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Deposited on: 22 Dec 2021

Interactive Virtual Reality Game for Online Learning of Science Subject in Primary Schools

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Abstract— **Education plays an important role in nurturing children. COVID-19 pandemic brings challenges or disruptions to school education, due to school closures in some countries. Science subject in primary schools is unique as hands-on experiments are important learning components. Its learning process may be affected, as a new norm of online learning or home-based learning. This research project creates a serious game on science subject for primary school students aging within 10 to 11 years old using virtual reality (VR) technology. It consists of three virtual learning phases. Phase 1 explains theories of science topics on electricity and electric circuits. Phase 2 provides interactive hands-on experiment exercises where students can practice theory knowledge learned in the previous phase. An interactive quiz session is offered to reinforce the learning in Phase 3. Interactive VR features enable primary school students learning abstract science concepts in an interesting way compared to conventional classroom settings. Meticulous design attentions have been placed in the details such as visual instructions, voice instructions, speech tempo, animations, and colorful graphics to create a sense of realism and keep students actively engaged. Preliminary case study has been conducted with 10 students at primary schools in Singapore to evaluate learning effectiveness in this research.**

Keywords—virtual reality, serious game, virtual learning, online learning, primary school science education

I. INTRODUCTION

Education is a key for all children to thrive in the future and lead a better life at their adulthood. Children must attend primary school education, e.g., compulsory education policy in Singapore. It reflects the importance of primary school education to children. Most of primary school learnings are usually conducted face-to-face (F2F) in classroom settings. School learning is deeply impacted by school closures during the COVID-19 pandemic. Without going to school, learning routine of students has been disrupted with major learning impediments. Children have lost their F2F classroom time with their teachers and have to adapt to online learning or home-based learning quickly. Online learning has become a necessity and the norm in the pandemic [1].

In Science, Technology, Engineering, and Mathematics (STEM) education, science subject is a practical and comprehensive subject [2]. It is a knowledge discipline [3].

Science education consists of learning activities including theory concepts, knowledge, observations, scientific practices, and experimentation [4]. Learning science subject is unique where hands-on practices and experiments are important to reinforce the knowledge. Some topics in the science subject in primary schools are considered tough to students, due to abstract concepts or dynamic processes. It is difficult to visualize or interact in the learning process, similar to other STEM subjects [5]. Such challenges will become severer with online learning or home-based learning, as time of physical hands-on experiments reduces significantly. It is necessary to explore complementary educational technologies to help the learning and laboratories experiments of the primary school science subject.

Educational simulations, serious games, interactive digital media, and immersive three-dimension (3D) technologies have been reported for technology-enhanced learning [6]. Simulation-based education is a way to improve hands-on learning activities [7]. Educational serious games are integrated with pedagogical theories and learning contents, benefiting students from positive learning motivations and performances [8]. It has been reported in various applications such as education, training, healthcare, etc. [9]. Interactive digital media is able to further improve learning engagement and effectiveness [10]. With the technology advancement and affordable cost on immersive 3D rendering, virtual reality (VR) has been adopted increasingly in educational serious games [10,11]. VR serious games construct realistic virtual game scenes and virtual world, with visualization and interactivity for education and learning components.

Positive learning outcomes of educational simulations and serious games on science education have been reported in the literature [8,12]. A science learning application with simulations running on iPads is presented to teach young children learning simple electricity concepts, electronic components and electric circuits [13]. A more depth virtual learning simulation built with Virtual Labs Electricity software is reported for undergraduate students learning concepts and behavior of electric circuits, such as measuring values of current, resistance, and voltage [14]. An educational game is introduced in learning science topic on falling objects for primary school students aging about 10 years old, where

comparisons have been made between virtual experiments and hands-on physical experiments with concrete materials [15]. Serious games are explored in learning science topics for elementary and middle schools, including force, motion, three states of water, transit of moon [16]. A virtual laboratory game is built for science education and chemical concepts for primary school students to visualize dynamic processes in three levels, i.e., macroscopic, symbolic, and sub-microscopic [17]. It helps students better develop the formation of mental models of science concepts on atoms, ions, or molecules, etc. A serious same is designed to conduct virtual science laboratory classes in secondary schools, to train science laboratory safety procedures and potential risks including existence of electricity, gas, chemicals, etc. [18].

