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An experience of teaching for learning by observation: Remote-controlled experiments on electrical circuits

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ABSTRACT

In order to facilitate senior primary school students in Hong Kong to engage in learning by observation of the phenomena related to electrical circuits, a design of a specific courseware system, of which the interactive human–machine interface was created with the use of an open-source software called the LabVNC, for conducting online remote-controlled experiments was developed in this study. The statistically significant results of a pre-test–post-test evaluation study showed that the LabVNC-based system has potential to promote students to learn the target topic under the approach of learning by observation. The assertion of the teacher on the pedagogical value of the remote-controlled experimentation and the enthusiasm of students in using the LabVNC-based system reveal the potential to integrate the use of the LabVNC-based system with the practice of scientific experiments. Based on the feedback from the teacher and students, the existing LabVNC-based system will be refined under the design-based research approach.

1. Introduction

The physical science topic ‘electrical circuits’ is one of the core elements of the strand ‘Science and Technology in Everyday life’ in the primary General Studies curriculum in Hong Kong. This topic focuses on the rudimental knowledge about patterns and phenomena related to electrical circuits. The learning scope covers the procedural knowledge about the correct setting of an operable electrical circuit, and the conceptual knowledge of the relationship between the operation of electrical devices and the change of electrical components in a basic circuit, a series circuit or a parallel circuit. Students are expected to understand the differences between basic circuit, series circuit and parallel circuit, and to investigate the influence of simple changes in electrical components on different types of circuits. The abstract nature of the knowledge about electricity makes the topic ‘electrical circuits’ a challenging topic in science education for senior primary students who are normally aged between nine and eleven. Researchers have suggested that providing students with opportunities to gain practical experience of working with circuits can facilitate students to appreciate phenomena related to electricity (Taber, de Trafford, & Quail, 2006).

The formulation and evaluation of scientific hypotheses depend on organised and accurate observations of natural phenomena. In science learning, opportunities for observation are clearly important for students to build their own sense of reality (Kearney, Treagust, Yeo, & Zadnik, 2001; Tomkins & Tunnicliffe, 2001). Therefore, the practice of scientific experiments, in which typically involve the processes of making prediction, making observation and making explanation, is an integral and important part in school science education with a threefold purpose (Braund & Driver, 2005; Colwell & Scanlon, 2002; Scanlon, Morris, Di Paolo, & Cooper, 2002; Wu, Yeung, & Kong, 2007). First, this helps students to deepen conceptual knowledge of science topics by allowing students to link scientific theories with the real-world. Second, this helps students to develop procedural understanding of science topics by familiarising student with the use of important instruments, equipment and techniques in relevant scientific investigations. Third, this helps to establish favourable attitudes of students towards science learning by placing students in an enjoyable and motivating learning environment with hands-on experience through a set of appropriate actions.

The step of making observation is considered crucial in the context of probing student understanding (Kearney, 2004; Kearney et al., 2001; Scanlon et al., 2002; White & Gunstone, 1992). Students often find discrepancy between an anomalous situation and a preconception

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in the process of observation. They, in turn, require thoughtful explanations for the incongruity between the observations and their preconceptions or misconceptions. Previous studies have shown that the approach of learning by observation allows students to directly construct scientific knowledge through the engagement in in-class scientific induction apart from absorption of sense data alone (Kearney, 2003; Tomkins & Tunnicliffe, 2001; White & Gunstone, 1992). As the axiomatic nature of observation, even much younger students find the approach of learning by observation straightforward for building up knowledge about natural phenomena. It is therefore suggested that, with the integration with the learning mode of guided inquiry, the approach of learning by observation could be suitable for primary science education.

Inquiry into real-world phenomena experienced by students in daily life is central to school science education. Under the learning mode of guided inquiry, students follow the directions from teachers to complete inquiry learning tasks for scientific investigations (Martin-Hansen, 2002). For primary science education, the more learner-centred type of guided inquiry is recommended to be integrated with the experimental activities, wherein teachers play a significant role in three aspects (Kearney, 2003; Martin-Hansen, 2002; White & Gunstone, 1992). Before the observation stage, it is necessary for teachers to provide a brief of experimental activities, a set of guiding materials and a choice of possible responses to encourage students to be committed to their prediction on a group basis. During the observation stage, it is important for teachers to direct students to collect certain data through the experimental activities. After the observation stage, it is crucial for teachers to lead whole class discussions when the observations are contentious and subsequently to consolidate the objectives of the experimental activities.

In view of the tight schedule of school curriculum, the limited number of school laboratories and the sparse stock of experimental apparatuses, primary school students in Hong Kong and many developing countries generally lack sufficient chances to conduct scientific experiences within class time. The experimental activities in primary science education usually retains at the level of in-class demonstrations by teachers (Colwell & Scanlon, 2002). In response to this problem, researchers have investigated the potential of integrating the use of information technology (IT) with the practice of scientific experiments. It is found that there are various ways to use IT to extend the opportunities to conduct experimental activities in school science education. The approach of remote-controlled experiment is one of the promising development directions in this aspect (Scanlon et al., 2002; Scanlon, Colwell, Cooper, & Di Paolo, 2004; Wu et al., 2007).

Remote-controlled experiment refers to the real-time computer-based or Internet-based controlled experiment. It allows students to manipulate or control real apparatuses to complete experimental activities for scientific investigations at a distance with the use of specific hardware and software (Scanlon et al., 2002, 2004; Wu et al., 2007). Previous studies have shown that students not only perceive remote-controlled experiments are sufficiently equivalent to their original implementations in laboratories, but also enjoy learning by observation via remote-controlled experiments. The approach of remote-controlled experiment is therefore considered to have two educational merits in science education (Colwell & Scanlon, 2002; Scanlon et al., 2004); On the one hand, remote-controlled experiments can help to increase students' participation in experimental activities, thereby solving the access problems. On the other hand, remote-controlled experiments can help to stimulate students' interest in science learning, thereby enhancing the learning outcomes. Researchers have also pointed out that with more teacher guidance, the approach of remote-controlled experiment is particularly appropriate for primary school students because the implementation of remote-controlled experiments is in particular helpful in developing basic observation skills, which are the core skills for scientific investigations (Scanlon et al., 2004).

The overwhelming majority of the primary school students in Hong Kong lack adequate opportunities for the practice of scientific experiments in science lessons. In the light of the potential of remote-controlled experiments in primary science education, this study aimed to devise an open-source courseware system for implementing remote-controlled experiments on the science topic 'electrical circuits' in primary schools. Such open-source courseware system targeted at facilitating senior primary school students, who are normally aged from nine to eleven, in Hong Kong to engage in learning by observation of the phenomena related to electrical circuits without constraints of time, space and resources in in-class experimental activities.

2. Design of the environment for conducting remote-controlled experiments

This study adopted the design-based research approach to designing a specific courseware system in supporting the performance of remote-controlled experiments on the science topic, the 'electrical circuits'. Design-based research is an attempt to combine theory-driven design with empirical studies of learning environments (Bell, 2004; Design-BasedResearch Collective, 2003; Hoadley, 2004). The most common type of design-based research combines software design and studies in education (Hawkins & Collins, 1992; Hoadley, 2002). The design-based research approach is a strategy for designing educational technology by eliciting information about aspects to be improved regarding the technology from users. The study reported herein combined a theory-driven design of a courseware system and an empirical study on the learning context involving the use of the courseware system in a real classroom setting.

