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Integrating Games, e-Books and AR Techniques to Support Project-based Science Learning

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ABSTRACT: The study integrated learning technology and various e-learning materials to assist teachers in conducting project-based learning for a science course. The activities were designed for learning science concepts such as circuits and the symbols of electricity firstly, and then for applying the concepts to produce a scientific toy. The study intended to integrate the value of the convenience and accessibility of e-books, the feature of interactive demonstration, a combination of visual information with physical objects using augmented reality (AR), and the enjoyment brought by game-based learning to create an integrated e-learning model to support project-based learning processes. A total of 51 elementary school students were invited to take part in the research and were separated into two groups, one using the game-based learning environment with AR-based materials and the other with e-books for the science project-based activity. Despite the quantitative data not presenting any learning differences for the two groups, the qualitative results showed that the e-learning materials with multimedia content were helpful for scaffolding students while completing the hands-on scientific electric current toy, and triggered peer discussion to achieve concept agreement. For example, the text and figures in the e-books helped the students to doubly confirm the processes of the learning information, while the colored blocks on the physical objects in the AR materials facilitated assembly of the elements to complete the science toy. It was noticed that the well-designed AR materials might hinder learners' thinking ability and restrict their creativity, and hence, the researcher proposes a revised e-learning integration model that combines the advantages of e-books and AR techniques to create more easily accessible e-learning supports and to encourage active thinking for fostering independent and self-regulated learners.

Keywords: Interdisciplinary projects, Project-based learning, Game-based learning, AR support learning

1. Introduction

Project-based learning emphasizes giving students chances to independently seek answers to questions and to solve problems via utilizing the learned knowledge. It also provides learners with opportunities to acquire manual skills through performing activities (Chen, 2004). Project-based learning has the potential to assist students in learning science (Panasan & Nuangchalerm, 2010) since a project-based science classroom encourages learners to explore phenomena, build up their own knowledge structure, try out new ideas and solve the problems they face (Remziye & Kargın, 2014). The key features of project-based activities are starting with a driving question and asking students to explore the question through inquiry processes. The students then learn and apply the idea to find solutions and are scaffolded by the learning technology during the inquiry processes (Krajcik & Shin, 2014). A good project-based activity would induce learners to progressively achieve higher order learning abilities at the levels of Bloom's taxonomy (Anderson & Krathwohl, 2001), where they use their basic level knowledge (remember and understand) to first solve the problems (apply and analyze), and then to produce concrete products (evaluate and create). However, it was noticed that when adopting project-based learning instruction in a course, teachers might face the challenge of limited course time, a tight course schedule, and heavy loading of course preparation (Lawson, 1995).

Researchers have argued that the abovementioned dilemma faced by teachers might be alleviated through integrating learning technology to assist instruction (Shapley et al., 2011). For example, e-books with interactive demonstration provide students with opportunities to interact with the learning content (Smeets & Bus, 2012), and using e-books with various learning methods such as the flipped classroom strategy can benefit learners' learning efficacy and achievement (Wang & Huang, 2017). The affordances of augmented reality (AR), a combination of visual information with physical objects, are helpful for presenting and explaining abstract scientific phenomena (Chen et al., 2018). The AR superimposing virtual elements onto real-world environments with visualized details provides scaffolds to help students acquire abstract science concepts (Yoon et al., 2017). Meanwhile, students have the freedom to observe phenomena, fail, experiment, and interpret in the game-based learning environment, allowing them to increase their physical skills (Klopfer et al., 2009), clarify their conceptual understanding (Barak & Dori, 2005), and promote their learning motivation (Rosen, 2009). Hence, games can serve as tools for scientific learning (Tsai & Tsai, 2020).

In short, the project-based learning approach has been shown to have positive effects on students' academic performance since it involves the transformation and construction of knowledge. It gives learners opportunities to transform and construct knowledge through asking questions, seeking answers, and performing investigations. Besides, in order to help students perform project-based activities effectively, the learning technology could be adopted in the classroom to lead more effective project-based instruction (Ozdamli & Turan, 2017), motivate learners' interest, and support them to achieve better academic performance (Chen & Yang, 2019).

