difference between students in the experimental and control groups: Basic Labs: F (1, 58) = 7.421, $p < .05$; Advanced Labs: F (1, 58) = 36.403, $p < .001$.

Table 3. Analysis of covariance of post-test 1 performance with pre-test 1 as a covariate (Basic Labs)

Source of variance	*SS*	*df*	*MS*	*F*	*Sig.*
Between groups	73.822	1	73.822	7.421	$.009^{**}$
Within group (errors)	576.978	58	9.948		
Total	5120.000	61			

Note. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 4. Analysis of covariance of post-test 2 performance with pre-test 2 as a covariate (Advanced Labs)

Source of variance	*SS*	*df*	*MS*	*F*	*Sig.*
Between groups	336.383	1	336.383	36.403	0.000^{***}
Within group (errors)	535.944	58	9.240		
Total	4417.000	61			

Note. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Moreover, *t*-test results of homework scores (see Table 5) show that the experimental group had significantly higher scores on Homework 1 (t = 7.283; p = .00), Homework 4 (t = 2.485; p = .016), and Homework 5 (t = 9.742; p = .00) than the control group; further, the average scores of Homework 2, 3, and 6 for the experimental group are higher than that for the control group. The primary reason for this difference is that experimental students usually discussed and answered homework questions with their partners and therefore attained higher homework scores.

Table 5. *t*-test results of homework

Assignment	Experimental group (n = 29)			Control group (n = 32)			t	p
	Mean	*SD*	*SE*	Mean	*SD*	*SE*		
Homework 1	4.48	0.91	0.17	2.66	1.04	0.18	7.283	0.0^{***}
Homework 2	3.50	0.82	0.15	3.19	0.68	0.12	1.621	0.11
Homework 3	4.21	0.73	0.13	4.16	0.99	0.17	0.226	0.822
Homework 4	2.93	0.65	0.12	2.56	0.50	0.09	2.485	0.016^{*}
Homework 5	4.46	0.87	0.16	2.79	0.35	0.06	9.742	0.0^{***}
Homework 6	3.72	0.80	0.15	3.69	0.78	0.14	0.181	0.857

Note. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Based on these findings, we can conclude that in both Basic and Advanced Labs, paired students in the experimental group performed better than solo students in the control group. We believe this is because they worked and synchronized with their partners in numerous discussions and engaged in knowledge-sharing to impart and receive more knowledge than might be gained through individual work (Lee, 2011).

Table 6. *t*-test results of command count and ratio of incorrect to total commands

Assignment	Experimental group (n = 14)			Control group (n = 32)			t	p
	Mean	*SD*	*SE*	Mean	*SD*	*SE*		
Lab 2 Command count	103.79	40.25	10.76	53.84	20.51	3.63	4.399	0.0^{***}
Lab 3 Command count	49.14	28.10	7.51	41.34	21.30	3.76	1.035	0.306
Lab 4 Command count	57.29	23.84	6.37	39.34	23.22	4.11	2.392	0.021^{*}
Lab 5 Command count	78.93	34.60	9.25	54.13	21.54	3.81	2.967	0.005^{**}
Lab 6 Command count	38.36	14.01	3.75	24.81	16.82	2.97	2.634	0.012^{*}
Lab 2 Ratio of incorrect to total commands	0.06	0.03	0.01	0.14	0.10	0.02	−4.142	0.0^{***}
Lab 3 Ratio of incorrect to total commands	0.07	0.04	0.01	0.16	0.15	0.03	−2.221	0.032^{*}
Lab 4 Ratio of incorrect to total commands	0.07	0.04	0.01	0.12	0.07	0.01	−2.823	0.007^{**}
Lab 5 Ratio of incorrect to total commands	0.05	0.03	0.01	0.08	0.04	0.01	−2.345	0.024^{*}
Lab 6 Ratio of incorrect to total commands	0.06	0.05	0.01	0.14	0.10	0.02	−3.148	0.003^{**}

Note. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

t-test results of command count and ratio of incorrect to total commands

There are statistically significant differences regarding command counts in Lab 2 (t = 4.339, p = .00), Lab 4 (t = 2.392, p = .021), Lab 5 (t = 2.967, p = .005), and Lab 6 (t = 2.634, p = .012) between the experimental and control groups. Even though it was found that the command count was not directly related to learning achievement, this finding demonstrates that the command count is possibly an indicator affecting students' learning. As indicated by Table 6, the mean of the lab command count of the experimental group was higher than the mean of the control group. This implies that the experimental group created more activities in command practices than the control group. Moreover, the significant differences in command count in Labs 2, 4, 5, and 6 show that paired students synchronized commands and helped each other perform assignments collaboratively in the VBLab. This led the experimental group to generate more commands than the control group (Braught, Eby, & Wahls, 2008).