To create an environment for conducting remote-controlled experiments with the aim of enabling senior primary school students to take part in in-class experimental activities in relation to the target subject without constraints of time, space and resources, an open-source software was employed in the design of the courseware system in this study. Open-source software refers to computer software whose source code is freely available under an open-source licence that permits users to use, change and share the software in original or modified form (Hill & Gaughan, 2006; von Krogh & von Hippel, 2003). In view of its high cost-effectiveness, accessibility, compatibility and security, open-source software has been increasingly used for educational purposes in the past decade (Hill & Gaughan, 2006).

The open-source software adopted in this study for the design of the courseware system was a modification of a widely-used open-source software called the LabVNC. The LabVNC is a free and open-source software. The development basis of the LabVNC is an open-source graphical desktop sharing system called Virtual Network Computing (VNC). This open-source software, similar to the well-known proprietary software the LabVIEW, enables users to remotely access graphical desktop displays and control computer programs of another computer running in any operation system (Mihura, 2001; Richardson, Stafford-Fraser, Wood, & Hopper, 1998; Travis, 2002). With the capability to turn any virtual instrument into a Java applet without further programming or modification, the LabVNC is considered as a flexible and powerful cross-platform toolkit for performing online remote-controlled experiments in a cost-effective manner (Travis, 2002; Wu et al., 2007).

Based on the curriculum rationale and teaching focus of the science strand in the primary General Studies curriculum, the prototype of a LabVNC-based system was modified in this study to a tailor-made version for conducting remote-controlled experiments on the electrical circuits (Wu et al., 2007). The primary function of such LabVNC-based system was to allow students to remotely complete experiments via the Internet without constraint of supply of experimental apparatuses. The objective of the integration of the present LabVNC-based system with traditional pedagogical approach was to increase the number of students and the opportunities for students to acquire scientific knowledge through learning by observation without time and location constraints. The interface of the LabVNC-based system consisted of three components to facilitate the performance of remote-controlled experiments. Fig. 1 shows the interface of the LabVNC-based system adapted for this study.

The first component was the control panel, which was located in the top-right corner of the display screen of the LabVNC-based system. The control panel aimed to enable users to change the experimental conditions easily so as to facilitate the observations of varying phenomena related to electrical circuits. There were two control boards in the control panel. The first control board was designed for the selection of the method of circuit connection. Three options were provided in this control board: ‘basic circuit’, which was functionable for circuits with one light bulb only; ‘series circuit’, which was functionable for circuits with more than one light bulb; and ‘parallel circuit’, which was also functionable for circuits with more than one light bulb. The second control board was designed for the selection of the number of electrical components. Two versions were provided in this control board: ‘number of battery’, which was activated under the designation of ‘basic circuit’ for the selection of number of battery from one to three; and ‘number of light bulb’, which was activated under the designation of ‘series circuit’ or ‘parallel circuit’ for the selection of number of light bulb from one to three.

The second component was the virtual circuit panel, which was located in the top-left corner of the display screen of the LabVNC-based system. The virtual circuit panel aimed to enable users to observe the phenomena of electrical circuits corresponding to the changes in connection method and electrical components via virtual computer graphics. The virtual circuit panel provided simultaneous display of the virtual circuit board corresponding to the instructions given by the users. The brightness of the light bulbs is represented by a scale of yellow colour, from the brightest in golden yellow to the least bright in pale yellow.

The third component was the web camera display, which was located at the bottom of the display screen of the LabVNC-based system. The web camera display aimed to enable users to observe the actual phenomena of electrical circuits corresponding to the changes in connection method and electrical components via real-time video clips. The web camera display offered simultaneous display of the real circuit board that was remotely controlled in a real experimental context corresponding to the instructions given by the users.

Fig. 2 depicts the environment for conducting remote-controlled experiments with the use of the LabVNC-based system. The LabVNC-based system was located in a web server of the host computer. Users were required to access the designated website by using a java-en-

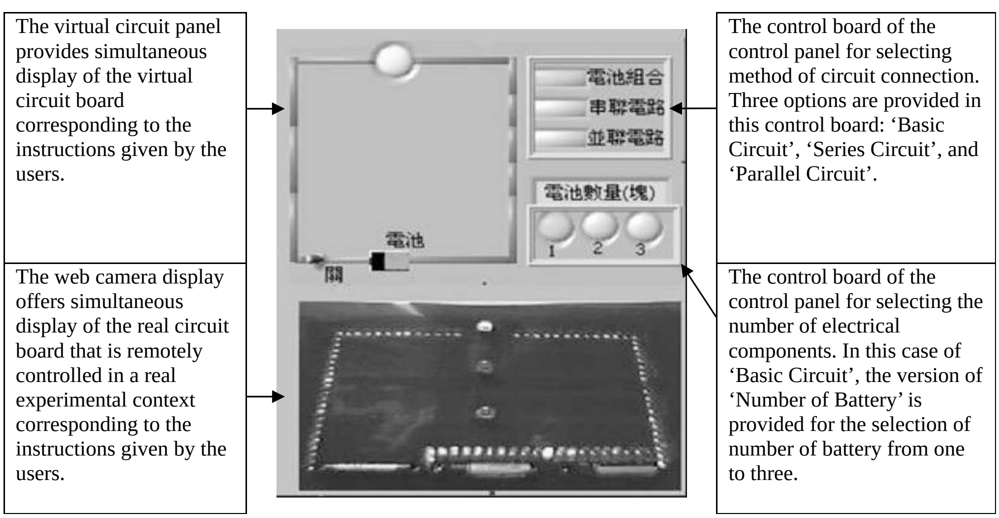

Fig. 1. The interface of the LabVNC-based system adapted for this study.

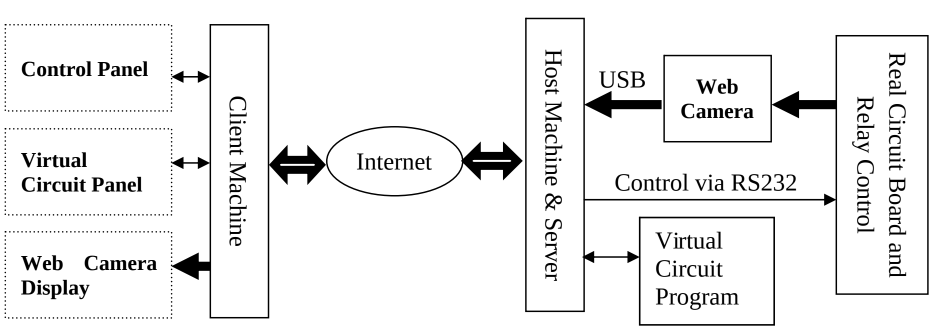

Fig. 2. The environment for conducting remote-controlled experiments with the use of the LabVNC-based system.

able browser or running a compact-file-size VNC client software in the client machines with computing functionalities (such as desktop computers, personal assistants (PDAs) and smart phones operating under the Windows, Linux or Mac environment). After entering their personal Internet Protocol (IP) address and password, users could login to the interface of the LabVNC-based system to conduct online remote-controlled experiments.