A VR simulation is presented for learning STEM electric circuits installations at home, usage of multimeter, measurement values of electrical voltage, current and resistance [19]. It is evaluated using four factors including feature, usability, learning experience and outcomes, showing that students can better gain knowledge to construct electric circuitry. A VR educational serious game with both head-mounted display (HMD) and monitor display is developed to learn knowledge and behavior of honeybees for learners aged in 13-16 years old [20]. Experimental comparisons have been performed among paper-based learning, HMD VR learning and monitor display VR learning, where both HMD based and monitor display based learning exhibit better engagement and enjoyment for students. Similar comparisons have been performed in learning chemistry concepts and visualizing microscopic chemical interactions for secondary STEM education, where students using HMD VR and monitor display VR reflect better effectiveness in the learning of abstract concepts [21]. Science learning contents including knowing various animals and plants implemented by immersive VR are reported, which help primary school students aging about 11 years old develop conceptual science knowledge [22]. VR teaching materials are introduced to learn science process of pinhole imaging and sun-moon-stars system by observing various experimental phenomena from different angles [23]. Evaluation comparisons are conducted between the scientific VR materials and conventional teaching videos with two groups Grade-5 students at primary schools, where evaluation results show better problem-solving abilities for students using VR materials. Immersive VR simulation and game for science and biology topics at college level are studied on human bloodstream through virtual tour into blood cells [24]. A 3D VR experiential game for science learning on formation process of rocks and minerals for Grade-6 primary school students [25]. Students learning through the 3D VR game show better learning achievements and problem-solving tendency comparing to students through conventional learning approach. An immersive VR simulator in K-12 science education is used to explore by students traveling in a virtual solar system and learning concepts of light years, spaceship, earth, etc. [26].

The objectives of this research project are to create an interactive VR serious game for hands-on laboratory experiments of the science subject at primary schools. It enables students to continue learning remotely without disruption, even with school closures due to pandemic. The interactive VR serious game named Talking Parrot teaches science topics about electricity and fundamental electric circuits to Grade 4-6 primary school students. The Talking Parrot is a cute virtual avatar designed by our research team

for the VR serious game to captivate the interests of students, as animals are comforting helpers to children in communication and learning [27]. The virtual Talking Parrot teaches students the knowledge of electricity, electrons, resistance, components, series circuits, parallel circuits, combination circuits, and short circuit, etc. It describes how the electric current flows in different types of electric circuits. Some science topics are abstract to primary school students. Usually, it is difficult for students to physically visualize electron and electrical current flows inside an operating electric circuit with conventional teaching aids or static materials. With the developed interactive Talking Parrot serious game, students are able to learn theory knowledge, perform hands-on practices to build various types of electric circuits, observe dynamic electron flows, understand short circuit phenomenon, compare outcomes with different configurations of components in electric circuits, etc.

Coupled with realistic VR features, the interactive learning and dynamic scenarios are able to keep students being engaged and make their learning fun. This Talking Parrot serious game is developed with Unity3D with user friendly graphic interfaces. The game objects are created as the same appearances as those physical items in electric circuits. It helps primary school students better correlate laboratory items in the virtual hands-on practices. With some training given to students, they can quickly know how to play the Talking Parrot serious game by themselves. After the virtual hands-on practice in this serious game, there is an interactive quiz to test students' learning outcomes.

The remaining parts of this paper are organized as follows: Section II presents the research methodology and learning phases of the Talking Parrot serious game. Its software design and implementation are introduced in Section III. Preliminary case study is conducted by comparing the conventional paper-based learning and the serious game based online learning, The evaluation results and survey feedback are discussed in Section IV. Section V concludes this paper, with some future improvements and recommendations.

II. METHODOLOGY

Experience is one of sources of learning process. By reflecting on experiences, experiential learning is a learning process through experiments or practice [28]. According to the experiential learning model of David Kolb [29], experiential learning consists of iterative 4-stage processes: concrete experience (feeling), reflective observation (watching), abstract conceptualization (thinking), and active experimentation & testing (doing). This continuous learning cycle keeps iterating to enable learners creating new experience and acquiring knowledge from previous learning.