Furthermore, according to Table 6, ratios of incorrect to total commands show statistically significant differences between experimental and control groups in all six labs as follows: ($t = -4.142$, p =.00), ($t = -2.221$, p = .032), ($t = -2.823$, p = .007), ($t = -2.345$, p = .024), and ($t = -3.148$, p = .003). These results demonstrate that students in the experimental group improved their typing capability more than their counterparts in the control group because paired synchronization can facilitate careful and correct work; therefore, students in the experimental group could reduce syntax and typing errors (Lui & Chan, 2006).

t-test results of chat message count and number of face-to-face helps

Regarding *t*-test results of the chat message count, as shown in Table 7, there are statistically significant differences in the command count in Lab 4 ($t = -2.404$, p =.019), Lab 5 ($t = -2.501$, p =.015), and Lab 6 (t = 2.737, p =.008) between the experimental and control groups. Furthermore, almost all average values of the chat message count of the experimental group are lower than those of the control group, excluding that of Lab 2. In addition to the activity designs in the experiment, the students were asked to use OSD to communicate with class members for discussing, completing assignments, and requesting help. Therefore, the chat message count refers to students' interactions with class members. According to the *t*-test results, compared with the control group, the experimental group shows lower interactions with class members. The main reason for this situation is that students in the experimental group could communicate directly with their partners to solve problems and to complete lab assignments efficiently; thus, compared with the control group that worked alone, the experimental group use less chat messages to accomplish assignments (Williams & Kessler, 2002).

Moreover, with regard to the number of face-to-face helps shown in Table 7, there are no significant differences between the experimental and control groups and the number of face-to-face helps are very limited. The cause for this situation could be the shyness of the Asian students when asking instructors for help (Liu, 2001). We now plan to deeply investigate the main reasons for the insignificant differences between the two groups in the number of face-to-face helps.

In conclusion, even though the two groups did the same assignments, the experimental group expended less effort than the control group in terms of chat interactions with group members, teaching assistants, and instructors.

Table 7. t-test results of the chat message count and number of face-to-face helps

Assessment	Experimental group (n = 29)			Control group (n = 33)			t	p
	Mean	*SD*	*SE*	Mean	*SD*	*SE*		
Lab 2 Chat message count	7.00	5.56	1.03	6.93	5.91	1.05	0.042	0.996
Lab 3 Chat message count	2.34	2.09	0.39	3.72	3.70	0.66	−1.757	0.084
Lab 4 Chat message count	4.14	3.82	0.71	6.53	3.93	0.70	−2.404	0.019*
Lab 5 Chat message count	2.24	2.54	0.47	4.31	3.84	0.68	−2.501	0.015*
Lab 6 Chat message count	0.72	0.88	0.16	1.28	0.68	0.12	−2.737	0.008**
Lab 1 Number of face-to-face helps	1.07	1.58	0.29	1.44	2.14	0.38	−0.759	0.451
Lab 2 Number of face-to-face helps	1.00	1.10	0.20	1.78	2.85	0.50	−1.437	0.158
Lab 3 Number of face-to-face helps	1.34	1.63	0.30	1.59	2.20	0.39	−0.498	0.620
Lab 4 Number of face-to-face helps	1.59	1.70	0.32	2.09	2.01	0.35	−1.060	0.293
Lab 5 Number of face-to-face helps	1.72	1.87	0.35	1.75	1.87	0.35	−0.056	0.955
Lab 6 Number of face-to-face helps	1.28	1.87	0.35	1.31	1.38	0.24	−0.088	0.930

Note. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Students' perceptions and behavioral intentions

A questionnaire survey was conducted to investigate students' perceptions and behavioral intentions when using the proposed system. The questionnaire was designed by following the technology acceptance model (Davis, 1986) for four dimensions (see questions numbered 6–9 in Table 1a in Appendix 1). It included five external dimensions (see questions numbered 1–5 in Table 1a in Appendix 1) that affect intention to use and actual use (Davis, Bagozzi, & Warshaw, 1989). Responses obtained from the two groups were ranked using a five-point Likert scale (ranging from strongly disagree [1] to strongly agree [5]). Statistical results of the survey are presented in Table 1a in Appendix 1. According to the *t*-test results, there was a statistically significant difference regarding the perceived subjective norm by classmates to use the proposed system ($t = 2.036$, $p = .046$). This finding demonstrates that the subjective norm among students in the experimental group can enhance use and continued use of the proposed system in their future studies, as pairing helps them have more confidence and motivation to complete lab assignments (Williams, Wiebe, Yang, Ferzli, & Miller, 2002). Moreover, all questionnaire dimensions were rated "agree" except two dimensions of the control group (comprising perceived readiness for using the proposed system and behavioral intentions when using it) that were "neutral," and all of the experimental group's questionnaire ratings were higher than those of the control group. This indicates that the experimental group has more readiness and intention to participate in this learning style than the control group.