1.1. Research purpose and questions

Understanding the above research background, this study aimed to conduct multi-phase research to propose a possible technology-enhanced integration model to support project-based science learning. The project-based activities in the study were designed and the technology-based learning materials were developed to support teachers with diverse curriculum materials for conducting science project-based learning activities. During the project-based learning processes, various technology-based learning materials were integrated according to their characteristics including (1)the convenience and accessibility of the e-books; (2)the nature of games that create an environment in which learners are free to explore knowledge in a low-stress and happy atmosphere, and (3)the characteristics of AR-based applications that combine virtual and real environments to offer students interactive and inquiry-based learning, adopted as scaffolding to help students acquire different cognitive knowledge levels of science concepts. The research questions of the study are:

- Are there differences in the learning performance of the students who learn through the game with e-book learning materials and the game with AR-based learning materials?
- What are the students' and teacher's feedback on using the game with e-book and the game with AR-based learning materials for learning?

2. Literature review

2.1. Project-based learning

The concept of project-based learning comes from Dewey's (1938) *learning by doing,* which is a student-centered model that organizes learning around projects or authentic learning experiences. Project-based learning encourages students to investigate questions, and to propose and explain the ideas through engaging in the activities as a form of situated learning that is based on constructivism. Constructivism encourages students to actively construct their own knowledge and reflect on how their understanding is changing (Elliott et al., 2000). The design of project-based learning is complex and is based on challenging (driving) questions or problems, for example, "How does science impact people's lives?" It involves students in learning by design, problem-solving, decision making, or investigative hands-on activities. The students could thus encounter and learn the discipline via projects (Marx et al., 1994). Krajcik and Shin (2014) summarized several key elements of project-based learning. First, start with a driving question. Use a good driving question to provide students with a context in science practice and let them build meaningful understandings of key scientific concepts when pursuing solutions to the driving question. Researchers have suggested that anchoring experiences present meaningful contexts for the science ideas explored in the project and show the value of the project's driving question. Second, encourage situated scientific inquiry and collaborations. Third, use technology tools to support learning. The learning technology tools enable learners to access information on the World Wide Web, extending to what could be done in the classroom. For example, the use of learning technology supports natural phenomenon simulation in an easier way within the limited amount of time. With the help of learning technology tools, it is possible for teachers to move away from the transmission and acquisition model of instruction, so that they are not the only ones to give knowledge, but the students can explore the environment to construct their own knowledge. Last, create a product. When students build artifacts, it enhances their understanding because they have to tie together science concepts to support the product. Besides, the teacher uses artifacts to know how students learn across various projects. Researchers have explored the effects of adopting project-based instruction in learning; for example, Remziye and Kargin (2014) made a comparison between using the project-based approach and a teacher's original method in the learning of the Electricity unit for elementary sixth graders. They found that the students succeeded more through project-based learning in the achievement tests because of their active participation.

The reviewed research has concluded that learners could promote their learning ability by proposing and investigating problems, and apply their knowledge in explaining and verifying ideas. Through these repeat processes of project-based activities, the learners would be able to progressively achieve higher order learning abilities from basic level knowledge to higher order learning skills, thus having positive effects on their learning.

2.2. Project-based science learning

Educators have noticed that learners might not be motivated to learn science since there is a lack of opportunities to help them develop their explanations of the real-world phenomena or because of the ineffective textbook design and instructional style that provide students with cookbook-like instructions, asking them to follow the procedures without having a deeper understanding of the materials (Krajcik & Shin, 2014). A project-based science classroom would be able to avoid the abovementioned situation since a project-based science course encourages learners to explore, investigate, discuss, implement and modify their ideas though trial and error procedures. According to Bloom's taxonomy, there are six levels of learning objectives in the cognitive domains of remember, understand, apply, analyze, evaluate and create (Bloom et al., 1956). A well-designed project-based science activity would induce learners to acquire knowledge from lower-order skills that require less cognitive processing to higher-order skills that require deeper and complex cognitive processing. Besides, project-based science learning would create contexts and driving questions to encourage learners to explore their idea, find solutions and have discussions to demonstrate how they understand and apply the learned knowledge (Marx, 1998). One study observed that the use of the project-based method increases learners' success in science (Ergül & Kargın, 2014), and found that students who did a project-based learning activity were able to produce new knowledge on their own investigation and exploration. Meanwhile, teachers and peers worked together and made conceptual advances through exchanging views (ChanLin, 2008). In the project-based learning scenario, students shared what they discovered during the co-operative activities and their disagreement aroused discussions that made them learn from each other (Sawyer, 2004).