The iterative experiential learning process of David Kolb integrates three key aspects: (1) **knowledge** including concepts and information gained from past learning, (2) **activity** for applying knowledge into real world scenarios, (3) **reflection** by creating new knowledge through synthesizing knowledge and activity [28]. The experiential learning cycle may occur at various settings and circumstances including on campus or off campus. It is possible to be applied in online learning or home-based learning.

Three design and learning phases are proposed in the Talking Parrot serious game as follows, according to the three key aspects of Kolb's experiential learning process.

- Phase 1 – virtual theory learning (**knowledge**)
- Phase 2 – hands-on interactive experiments (**activity**)
- Phase 3 – quiz and reinforcement learning (**reflection**)

The three key aspects of Kolb's experiential learning process are integrated into the three learning phases, that are shown in Table I. Main science topics and learning activities are listed at each learning phase. Students can conduct their learning virtually in the experiential learning cycle.

TABLE I.   THREE LEARNING PHASES AND KEY ASPECTS

Phase	Key Aspect	Learning topics and activities
1	Knowledge	Virtual theory learning ➢ theories of electricity and electric circuits. ➢ knowledge of various types of circuits. ➢ principle of electron, electrical flow, resistance, open circuit, short circuit, switch, positive or negative polarity, etc.
2	Activity	Hands-on interactive experiments ➢ construction of various types of electric circuits. ➢ correlation circuit resistances and dimmer of light bulbs with various number of light bulbs. ➢ comparisons of various configurations of electric circuits.
3	Reflection	Quiz and reinforcement learning ➢ randomization of quiz questions to reinforce knowledge learned. ➢ stimulation and syntheses of knowledge and activity. ➢ score board as grading system to evaluate learning outcomes.

III. SOFTWARE DESIGN AND IMPLEMENTATION

The Talking Parrot serious game is designed according to three learning phases. The game scripts and objects are created according to the curriculum of science subject of Singapore primary schools. In the learning of science topics on electric circuits, every student receives a set of physical electric components including a pair of battery with a battery holder, two light bulbs with the holders, a toggle switch, electric cable wires, etc. It is for students conducting hands-on experiments to construct electric circuits by themselves. Students need to return the set of components to school in the middle of the academic year. With the designed VR serious game, students are able to construct more varieties of electric circuits with more virtual electric components. Side by side comparisons become possible and visualizable for students to observe the outcomes of different types of electric circuits virtually.
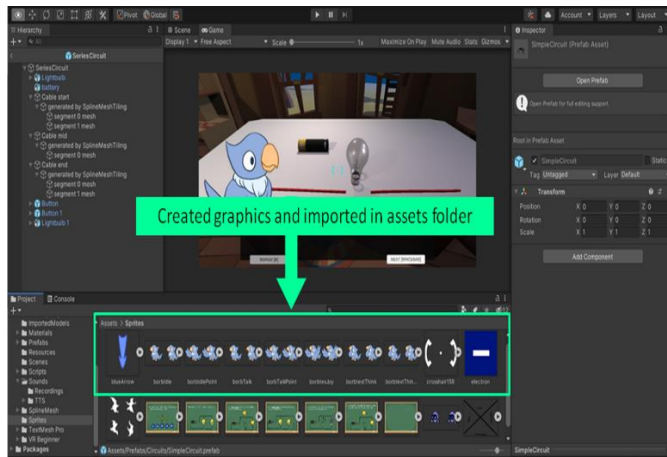

Fig. 1.   Graphic design of the talking parrot virtual teacher in Unity3D

The software design of game objects and game scenes is mainly with the tool of Unity3D, that is a very popular tool for developing VR serious games. Besides, several other software tools are also used including Photoshop, Microsoft Paint, speech-to-text engine, and speech tempo reduction engine.

The talking parrot teacher is the virtual avatar in the serious game to better engage students. The reasons for choosing the parrot as the avatar are its colorful appearance and being commonly seen in zoos, bird parks or cartoons, etc. Several types of moods of the talking parrot have been created in different game scenes, as shown in Fig. 1.

Both visual instructions and voice instructions are integrated in the game scenes of the serious game. It enables students following clear instructions to "see and listen" for better learning effectiveness. The voice conversations and dialogues scripts are developed using C# programming language in Unity3D.