There were two processes involved in this environment: the control of experimental apparatuses by the users, and the display of experimental results by the LabVNC-based system. In the first process, users made use of the control panel to set the experimental conditions for the remote-controlled experiments by pressing the designated buttons on the control panel. In the second process, the LabVNC-based system generated displays according to the received commands under three steps. The first step was about command transmission. This step allowed users to make use of the control panel of the LabVNC-based system to set the experimental conditions. The signals in the client machines would be transmitted to the host machine and server via the Internet. The second step was about command processing. A twofold processing procedure was involved in this step. For the result generation in the virtual experimental context, the signals would then be transmitted to the virtual circuit program for data processing. For the result generation in the authentic experimental setting, the signals would then be transmitted to a single chip via a RS-232 serial communication port. A number of relays, which were controlled by the abovementioned single chip, were incorporated into a revamped real circuit board for the remote-controlled experiments. The electrical components on the real circuit board were manipulated by the relays based on the received commands. The third step was about result display. This step allowed users to observe the theoretical resulting phenomena in the form of virtual computer graphics via the virtual circuit panel of the LabVNC-based system, and compare the actual resulting phenomena in the form of real-time video clip via the web camera display of the LabVNC-based system. A twofold procedure was involved in this step. For the result display in the form of virtual computer graphics, the virtual circuit program transmitted the relevant signals to the host machine and server after data processing. The virtual circuit panel of the LabVNC-based system would generate the corresponding virtual computer graphics according to the signals received from the host machine and server via the Internet. For the result display in the form of real-time video clips, the actual happenings in the real circuit board were captured on the video by the web camera which was connected to the server by its USB port. The web camera display of the LabVNC-based system would make a real-time video clip based on the signals transmitted by the host machine and server through the Internet.

3. The empirical study

To investigate the potential of the LabVNC-based system for supporting the learning and teaching of the science topic, the ‘electrical circuits’, an empirical study was conducted in a real classroom setting. Researchers have suggested that the major criteria for the evaluation of educational software include the learning achievement of students after using the software, the judgement of teachers for the use of the software in teaching, and the preference of students for the use of the software in learning (Hawkins & Collins, 1992). In this respect, three specific research questions were investigated in this study.

1. What is the learning outcome of students after using the LabVNC-based system for learning?
2. What are the opinions of the teacher on the use of the LabVNC-based system in teaching?
3. What are the views of students on the use of the LabVNC-based system in learning?

A class of Primary Four students in a primary school in Hong Kong was invited to participate in this study. Table 1 shows the profile of the class of Primary Four students who participated in this study.

The use of the LabVNC-based system was incorporated into a double teaching lesson of ‘electrical circuits’ in the invited school, in which each lesson lasted for 30 min. The trial teaching took place in a general classroom where a set of projector, visualiser and desktop computer with Internet connectivity is installed. The teaching materials for the students included an interactive electronic whiteboard, the LabVNC-based system, and an activity worksheet. Since the scientific rationale behind the target phenomena is not required to be introduced to students at the stage of primary school education in Hong Kong, the activity worksheet adopted in this study (see Appendix B) focused on the elementary phenomenal knowledge of the target subject so as to enable students to recognise the fundamental patterns and phenomena related to electrical circuits. In this activity worksheet, the first question was about the circuit diagram of a basis circuit; the second and third questions were about the relationship between the illumination of light bulb and the contact state of the switch in a basic circuit, and the relationship between the change of the number of battery and the change of the brightness of light bulb in a basic circuit; the fourth and fifth questions were about the relationship between the change of the number of light bulbs and the change of the brightness of light bulbs in a series circuit, and the relationship between the illumination of light bulbs and the burn-out of a light bulb in a series circuit; the sixth and seventh questions were about the relationship between the change of the number of light bulbs and the change of the brightness of light bulbs in a parallel circuit, and the relationship between the illumination of light bulbs and the burn-out of a light bulb in a parallel circuit.

Table 2 summarises the major learning and teaching activities for students with the use of the LabVNC-based system. The learning and teaching activities for the students focused on the guided inquiry learning of the target subject through the teacher-guided observation of the phenomena related to electrical circuits. The teacher mainly asked the students, in groups of three to four, to complete the learning

Table 1
Profile of the students who participated in this study.

Description	Profile
Number of students	23
Ratio of boys to girls	10:13
Mean age in years	9.91 (S.D. = 0.36)

Table 2
The major learning and teaching activities for students.

	Learning and teaching activities
1	Grouping of students: students were randomly divided into six groups, of which each group consisted of three to four students
2	Instruction in the target subject: the teacher made use of a real circuit board to illustrate the target subject
3	Brief of the functions of the LabVNC-based system: the teacher introduced the use of the LabVNC-based system
4	Completion of activity worksheet: an iteration of the three-step learning tasks in the process of whole class answer guess, individual group discussion and presentation and whole class answer check

tasks specified on the activity worksheet with the use of the LabVNC-based system. No teacher demonstration or real experiment concerning the learning task was carried out throughout the trial teaching.

Initially, the teacher used a real circuit board to introduce the types of electrical circuits and the relevant terminologies in the target subject (see Figs. 3a and 3b). The use of the LabVNC-based system was subsequently introduced to students by the teacher. As a warm-up, the teacher used the LabVNC-based system to conduct a remote-controlled experiment according to the experimental conditions stipulated in the first question, and then requested the whole class of students to speak out their observations by referring to the virtual circuit panel of the LabVNC-based system displayed on the interactive electronic whiteboard. The students were subsequently asked to complete the other six questions on the activity worksheet under the approach of learning by observation. An iteration of three steps was involved in this session.

First, the whole class of students were asked to make predictions about the outcomes of the changes in the electrical components of the circuits according to the given situation as stated in individual questions. A list of possible outcomes was provided in each question to stimulate students' predictions. Second, students were invited on a group basis to conduct the remote-controlled experiments in front of the whole class by using the LabVNC-based system displayed on the interactive electronic board. Members in each group took turns to set-up the real circuit board at the remote location by using the control panel of the LabVNC-based system according to the experimental conditions stipulated on the activity worksheet. Third, the whole class of students were requested to speak out their observations from the displays on the LabVNC-based system and write down the answers on the activity worksheet. The teacher finally drew a short summary on the observation results and reiterated the relevant scientific terminologies.

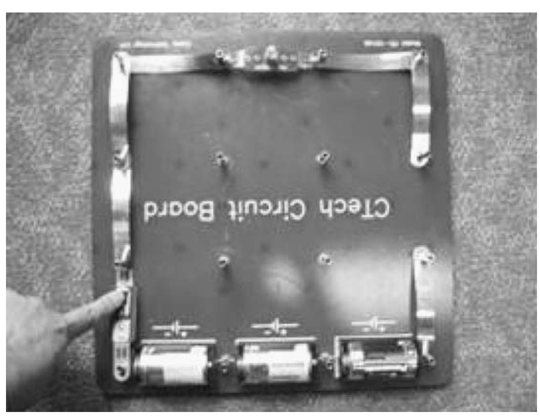

Fig. 3a. The real circuit board demonstrating an open circuit.

Fig. 3b. The real circuit board demonstrating a closed circuit.

4. Evaluation methods

Quantitative and qualitative methods were adopted in the empirical study to collect data on the potentials of the LabVNC-based system to assist in the teaching and learning of the 'electrical circuits' with regard to the learning achievement of students after using the LabVNC-based system, the judgement of the teacher for the use of the LabVNC-based system in teaching, and the preference of students for the use of the LabVNC-based system in learning.