Interviews and in-depth investigation

During the one-on-one, semi-structured interviews, students mentioned that they could benefit from using SPC in VBLab for labs class. Four summaries of interviews are explained below.

Regarding the use of SPC for experiments, students in the experimental group indicated that SPC influenced their behavior—to have more discussions and share more—which related to the Linux commands and network configurations (Flor & Hutchins, 1991).

In addition, in SPC, students were typically able to find solutions to lower-level problems, such as syntax and typing errors, without assistance, and instances of asking instructors for help were much less frequent (Braught et al., 2011).

The use of SPC in our study was also intended to give students an opportunity to experience two different roles (driver and navigator) while completing the experiment. In either case, if one student in the pair was struggling or absent, the partner could swap roles and become the driver for the lab (Wiebe et al., 2003).

On the other hand, solo students in the control group frequently asked for help and had questions for instructors and other students both in face-to-face and online discussions of assignments (Wiebe et al., 2003). Furthermore, some students in the solo class had no self-confidence in doing assignments by themselves, and they did not ask others for help; thus, they did not finish assignments on time (Williams & Kessler, 2002).

Implications regarding education and technology

Based on these findings, the current study presents the following implications and recommendations for instructors who plan to teach computer networks. First, we recommend using SPC in VBLab for enhancing students' understanding of lab contents. Secondly, SPC is a collaborative learning environment in which paired students can work and share knowledge for completing assignments; in addition, paired students and instructors can have direct conversations via a chat feature, and instructors can simultaneously monitor paired students in class and help them correct certain configurations by sending messages. Therefore, SPC can increase students' attention when performing assignments during lab class. Thirdly, we observed that paired students had many online discussions with their partners during both Basic and Advanced Labs. Thus, instructors should chat directly into class chat window (not individual chat window) and discuss assignments with all pairs, especially when giving guideline commands. Fourthly, we recommend that instructors assign pairs based on students' ability levels. Each pair should have at least one high-achieving student, because he/she will help his/her partner obtain better understanding of lab contents (Dawande, Johar, Kumar, & Mookerjee, 2008). Finally, this experiment shows that VBLab can be a cost-efficient lab solution when the alternative is to buy expensive high-profile network equipment directly from manufacturers.

Conclusion

This study applied the SPC mechanism for computer network labs to determine its effectiveness in students' learning performance. In addition, the study investigated students' perceptions and behavioral intentions when implementing SPC in VBLab. First of all, this study successfully proposed SPC for learning in computer network labs. Second, the experimental group in the SPC class was more productive in command count; moreover, there was decreased effort from the instructor in terms of chat message count. Thus, the experimental group significantly outperformed the control group in both post-tests. Third, this study successfully deployed a VBLab into computer network labs, a technique that allowed instructors to create a variety of virtual network topologies to be deployed as lab facilities. Therefore, students learned with real experience and accepted VBLab for completing assignments during lab class. With regard to this study, one limitation is the relatively small sample used, which restricts broad generalization of results. Therefore, future studies should increase the number of participants. Finally, future efforts should compare performance of students working in pairs with synchronized and non-synchronized configurations.

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Appendix 1. Questionnaire survey

Table 8. t-test of questionnaire survey

#	Item	Group	Dimension mean	*SD*	*t*	Sig. (2-tailed)
1.	**System characteristics of the proposed system.**					
1-1	I think that the proposed system can provide a real Linux networking environment as working in a real machine.	Experimental Control	3.80 3.77	0.49 0.52	0.223	0.824
1-2	I think that the Virtual Box can provide a real Linux networking environment as working in a real machine.					
1-3	I think that the proposed system has good facilitation.					
1-4	I think that the proposed system has helpful peer and tutor support.					
2.	**System accessibility of the proposed system.**					
2-1	I have no difficulty accessing and using Virtual Box.	Experimental Control	3.57 3.46	0.88 0.70	0.533	0.596
2-2	I have no difficulty accessing and using this system.					
2-3	I think that I can remote to this system and it is stable everywhere.					
2-4	I think that I can access this system faster and smoothly.					
3.	**Perceived readiness from using the proposed system.**					
3-1	I always peer review laboratory contents on the proposed system before class.	Experimental Control	3.43 3.16	0.60 0.58	1.746	0.086
3-1	I think that our educational (style) culture in class is ready for the proposed system.					
3-3	I think that the proposed system makes students ready to do lab assignments.					
4.	**Perceived usefulness of the proposed system for collaborative group work.**					
4-1	I would like to collaborate with class mates in the same group for doing lab assignments.	Experimental Control	3.72 3.62	0.75 0.69	0.563	0.575
4-2	I would like to collaborate with class mates in another group for doing lab assignments.					
4-3	I would like to share networks configuration and topology with group members for doing lab assignments.					
4-4	From my experience, “collaboration” among classmates usually succeeds in finishing assignments faster.					
5.	**Perceived subjective norm from classmates using the proposed system.**					
5-1	I think other students in my group should be aware of how to use this system.	Experimental Control	3.71 3.63	0.13 0.11	2.036	0.046*
5-2	I think other students in my group would be willing to use this system.					
5-3	I think other students in my classes would be willing to use this system.					
5-4	Most people who are important to me think that it would be fine to use this system to do lab assignments.					