Teaching tones, voices, and speech tempo of teachers in classroom settings are important elements, as these can impact how young students learn and absorb knowledge [30]. Lowering speech tempo of a teacher has positive impacts on intelligibility by students according to prior studies. As such, all audio dialogues in this serious game have been undergone through speech tempo reduction engine, to reduce the speech rate. The visual instructions have been also synchronized with the low speech tempo of voice dialogues.
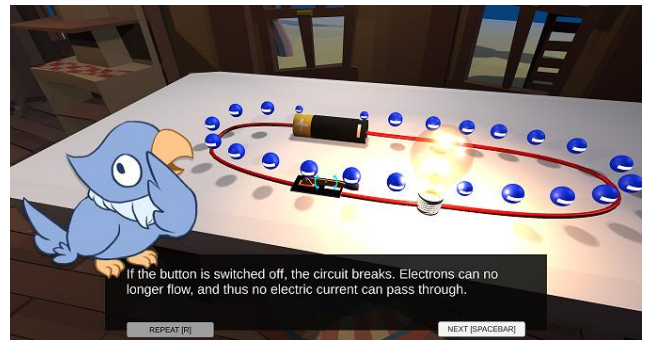
(a) Series circuit with one light bulb and one switch
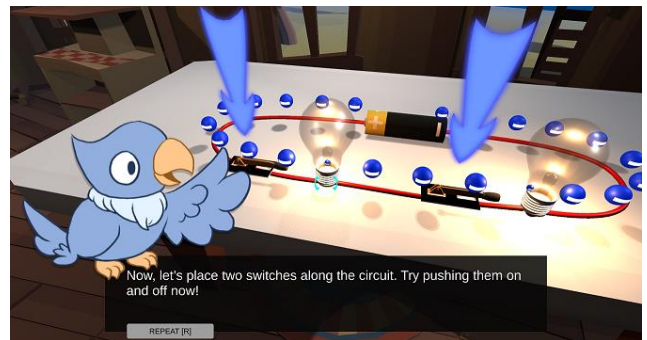
(b) Series circuit with two light bulbs and two switches

Fig. 2.   Example of screenshots of series circuit comparisons

For the learning topics and activities in Phase 1 shown in Table 1, corresponding game scenes are developed in the serious game. Students are taught theories for electron flows, resistance, components, and various types of electric circuits, i.e., series circuit, parallel circuit, combination circuit, and short circuit, etc. For example, students are able to learn differences between series circuits and parallel circuits under configurations of different number of light bulbs and switches.

If more light bulbs are added in a series circuit, it will reduce the brightness of each light bulb, due to the increment of circuit resistances. Exemplar screenshots of comparisons of series circuits are shown in Fig. 2 and Fig. 3.


Fig. 3. Series circuit with more light bulbs for brightness comparisons

Any toggle switch in an electric series circuit is going to turn on/off the entire series circuit. While for a parallel circuit, toggle switches can only control the light bulbs in the same branches. Exemplar screenshots of comparisons of parallel circuits are shown in Fig. 4. Besides, more light bulbs are added in branches of a parallel circuit, the brightness of each light bulb keeps unchanged. It is because the electric current flows through each parallel branch are the same.
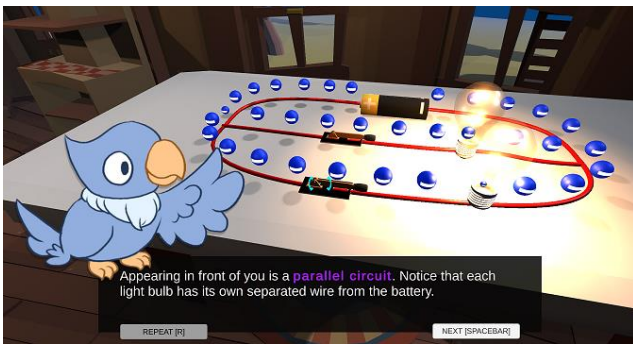
(a) Parallel circuit with both switches and light bulbs being on
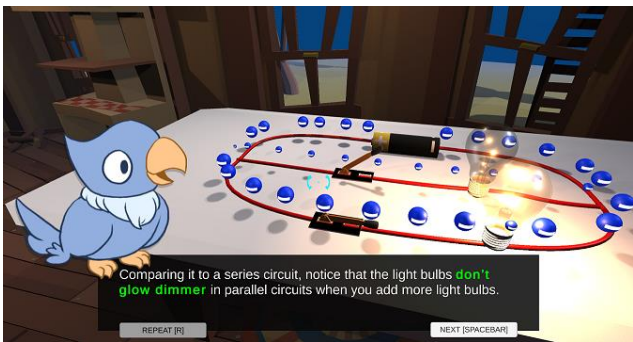