To study the impact of the LabVNC-based system on the learning achievement of the students, a pair of tests was administered for all of the students who participated in this study before and after the trial teaching. The tests targeted on garnering quantitative data concerning the learning benefits to students in terms of academic results after working with the LabVNC-based system. Under the pre-test–post-test design, a set of pre-test–post-test instruments was designed to measure the knowledge of students about 'electrical circuits'. A test paper consisting of six questions about the phenomena related to electrical circuits was designed in Chinese for the pre-test (please refer to Appendix A for the English version of the test paper) and the post-test (please refer to Appendix C for the English version of the test paper), respectively. The first question in the test papers concerned the procedural knowledge about the correct setting of an operable electrical circuit. The other five questions targeted the conceptual knowledge about the relationship between the operation of electrical devices and the change of electrical components in a basic circuit, a series circuit or a parallel circuit. The test papers were developed and cross-validated by two experts in the related field. The level of difficulty of these test papers was also judged to be appropriate for Primary Four students by the teacher who participated in this study. The Cronbach's alpha reliability coefficients of the pre-test and the post-test are 0.577 and 0.689, respectively. Fig. 4 shows a sample question in the test paper. The question that is shown in Fig. 4 is in English, but the Chinese version of the question was provided for the students. During the pre-test and post-test, the students were allowed to make queries about the gist of the questions when they were unable to understand the questions on the test papers.

To investigate the judgement of the teacher for the use of the LabVNC-based system in teaching, a semi-structured, individual interview with the teacher who used the LabVNC-based system was conducted after the trial teaching. The teacher interview targeted at gathering qualitative data regarding the teacher's opinions of the use of this system in terms of application situation and teaching effect. Five questions about perception of teaching benefits and suggestions for further improvement of the LabVNC-based system were designed for the interview. The responses were processed by content analysis of the interview record.

To study the preference of students for the use of the LabVNC-based system in learning, a questionnaire survey for students who participated in this study was conducted after the trial teaching. The student survey targeted on collecting qualitative data reflective of the students' perception of the use of this courseware in terms of application situation and learning effect. Students were asked to indicate their level of agreement with five statements about learning benefits in relation to the use of the LabVNC-based system. The mean rating of each statement on a 4-point Likert scale, from 1 = 'strongly disagree' to 4 = 'strongly agree', and the corresponding standard deviation were calculated. The Cronbach's alpha reliability coefficient of the questionnaire survey is 0.711. In addition, two open-ended questions were prepared at the end of the questionnaire to collect the views of students on the perceived learning gains and the usage difficulties in relation to the use of the LabVNC-based system. The relevant responses were processed by content analysis of the textual feedback.

5. Results and discussions

5.1. Learning outcome of students from Pre-test–Post-test instruments

This section reports the learning achievement of students after using the LabVNC-based system for learning. The findings show that the use of the LabVNC-based system for remote-controlled experiments helped students to deepen knowledge of the target topic. Table 3 and Fig. 5 show the effects of the LabVNC-based system on the students who participated in the study.

The paired *t*-test result in Table 3 indicates that the mean difference between the pre-test and post-test measures of the students is significantly different. The statistically significant result shows that the integration of the LabVNC-based system with the practice of scientific experiments in classroom instruction could engage students in meaningful observation of the phenomena in relation to electrical circuits, and bring them a gain in the knowledge of the target subject after the trial teaching. This reveals that the use of the LabVNC-based system together with the appropriate pedagogy of the teacher and supporting learning materials has a potential to foster students to for-

3. If the number of light bulb is increased to 2 or 3 in a correct closed circuit, in which the light bulbs are connected in a **series circuit** as shown in the diagrams below:

what will be the changes in each light bulb?

(A) No change in brightness
(B) Getting dimmer than the sole light bulb in the basic circuit
(C) Getting brighter than the sole light bulb in the basic circuit
(D) No idea

Answer: ☐

Fig. 4. A sample question in the test paper.

Table 3
Mean, standard deviation and paired *t*-test of the pre-test and post-test measures for the students who participated in the study.

Number of students	Pre-test		Post-test		Paired *t*-test[a]	
	Mean	(S.D.)	Mean	(S.D.)		
23	3.17	(1.70)	4.39	(1.56)	−2.66[*]	*t*(23)

Note: [a,*] $p < .05$.

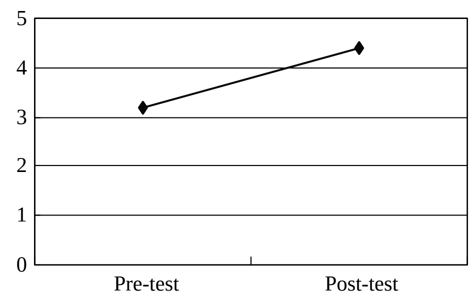

Fig. 5. Effects of the LabVNC-based system on the students on their knowledge and concepts of electrical circuits.

mulate association between the real-world observations and the scientific theories in the target topic. This piece of findings can be considered as a preliminary support for the constructive potential of the use of the LabVNC-based system to the learning of ‘electrical circuits’, as the post-test was administered based on a double teaching lesson only.

5.2. Feedback of teacher from interview

Table 4 shows the key points that the teacher made during the interview about the use of the LabVNC-based system for teaching the ‘electrical circuits’. The teacher asserted that the LabVNC-based system allowed students to effectively learn the target subject knowledge by observation. The teacher stated that his students were very interested in using the LabVNC-based system because the students knew that by using the LabVNC-based system, they could remotely control the real experimental apparatuses that were located outside school. The teacher also observed that his students were highly involved in the in-class learning activities because they were fascinated by the use of the LabVNC-based system, which is a completely innovative learning tool for them. The teacher pointed out that the LabVNC-based system exhibited its pedagogical value in five aspects: providing students with an interactive tool with a high authenticity in the simulation of real experimental contexts; offering students more chances to conduct experiments without the constraint of limited stock of experimental apparatuses; allowing students to instantly receive relevant feedback from the teacher and fellow classmates when they were invited to give class demonstrations; enabling students to conduct experiments that were unable to conduct in real contexts; and allowing students, especially those had not used the tool in-class or wanted to try it once more, to use the LabVNC-based system in their extended learning outside school. Although the technical operation of the LabVNC-based system was not difficult, the teacher, who does not specialise in

Table 4
Key points that the teacher made during the interview about the use of the LabVNC-based system for teaching the ‘electrical circuits’.

Question theme	Teacher response
Teaching effect of the use of the LabVNC-based system	The LabVNC-based system enabled students to effectively learn the target subject knowledge
Student involvement in the use of the LabVNC-based system	Students were very interested in using the LabVNC-based system
	Students were highly involved in the in-class learning activities with the use of the LabVNC-based system
Pedagogical value of the use of the LabVNC-based system	The LabVNC-based system offered students a high authenticity in the simulation of real experimental contexts
	The LabVNC-based system offered students more chances to conduct experiments without the constraint of limited stock of experimental apparatuses
	The LabVNC-based system enabled students to receive instant feedback on their experimental work from the teacher and fellow classmates
	The LabVNC-based system enabled students to conduct experiments that were unable to conduct in real contexts
	The LabVNC-based system enabled students to engage in the relevant extended learning outside school
Pedagogical challenge of the use of the LabVNC-based system	There was no technical problem related to the use of the LabVNC-based system
	There was the inability of the teacher to immediately provide a detailed and convincing explanation in response to the unexpected challenging questions from the students with the use of the LabVNC-based system
Teacher suggestion on the future use of the LabVNC-based system	The possibility of using the LabVNC-based system to conduct experiments in an intra-class, inter-class, inter-school or cross-region approach should be emphasised
	The feasibility of the use of the LabVNC-based system for students to conduct online-based self-learning should be studied
	An online package should be developed for the extended learning of students beyond school hours
	Each group of students should be assigned with a set of computer with the access to the LabVNC-based system
	Appropriate teacher guidance should be provided for student if needed
	Preparation for the comprehensive understanding of teaching content and experimental procedures should be conducted by teachers before the use of the LabVNC-based system

physics, encountered the problem of the inability to immediately provide a detailed and convincing explanation to the unexpected challenging questions posed by his students with the use of the LabVNC-based system.