Note. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 9. *t*-test of questionnaire survey

#	Item	Group	Dimension mean	*SD*	*t*	Sig. (2-tailed)
6.	**Perceived ease of the proposed system use.**					
6-1	I think that the proposed system is very convenient to do lab assignments.	Experimental Control	3.68 3.53	0.53 0.67	0.960	0.341
6-2	I think that the operation of the proposed system does not require too much time.					
6-3	I think that the proposed system is very easy for doing practical lessons and exercises after class.					
6-4	I feel that learning to use this system is quite easy.					
6-5	I think that the proposed system is very easy for communication with the instructor and other students.					
7.	**Perceived usefulness of the proposed system.**					
7-1	I think that the chat window can communicate with other group members to have suggestions for accomplishing lab assignments.	Experimental Control	3.73 3.69	0.54 0.67	0.266	0.791
7-2	I think that the sharing of virtual network devices is helpful for doing lab assignments.					
7-3	I think that the sharing of the chat window is useful for doing lab assignments.					
7-4	I think that the proposed system increases collaborative work with other group members when doing lab assignments.					
7-5	I think that the proposed system enhances my attention.					
7-6	I think that I can decrease my workload when working with the proposed system.					
7-7	I think that I can memorize well when working with the proposed system.					
8.	**Attitude toward using the proposed system.**					
8-1	I like using this system to learn computer networks.	Experimental Control	3.78 3.56	0.69 0.61	1.367	0.177
8-2	I have a positive attitude toward using this system.					
8.3	I feel that using this system to do lab assignments is a good method.					
9.	**Behavioral intentions when using the proposed system.**					
9-1	If I have access to this system, I will use it to learn computer networks.	Experimental Control	3.56 3.36	0.68 0.63	1.204	0.233
9-2	If I do lab assignments, I will enjoy doing it with this system.					
9-3	I think that I will use this system to help me when I do my homework.					

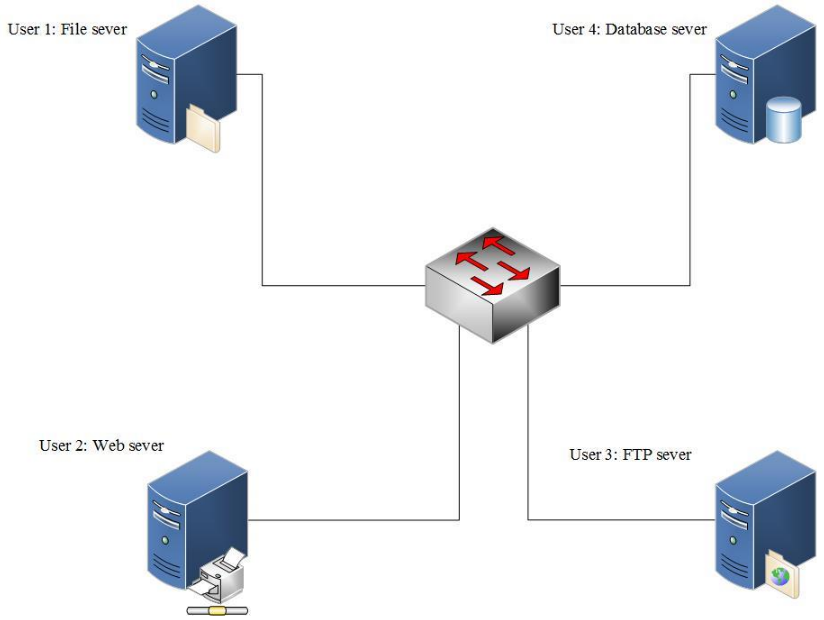
Note. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Appendix 2. Topic of Laboratory assignment

Basic Labs: Linux concepts and basic practices
Lab1 Introduction to Linux and Linux command
Lab2 Linux Script
Lab3 Install Linux

Advanced Labs: Linux networking and advance practices
Lab4 Linux Networking, Configuration
Lab5 Linux Networking, Static Routing
Lab6 Linux Networking, Dynamic Routing

Appendix 3. Network topology of Linux networking, configuration: Lab4



Appendix 4. Network topology of networking, static routing and dynamic routing: Lab5 and Lab6