(b) Parallel circuit with one switch being off

Fig. 4. Example of screenshots of parallel circuit comparisons

In the Phase 2 learning, students are asked to construct different types of electric circuits using multiple light bulbs, based on their knowledge gained in Phase 1. They can make comparisons of different configurations of electric circuits by themselves through hands-on experiments virtually. Example screenshots of a parallel circuit and a combination circuit are shown in Fig. 5.

Students can also construct and observe the electron behaviors of a short circuit, that is difficult to visualize in a physical electric circuit. The short circuit is caused by connecting the electric cable wires directly between the positive and negative polarities of the battery without going through any light bulb or resistors in between. In the real world, the connection of a short circuit damages the electric components or cause safety risks. The VR serious game illustrates very fast electron flows that keep running in the short circuit, which alarms to students. The electron flows stop once the connection in the short circuit is broken down.
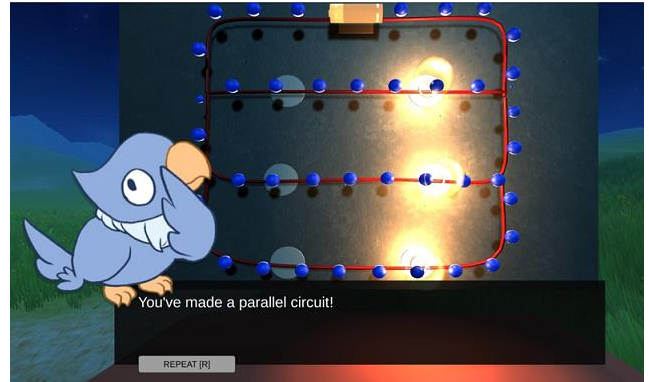
(a) An example parallel circuit constructed
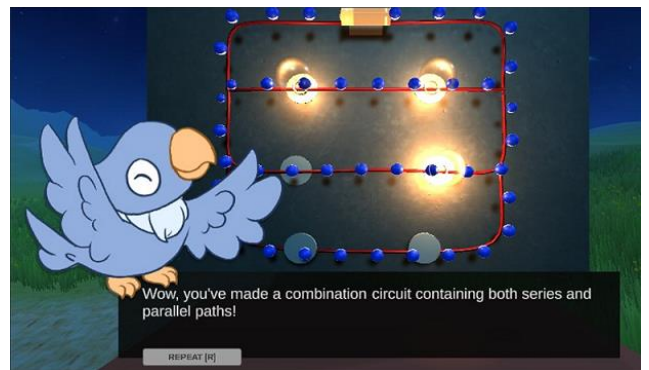
(b) An example combination circuit constructed

Fig. 5. Examples of screenshot of constructed electric circuits

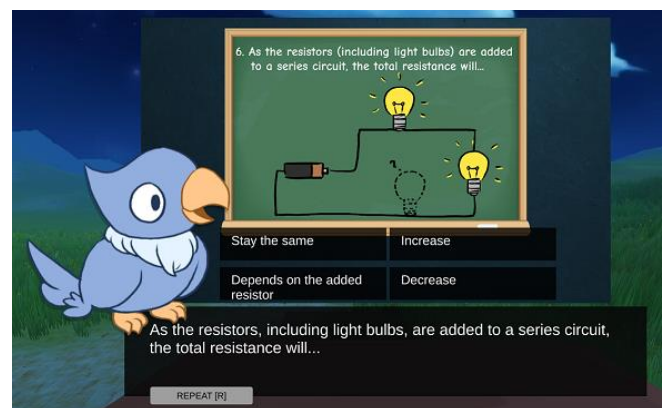Fig. 6. Example of quiz questions in Phase 3

In the Phase 3 learning, the serious game generates six multiple-choice questions (MCQ) in randomized order each time as the quiz. Students are required to perform the quiz in the serious game. Each answer chosen by a student, for either right or wrong, is accompanied with the detailed explanation by the serious game. It helps students reinforce their learning

and better knowledge retention. The quiz is graded at each session. The results will be given to students for them to improve in the next experiential learning cycle. An example quiz question is shown in Fig. 6.