With respect to the future use of the LabVNC-based system, the teacher made several suggestions on the development direction and the pedagogical design of this innovative IT tool. Regarding the development direction of the LabVNC-based system, the teacher suggested that the possibility of using the LabVNC-based system to conduct experiments in an intra-class, inter-class, inter-school or cross-region approach should be emphasised. The teacher thought that it would be meaningful for students to fix a time with their counterparts in, for example, other groups of their class, other classes of their school, other schools in their region, or other schools in the overseas, to access the LabVNC-based system at the same time to collaboratively conduct remote-controlled experiments.

In addition, the teacher noted that the feasibility of the use of the LabVNC-based system for students to conduct online-based self-learning after school should be studied. He further proposed that online quizzes, which are migrated from the paper-based activity worksheet, should be prepared for such online learning activities. Features such as interlinks for theoretical explanation of specific phenomenon and toggle between quiz interface and LabVNC-based system interface should be provided for students to facilitate the learning of scientific knowledge. Concerning the pedagogical design of the LabVNC-based system, the teacher thought that each group of students should be assigned with a set of computer with the access to the LabVNC-based system.

The teacher also suggested that mediation from teachers should be made in the integration of the use of the LabVNC-based system with traditional experimental practices because he thought that appropriate teacher guidance could prevent students from distracting by the innovative IT learning tool and support students with varying learning abilities to solve their individual learning problems. Above all, the teacher pointed out that teachers should get familiar with the teaching content and experimental procedures before conducting the remote-controlled experiments with the use of the LabVNC-based system in order to prevent the adverse effect on the experimental results.

In summary, the teacher expressed his positive views on the integration of the LabVNC-based system with the practice of scientific experiments. He recognised the positive impact of the LabVNC-based system on students in learning the target subject. The teacher appreciated the potential of the LabVNC-based system for promoting active participation of students in in-class learning activities, broadening the possible scope for students in scientific experimentation, and fostering extended learning of students beyond school hours.

5.3. Feedback of students from questionnaire survey

The students showed their strong preference for using IT to conduct experiments. Table 5 shows students' perception of integrating the use of IT with the practice of scientific experiments. Over 80% of the students strongly agreed that such integration could increase their interest in taking General Studies lessons, studying the science strand in General Studies lessons, and conducting experiments with the use of IT in General Studies lessons. Nearly three quarters of the students expressed their strong agreement that they would be more interested in learning at school and completing learning activities with other classmates if their school adopted IT for conducting scientific experiments during class time.

In line with their positive perception of the integration of the use of IT with the practice of scientific experiments, the students had a high recognition for the use of the LabVNC-based system for conducting remote-controlled experiments. Table 6 lists the perceived learning gains of students in the remote-controlled experiments with the use of the LabVNC-based system. The majority of the responded students indicated that they knew more about the definition, types and phenomena related to electrical circuits. A number of the responded students expressed that they learned more about the ways to use computer to conduct remote-controlled experiments. Some responded students stated that they understood more the rationale behind experimentation in science learning. A few responded students emphasised that they were more interested in learning science after using the LabVNC-based system to conduct remote-controlled experiments.

Despite their strong preference for using the LabVNC-based system in science learning, part of the students indicated that they encountered difficulties in the remote-controlled experiments with the use of the LabVNC-based system. Table 7 shows the usage difficulties of students in the use of the LabVNC-based system for conducting remote-controlled experiments.

There were two main types of difficulties encountered by the responded students. The first type of difficulties was the problem in relation to the technical operation of the LabVNC-based system. Over a third of the responded students expressed that it was difficult to operate the LabVNC-based system because the responsiveness of the buttons on the control panel was not prompt enough. The second type of difficulties was the problems in relation to the learning process with the use of the LabVNC-based system. A proportion of the responded students indicated that they were unable to understand the gist of the questions on the activity worksheet, predict experimental results, and get familiar with the experimental procedures during the remote-controlled experiments with the use of the LabVNC-based system. Some responded students reported that they had inharmonious collaboration in which they argued with their groupmates over the completion of learning tasks involving the use of the LabVNC-based system. It is worth of noting that one of the responded students thought that it was inappropriate to conduct such remote-controlled experiments in general classrooms.

In summary, the students had a positive perception of the integration of the use of IT with the practice of scientific experiments. Despite some problems in the aspects of technical operation and learning process related to the use of the LabVNC-based system, the students as-

Table 5
Students' perception of integrating the use of IT with the practice of scientific experiments.

Evaluation item	Mean (1–4)[a]	(S.D.)
I will be more interested in taking General Studies lessons if IT is used for conducting experiments in my school	3.87	(0.34)
I will be more interested in conducting experiments with the use of IT in General Studies lessons if IT is used for conducting experiments in my school	3.87	(0.34)
I will be more interested in studying the science strand in General Studies lessons if IT is used for conducting experiments in my school	3.83	(0.39)
I will be more interested in learning at school if IT is used for conducting experiments in my school	3.74	(0.45)
I will be more interested in completing learning activities with other classmates if IT is used for conducting experiments in my school	3.70	(0.56)

Note. [a]4-Point Likert scale where 1 = strongly disagree; 2 = disagree; 3 = agree; 4 = strongly agree.

Table 6
Perceived learning gains of students in the remote-controlled experiments with the use of the LabVNC-based system.

Perceived learning gain	Count	Percentage (%)
Increase in the knowledge of the target subject	15	68.2
Increase in the knowledge about computer	3	13.6
Increase in the knowledge about scientific experiments	2	9.1
Increase in the interest in science learning	2	9.1
Total	22	100

Table 7
Usage difficulties of students in the use of the LabVNC-based system for conducting remote-controlled experiments.

Type of diffuculty	Problem description	Count	Percentage (%)
Problem in relation to the technical operation of the LabVNC-based system	Occasional unresponsiveness of the LabVNC-based system	5	35.7
Problem in relation to the learning process with the use of the LabVNC-based system	Inability to predict experimental results	3	21.5
	Inability to understand the gist of the questions on the activity worksheet	2	14.3
	Inharmonious collaboration with groupmates	2	14.3
	Inability to get familiar with the experimental procedures	1	7.1
	Inappropriateness of conducting remote-controlled experiments in general classrooms	1	7.1
Total		14	100

serted the effectiveness of this innovative IT tool on learning the knowledge of 'electrical circuits'. The students showed a great enthusiasm for using the LabVNC-based system for conducting remote-controlled experiments on the target topic.

5.4. Implications of the empirical study

The results of the empirical study reveal that there is a potential integration of the LabVNC-based system into the practice of scientific experiments to achieve optimal learning outcome. Based on the abovementioned results, four implications in connection with the development and implementation of the designed courseware system were drawn.