IV. CASE STUDY

A. Configurations of Case Study

The case study has been conducted with 10 students from primary school Grade 4-5 in Singapore. Amongst these 10 students, four are girls and six are boys. These 10 students are randomly chosen from members of a church in Singapore. These students and their family members visit this church every weekend. Prior consents have been obtained from the parents or guardians of these students. The topics on electricity and electric circuits in the science subject are taught in Grade 5 in their schools. These students have not learned these science topics in their schools yet before the case study.

There are two case study sessions, with four weeks' gap in between. The four weeks' gap is to reduce the knowledge retention or coupling from Session 1 into Session 2 [31, 32]. The procedure of the case study is shown as follows.

1) In Session 1, all 10 students are taught using conversional classroom setting with paper-based teaching materials on these science topics.

2) A paper-based quiz is conducted for all 10 students. There are six MCQ questions with four options for each quiz question, one mark for each quiz question.

3) Sessions 2 is conducted after four weeks later. All 10 students are invited to play the Talking Parrot serious game to learn these science topics. The wordings and descriptions in the serious game are different from the paper-based teaching materials.

4) All students attempt the quiz in the serious game after their game plays. There are six MCQ questions with different descriptions, but testing similar learning outcomes as those of the Session 1 quiz. One mark is for each quiz question. The orders of six questions are shuffled randomly. There are four options of each quiz question with randomized orders.

5) All students take the survey questionnaires after completing the two sessions.

In Session 2, we assume that students cannot easily refer to their knowledge learnt in Session 1, due to the four weeks' gap, different descriptions, randomly shuffled quiz questions, and randomly shuffled option orders of each question.

B. Result Analyses

The quiz results are recorded for all students and compared between these two sessions of the case study, as shown in Table II. It is observed that the mean score percentage of Session 1 with the conventional paper-based teaching is 55% (i.e., 3.3 marks out of 6 marks). While the mean score percentage of Session 2 with the Talking Parrot serious game learning is about 91.7% (i.e., 5.5 marks out of 6 marks). The average quiz performance improvements of these 10 students are about 36.7% in Session 2. It is observed a significant improvement of the learning performance.

Besides the quiz results analysis, all students are asked to fill up a questionnaire survey form after the completion of two case study sessions. It is to obtain their feedback on the VR serious game learning compared to the conventional paper-based learning. The questionnaire survey form is shown in Table III.

TABLE II. QUIZ RESULTS COMPARISONS

Student No	Session 1 Quiz	Session 2 Quiz
1	3 marks	6 marks
2	3 marks	6 marks
3	2 marks	5 marks
4	5 marks	5 marks
5	4 marks	6 marks
6	4 marks	6 marks
7	3 marks	6 marks
8	4 marks	5 marks
9	2 marks	5 marks
10	3 marks	5 marks
Mean Score	3.3 marks	5.5 marks
% of Mean Score	55.0%	91.7%

TABLE III. SURVEY FORM IN THE CASE STUDY

No	Questionnaire	Your responses
(1)	Do you like the conventional paper-based learning method?	Yes / No
(2)	Do you like the learning method of playing Talking Parrot serious game?	Yes / No
(3)	Compared to learning method (1) and (2), which learning method do you like more?	(1) / (2) / Both / Neither
(4)	After playing the serious game, I can recognize the items in electric circuits.	Yes / No
(5)	Playing the serious game helps me better understand about series circuits.	Yes / No
(6)	Playing the serious game helps me better understand about parallel circuits.	Yes / No

TABLE IV. SURVEY RESPONSES OF ALL STUDENTS

Student No	Question (1)	Question (2)	Question (3)	Question (4)	Question (5)	Question (6)
1	No	Yes	(2)	Yes	Yes	Yes
2	No	Yes	(2)	Yes	Yes	Yes
3	No	Yes	(2)	Yes	No	No
4	No	Yes	(2)	Yes	Yes	Yes
5	No	Yes	(2)	Yes	Yes	Yes
6	No	Yes	(2)	Yes	Yes	Yes
7	No	Yes	(2)	Yes	Yes	Yes
8	No	Yes	(2)	Yes	Yes	Yes
9	Yes	Yes	(2)	Yes	Yes	Yes
10	No	Yes	(2)	Yes	Yes	Yes

Printed hardcopies of questionnaire survey forms are distributed to all students. As these young students are at their 10-11 years' ages, they are under the guidance or helps of their guardians when filling up the survey forms. Their guardians explain the meaning of survey questions in the questionnaire, in case these students have difficulty to understand correctly

the survey questions. Their feedback responses for the survey questions are recorded, as shown in Table IV.

It is observed from the survey responses in Table IV that 100% of the students like the learning method of playing the Talking Parrot serious game. All of them prefer to the online learning serious game compared to paper-based learning method. It is also observed that 90% of the students are able to better understand the theories of electric circuits after playing the Talking Parrot serious game. It closely matches with the mean score percentage of 91.7% in the quiz of Session 2, shown in Table II. Observed from the case study, all students have responded very positively to the Talking Parrot serious game. Their enjoyments and exciting are observed during their game playing in Session 2 of the case study.

V. Conclusions and future works

The mode of conventional classroom learnings has been changed by the COVID-19 pandemic. Online learning or home-based learning have become the new norm. Teachers and students have been adapted into such new learning modes. A Talking Parrot serious game has been developed according to Kolb's experiential learning process, guided by a virtual science teacher. This project leverages on interactive digital media and VR technologies for primary school students learning abstract topics in science subject more effectively. Young students get to immerse in colorful virtual game scenes and learn through interactive game playing in the VR serious game. It is useful for virtual laboratories sessions for hands-on experiments remotely under online learning or home-based learning. The developed VR serious game is not to replace teachers and conventional learning mode. Instead, it provides a complementary learning mode to the conventional teaching. It provides students with another layer of engagements and fun elements in the learning.

Case study has been conducted with 10 students from primary school Grade 4-5, with the consents of their guardians. Students attend two sessions of case study, where the learning modes are different. In Session 2 of the case study, students learn science topics on the electricity and electric circuits using the Talking Parrot serious game. Quizzes are conducted to all students in each session of the case study. The quiz results are compared and analyzed. Students' feedback on the learnings are collected through a questionnaire survey form after they complete two sessions of the case study. It is observed from the quiz performance and survey feedback, students gain knowledge more effective by the VR serious game learning. Most students in the case study express their preference to the Talking Parrot serious game learning compared to the conventional paper-based learning.

There are several limitations in the current design of the Talking Parrot serious game. Future improvements could be developed to the items as follows.

1) *Adding the Backwards button:* Currently the Talking Parrot serious game has no button to go back to the previous game scenes in each learning phase. It only has two options of repeating the current game scene and going to the next game scene. If students want to go back the previous game scene, they have to repeat from the beginning game scene of the correpsonding learning phase. Adding the Backwards button can better help students return to previous game scenes easily.

2) *Add a digital countdown timer for the quiz:* Currently, the quiz in Phase 3 of the Talking Parrot serious game has no timer. Students can spend long time in answering each quiz question. In reality, school examinations are mostly timed. Adding a digital countdown timer into the quiz can train young students to be time sensitive in attempting quiz questions. Students need to complete the quiz within certain time limit.

3) *Adding more quiz questions:* Currently, each time there are only six MCQ questions generated and shuffled randomly with random answer options in the quiz. Through the feedback from the students in the case study, the interactive quiz is a fun "highlight" of the Talking Parrot serious game. But the number of quiz questions are small. More quiz questions are required to be generated in the serious game, to achieve more in-depth and thorough assessments.

4) *Saving quiz results of each student in cloud storage:* If adding this feature into the Talking Parrot serious game, the quiz results of each student can be saved in cloud storage. It can help teachers know the learning performance of each student remotely.

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