The first implication is related to the pedagogical value of the designed courseware system. In the student survey, the students showed their great enthusiasm for using the LabVNC-based system in learning the target subject. In the teacher interview, the teacher asserted the effectiveness of the LabVNC-based system on promoting the involvement of students in participating in the in-class experimental activities. It is noteworthy that the LabVNC-based system could foster students to actively engage in the process of learning by observation because the students were observed to be very observant to the displays on the LabVNC-based system. For the sixth question on the activity worksheet, which was about the relationship between the addition of light bulbs and the brightness of light bulbs in a parallel circuit, the web camera display of the LabVNC-based system showed that the light bulbs were dimmer after the addition of light bulbs; whereas the virtual circuit panel, on which the display was in accord with theoretical generalisation, showed that the brightness of the light bulbs was unchanged. In reporting their observations, over 80% of the students stuck to the display on the web camera display to report their observation results. Even their observation results were questioned by the teacher, the students insisted on their correctness based on the actual situation of the real circuit board displayed on the web camera display of the LabVNC-based system. These findings reveal that the LabVNC-based system had a potential to act as a good mediator to facilitate students to actively engage in learning by observation of the phenomena related to electrical circuits under the guided inquiry approach. The LabVNC-based system could attract students to concentrate on the process of the experimentation and induce students to engage in deep observations on the details of the phenomena. This facilitated students to lay a foundation for scientific inquiry through experimental activities.

The second implication relates to the pedagogical use of the designed courseware system. Three issues in relation to the preparation work and teaching practices were revealed for the future use of the LabVNC-based system. Firstly, the teacher indicated his inability to immediately offer a detailed and convincing explanation in response to the unexpected challenging questions from the students with the use of the LabVNC-based system. This implies that teacher should get familiar with the teaching content and experimental procedures before using the LabVNC-based system for conducting remote-controlled experiments. Secondly, the teacher expressed his concern about the use of the LabVNC-based system to perform experiments in an intra-class, inter-class, inter-school or cross-region approach, and to conduct extended learning beyond school hours. This reveals that teachers should realise the full potential of the LabVNC-based system as a supportive learning tool for in-class experimental activities in a collaborative approach, and for after school extended learning activities on an individual basis. Thirdly, the students indicated their encounter with some problems in the learning process involving the use of the LabVNC-based system. This implies that there is a need for teachers to offer teacher guidance in three aspects. The first type includes tangible support such as carefully-designed learning materials, and intangible support such as repeated encouragement and suitable guidance to students for addressing the inability of students to understand the gist of the questions on the teaching materials, predict experimental results, and get familiar with the experimental procedures. The second type is timely mediation for handling the problems of inharmonious collaboration among students. The third type is strategies for redressing the bias on the inappropriateness of experiments in general classrooms.

The third implication concerns the pedagogical design of the designed courseware system. Two issues related to the role of teachers and arrangement for in-class activities were revealed for the future use of the LabVNC-based system. Firstly, the teacher was observed to act as a learning guide rather than a learning authority in the trial teaching. The teacher had introduced the key terminologies, but not the typical phenomena and model explanation related to the target subject before the remote-controlled experiments. The students could thus predict and observe the experimental results without predominant conceptions under this teaching approach, thereby insisting on the accuracy of their observation but not that of the model answers from the teacher in view of the subtle differences in the experimental results between the real context and the virtual context. This reflects that teachers should adopt an open teaching approach in the use of the LabVNC-based system for conducting remote-controlled experiments. The mention of typical phenomena and model explanation related to the target subject at the initial stage should be deliberately avoided in order to prevent the establishment of predominant conceptions of students before the performance of experiments. Teachers should also be open to the unexpected queries or challenges from students in order to prevent hindrance to students' curiosity to find the truth related to the target subject. Secondly, in order to address the discontent of students over the inability of their teacher to immediately provide a clear and reasonable explanation on the differences in the experimental results between the one shown on the web camera display and the one on the virtual circuit panel, the investigators of this study gave a post-experiment explanation on the experimental deviations after the trial teaching. Such arrangement not only enabled students to learn the reasons for the occurrence of the experimental errors, but also allowed students to understand the accuracy of their observations. This implies that teachers should offer a post-experiment explanation in the use of the LabVNC-based system for performing remote-controlled experiments. The delivery of basic concepts and additional information corresponding to the experimental results after experiments can provide not only the direct support for students to grasp supplementary information related to the target subject; but also the indirect encouragement for students to induce confidence in conducting scientific experiments and reflecting experimental results individually.

The final implication relates to the improvement work for the designed courseware system. The design-based research approach was adopted in this study for designing the courseware system by eliciting information about aspects to be improved regarding the technology from the teacher and the students. According to the feedback from the student survey, the responsiveness of the LabVNC-based system should be increased in order to prevent the slowdown of the experimental process. In addition, it is noteworthy that there is a need to implement experimental checks on the set-up of the real circuit board for the LabVNC-based system. In theory, the brightness of light bulbs in a parallel circuit remains unchanged regardless of the change in the number of light bulbs. In the trial teaching, however, there was an experimental error that the brightness of each of the light bulbs in a parallel circuit became dimmer along with the addition of light bulbs. There are two possible reasons for this experimental error. The first one is related to the unexpected resistance inherent in the additional electrical components such as wires and light bulbs. The addition of such electrical components in the circuit might increase the resistance to the electric current and reduce the electric current passing through the light bulbs. The second one is related to the imperfect installation of the apparatuses in the real experimental context. The real circuit board was slightly leaned against a wall for the convenience of connection to the host computer. This might affect the display quality, such as the one in relation to the brightness of light bulbs, on the LabVNC-based system because shadows might be appeared. To prevent the occurrence of the abovementioned experimental error, precautions such as careful selection of electrical components and proper arrangement for the installation of the real circuit board and the LabVNC-based system should be adopted.

6. Conclusion

With the aim of facilitating senior primary school students aged from nine to eleven in Hong Kong to engage in learning by observation of the phenomena related to electrical circuits without constraints of time, space and resources in in-class experimental activities, this study adopted a design-based research approach, with the employment of an open-source software called the LabVNC, to developing a specific courseware system for conducting online remote-controlled experiments on the science target topic. The statistically significant results of a pre-test–post-test evaluation study showed that the LabVNC-based system has potential to promote students to learn the target topic under the approach of learning by observation. The teacher asserted the pedagogical value of the LabVNC-based system and the students were enthusiastic about the use of the LabVNC-based system to conduct remote-controlled experiments.

The encouraging results of this study reveal a potential for further promotion of the real classroom use of the LabVNC-based system. Particular emphasis will be placed on the possibility for the use of the LabVNC-based system to perform experiments in a collaborative approach. It is considered that at the preliminary stage a designated period for the single-login to the LabVNC-based system will be provided after school hours to encourage extended learning with the use of this courseware system. At a later stage the function of the multiple-login to the LabVNC-based system will be provided for concurrent usage of this courseware system to facilitate remote-controlled experiments under an intra-group, inter-group, intra-class or inter-class approach in anywhere anytime.

Apart from the trial teaching on the designated test-bed as done in this study, more empirical research of implementation and evaluation of the use of LabVNC-based system will be carried out in a school-based approach to justify its value for promotion and identify its areas for improvement from the school management, school teachers and education policy-makers for future widespread applications in various science-related curricula. One of the research directions deserving of attention is the cost-effectiveness analysis that compares the use of LabVNC-based system and other realistic alternatives, such as solely referring to descriptive contents in textbooks or doing real experiments in general classrooms, for the classroom learning of the target scientific knowledge. In addition to the effect of the use of LabVNC-based system on enhancing learning achievement of students, an emphasis will also be placed on the motivation of students in using the LabVNC-based system for science learning. Pre-test–post-test control group quasi-experimental studies, with a longer duration for lesson observation, will be considered after refining the instruments and enriching the teaching schemes for the further school-based empirical research at a later stage.

Alongside such empirical research, three types of technical modifications will be undergone to enhance the designed courseware system for supporting remote-controlled experiments. First, for the long-term development, the configuration of the enhanced version of the LabVNC server will be made to be operable in the Windows XP/Vista and Linux environments with the support of the latest LabVIEW 8.0 version. Second, for the rapid deployment of many other remote-controlled experiments, a general-purpose chip for controlling an array of relays will be constructed. Third, for the free construction of the graphical user interface of the system control panel, the development suite of the enhanced version will be changed from the proprietary software LabVIEW to another free- and open-source software.

Acknowledgement

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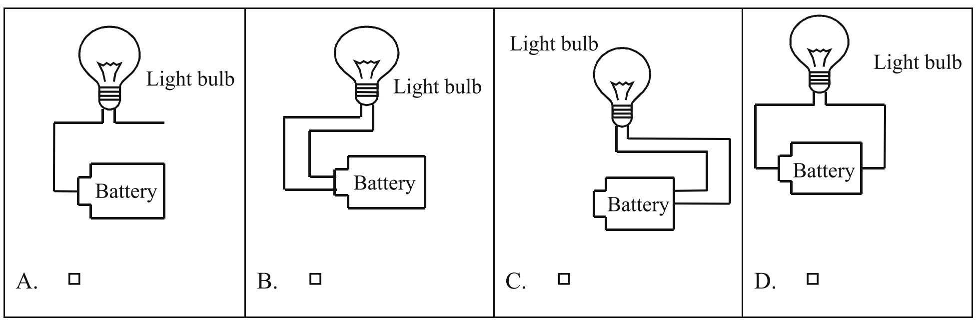
Appendix A. Pre-test paper

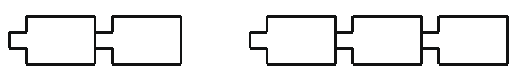
Primary General Studies – Electrical Circuits (Pre-Test)

Answer the following questions according to your experience or previous knowledge. Put '✓' or write 'A', 'B', 'C', 'D' in the appropriate boxes.

1. Which of the following circuit(s) will light up the light bulb?



2. For the circuit(s) above that can light up the light bulb, what will be the changes in the light bulb if we increase the number of battery to 2 or 3?



(A) No change in brightness
(B) Getting dimmer
(C) Getting brighter
(D) No idea

Answer: ☐

3. If the number of light bulb is increased to 2 or 3 in a correct closed circuit, in which the light bulbs are connected in a **series circuit** as shown in the diagrams below:

what will be the changes in each light bulb?

(A) No change in brightness
(B) Getting dimmer than the sole light bulb in the basic circuit
(C) Getting brighter than the sole light bulb in the basic circuit
(D) No idea

Answer: ☐

4. If the number of light bulb is increased to 2 or 3 in a correct closed circuit, in which the light bulbs are connected in a **parallel circuit** as shown in the diagrams below:

what will be the changes in each light bulb?

(A) No change in brightness
(B) Getting dimmer than the sole light bulb in the basic circuit
(C) Getting brighter than the sole light bulb in the basic circuit
(D) No idea

Answer: ☐

5. In the **series circuit** as given in Question 4, what will happen to the other light bulbs if one of the light bulbs burns out?

(A) No change in brightness
(B) Getting dimmer
(C) Getting brighter
(D) No illumination
(E) No idea

Answer: ☐

6. In the **parallel circuit** as given in Question 5, what will happen to the other light bulbs if one of the light bulbs burns out?

(A) No change in brightness
(B) Getting dimmer
(C) Getting brighter
(D) No illumination
(E) No idea

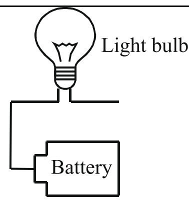
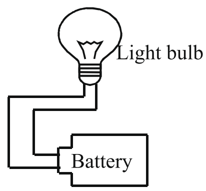
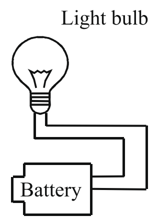
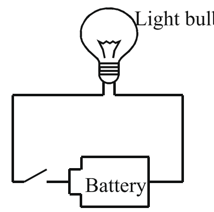
Answer: ☐

Appendix B. Activity worksheet

Primary General Studies – Worksheet for Remote-controlled Experiment on Electrical Circuits

Please follow the instructions of the worksheet to complete the below experiments on electrical circuits. Fill in your observation results in the space provided.

1. Which of the following circuits resembles most to the setting in this remote-controlled experiment?

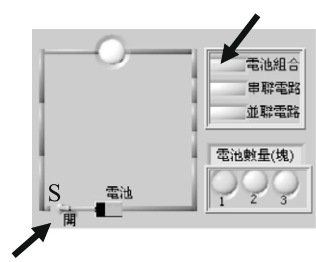
 A □	 B □	 C □	 D □

2. What will be the changes in light bulbs if the switch in the diagram below is closed? Discuss your prediction first and then record your observation results.
   (a. Getting illuminated / b. No illumination)

Steps:

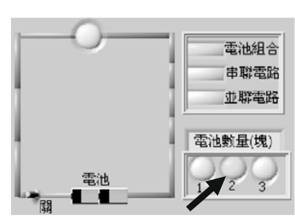
1. Press the key 'Basic Circuit' (until turning to green).
2. Then press the switch 'S' once or twice.

Switch	The light bulb is predicted to be	The light bulb is observed to be
Closed		
Opened		



3. Observe the changes in the light bulbs when the number of battery is increased to 2 or 3 (press the button '2' or '3'), as shown in the diagram below.
   (a. No change in brightness / b. Getting dimmer / c. Getting brighter)

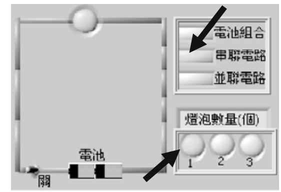
Number of battery	Prediction	Observation
2		
3		



4. After pressing the key **'Series Circuit'** (until turning to green), observe the changes in the light bulbs when the number of light bulb is increased to 2 or 3 (press the button '2' or '3'), as shown in the diagram below.

   (a. No change in brightness / b. Getting dimmer than the sole light bulb in the basic circuit / c. Getting brighter than the sole light bulb in the basic circuit)

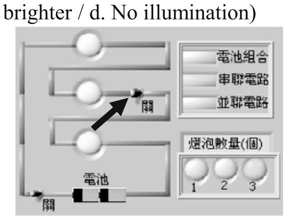
Number of light bulb	Prediction	Observation
2		
3		



5. Referring to the **<u>series circuit</u>** as given in Question 4 above, observe the changes in other light bulbs when one of the light bulbs is switched off, as shown in the diagram below.

   (a. No change in brightness / b. Getting dimmer / c. Getting brighter / d. No illumination)

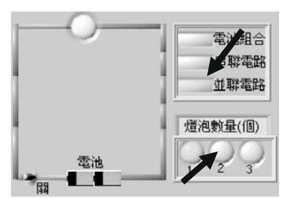
Prediction	Observation



6. After pressing the key **'Parallel Circuit'** (until turning to green), observe the changes in the light bulbs when the number of light bulb is increased to 2 or 3, as shown in the diagram below.

   (a. No change in brightness / b. Getting dimmer than the sole light bulb in the basic circuit / c. Getting brighter than the sole light bulb in the basic circuit)

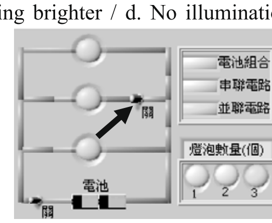
Number of light bulb	Prediction	Observation
2		
3		



7. Referring to the **<u>parallel circuit</u>** as given in Question 6 above, observe the changes in other light bulbs when one of the light bulbs is switched off, as shown in the diagram below.

   (a. No change in brightness / b. Getting dimmer / c. Getting brighter / d. No illumination / e. No idea)

Prediction	Observation

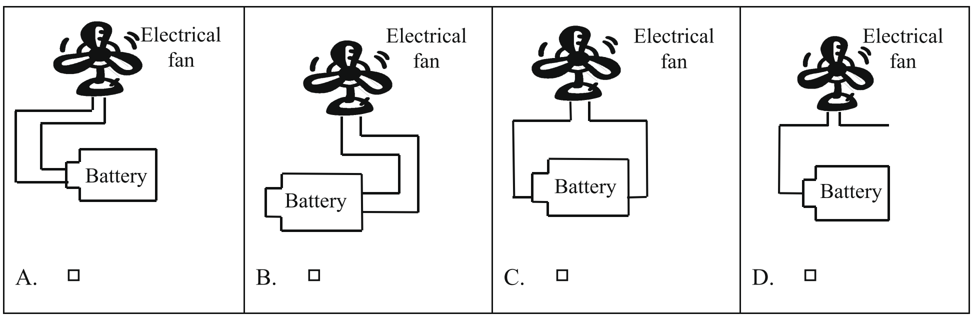


Appendix C. Post-test paper

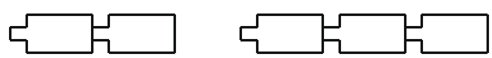
Primary General Studies – Electrical Circuits (Post-Test)

Answer the following questions according to your experience or previous knowledge of using computer to conduct remote-controlled experiments. Put '✓' or write 'A', 'B', 'C', 'D' in the appropriate boxes.

1. Which of the following circuit(s) will turn on the electrical fan?



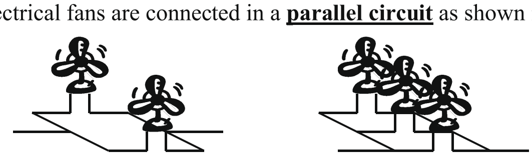
2. For the circuit(s) above that can turn on the electrical fan, what will be the changes in the electrical fan if we increase the number of battery to 2 or 3?



(A) Turning faster
(B) Turning slower
(C) No change in speed
(D) No idea

Answer: ☐

3. If the number of electrical fan is increased to 2 or 3 in a correct closed circuit, in which the electrical fans are connected in a **parallel circuit** as shown in the diagrams below:



what will be the changes in each electrical fan?

(A) Turning faster than the sole electrical fan in the basic circuit
(B) Turning slower than the sole electrical fan in the basic circuit
(C) No change in speed
(D) No idea

Answer: ☐

4. If the number of electrical fan is increased to 2 or 3 in a correct closed circuit, in which the electrical fans are connected in a **series circuit** as shown in the diagrams below:

what will be the changes in each electrical fan?

(A) Turning faster than the sole electrical fan in the basic circuit
(B) Turning slower than the sole electrical fan in the basic circuit
(C) No change in speed
(D) No idea Answer: ☐

5. In the **parallel circuit** as given in Question 3, what will happen to the other electrical fans if one of the electrical fans breaks down?

(A) No movement
(B) Turning faster
(C) Turning slower
(D) No change in speed
(E) No idea Answer: ☐

6. In the **series circuit** as given in Question 4, what will happen to the other electrical fans if one of the electrical fans breaks down?

(A) No movement
(B) Turning faster
(C) Turning slower
(D) No change in speed
(E) No idea Answer: ☐

References

Bell, P. (2004). On the theoretical breadth of design-based research in education. *Educational Psychologist, 39*(4), 243–253.
Braund, M., & Driver, M. (2005). Pupils' perceptions of practical science in primary and secondary school: Implications for improving progression and continuity of learning. *Educational Research, 47*(1), 77–91.
Colwell, C., & Scanlon, E. (2002). Using remote laboratories to extend access to science and engineering. *Computers and Education, 38*(1–3), 65–76.
Design-BasedResearch Collective (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher, 32*(1), 5–8.
Hawkins, J., & Collins, A. (1992). Design-experiments for infusing technology into learning. *Educational Technology, 32*(9), 63–67.
Hill, A., & Gaughan, S. (2006). Open source software: Is it a solution for schools? *Library Media Connection, 25*(3), 58–59.
Hoadley, C. P. (2002). Creating context: Design-based research in creating and understanding CSCL. In G. Stahl (Ed.), *Computer support for collaborative learning 2002* (pp. 453–462). Mahwah, NJ: Erlbaum.
Hoadley, C. M. (2004). Methodological alignment in design-based research. *Educational Psychologist, 39*(4), 203–212.
Kearney, M. (2003). A new tool for creating predict–observe–explain tasks supported by multimedia. *Science Education News, 52*(1), 13–17.
Kearney, M. (2004). Classroom use of multimedia supported predict–observe–explain tasks in a social constructivist learning environment. *Research in Science Education, 34*(4), 427–453.
Kearney, M., Treagust, D., Yeo, S., & Zadnik, M. (2001). Student and teacher perceptions of the use of multimedia supported predict–observe–explain tasks to probe understanding. *Research in Science Education, 31*(4), 589–615.
Martin-Hansen, L. (2002). Defining inquiry. *The Science Teacher, 69*(2), 34–37.
Mihura, B. (2001). *LabVIEW for data acquisition*. Upper Saddle River, NJ: Prentice Hall PTR.
Richardson, T., Stafford-Fraser, Q., Wood, K. R., & Hopper, A. (1998). Virtual network computing. *IEEE Internet Computing, 2*(1), 33–38.
Scanlon, E., Morris, E., Di Paolo, T., & Cooper, M. (2002). Contemporary approaches to learning science: Technologically-mediated practical work. *Studies in Science Education, 38*, 73–114.
Scanlon, E., Colwell, C., Cooper, M., & Di Paolo, T. (2004). Remote experiments, re-versioning and rethinking science learning. *Computers and Education, 43*(1–2), 153–163.
Taber, K. S., de Trafford, T., & Quail, T. (2006). Conceptual resources for constructing the concepts of electricity: The role of models, analogies and imagination. *Physics Education, 41*(2), 155–160.
Tomkins, S. P., & Tunnicliffe, S. D. (2001). Looking for ideas: Observation, interpretation and hypothesis-making by 12-year-old pupils undertaking science investigations. *International Journal of Science Education, 23*(8), 791–813.
Travis, J. D. (2002). *LabVIEW for everyone*. Upper Saddle River, NJ: Prentice Hall.
von Krogh, G., & von Hippel, E. (2003). Special issue on open source software development. *Research Policy, 32*, 1149–1157.
White, R., & Gunstone, R. (1992). Prediction–observation–explanation. In R. White & R. Gunstone (Eds.), *Probing understanding* (pp. 44–64). London: The Falmer Press.
Wu, X. Q., Yeung, Y. Y., & Kong, S. C. (2007). Application of the LabVNC-based system open source software in web-based remote-controlled experiments. In J. Lee, T. Shih, Q. Wang, & Y. Zhao (Eds.), *Research in IT and education: A multi-disciplinary perspective* (pp. 218–221). Beijing: Beijing Normal University Press.