It was noticed that the project-based course takes comparatively more time for teachers and students to design and complete the learning tasks since the processes of knowledge construction are not easy to perform. Moreover, instructors have revealed the difficulty of improving learners' motivation and making them concentrate on learning tasks, especially when project-based activities are applied in large classes (Sumarni, 2015). From this point of view, technology tools would be helpful because learning technologies allow students to access real data and extend what they can do in the classroom for actively constructing knowledge.

2.3. Technology-supported project-based science learning

The use of learning technology tools presents learning information in more dynamic and interactive formats that could serve as powerful instructional tools to help teachers more effectively foster inquiry learning (Nielsen et al., 2016). For example, some science phenomena, such as magnetic fields, atoms or galaxies, cannot be easily observed, and researchers have indicated that computerized visualization or animation to present and explain abstract scientific phenomena is more effective and permanent than traditional learning (Dori & Belcher, 2005). Besides, traditional hands-on experiments in science laboratories could be broadened or enhanced through integrated simulation and animation tools (Krajcik & Mun, 2014). It has been argued that teaching physics through computer-based simulations, 2D-based animations or animated movies makes the content more easily graspable (Barak et al., 2011;).

Several studies have integrated the learning technology into support project-based learning activities, and have suggested that technology-supported learning could be a good way for teachers to create more interactive and student-centered learning when integrating project-based activities into courses (Ozdamli & Turan, 2017). For example, Eskrootchi and Oskrochi (2010) found that using a computer-based project-based environment for simulation helped to improve students' understanding of the science watershed concept learning. Ozdamli and Turan (2017) adopted a blended learning environment to support a project-based science learning activity for college students taking a mobile application development course, and explored the effects on students who learned with and without the technology supported project-based learning steps. They found that these students showed better learning success than those learning with traditional methods. Sung and Wu (2018) explored the effects of integrating project-based activities with or without e-books to support a nursing course for learning health concepts, and found that the comprehension and ability of the learners with the e-books were improved, and learners' cognitive skills and problem-solving ability were improved via the project-based learning. Using technology tools during project-based learning enables learners to access information easily on the World Wide Web, extending what could be done in the classroom (Krajcik & Shin, 2014), and creating more interactive and student-centered learning (Chauhan, 2017).

2.4. The learning media: games, e-Books and AR for learning

Learning media have evolved quickly with the development of learning technologies. The value of the convenience of e-books, a combination of visual information with physical objects using AR, and the enjoyment brought by game-based learning are new media which in some sense subsume earlier media (Collins, 1994).

E-books, also known as e-textbooks, digital-textbooks or electronic textbooks, embed multimedia and have more interactive functions than traditional textbooks (Weng et al., 2018). The value of the accessibility of the e-books makes them welcome by most teachers and students (Embong et al., 2012). Meanwhile, the creation of individualization and learning based on students' self-paced learning, and the embedding of an appropriate number of multimedia in e-books can help learners to improve their learning (Spanovic, 2010). Weng et al. (2018) stated that good utilization of e-books provides students with chances to engage collaboratively. Hwang and Lai (2017) adopted e-books to support flipped learning, and revealed that the use of e-books with interactive learning content facilitates in- and out-of-class learning. Chen and Su (2019) used an e-book reading system to trace students' learning progress, and found that the system supported students' self-regulated learning and self-efficacy.

Game-based learning is a highly exciting medium which refers to using game elements to engage students in tasks for achieving learning goals (Liao et al., 2013). The game-based learning environment provides students with a wide range of ways to experience trial-and-error processes, and they could hence achieve self-regulated learning in solving the tasks during gameplay (Plass et al., 2015). Meanwhile, learning occurs during gameplay providing a powerful affordance for supporting learning interaction, increasing learning motivation and promoting learning performance (Gee, 2003). Researchers (Liao et al., 2013) have revealed that students improved their science concepts and performance with the game-based practice, and that the game-based interaction was effective in terms of engaging students in discovering environments and enacting problem solving.

The AR-based learning materials merge virtual information with real objects and present virtual information such as text, video, audio, and three-dimensional learning content for instruction interaction. The characteristics of AR-based application include the integration of static and dynamic content, and the combination of virtual and real environments plays a beneficial role in science education regarding concept change, inquiry-based learning, practical skills and scientific argumentation (Chen, Huang & Chou, 2017). Teachers have suggested that AR learning materials would be more helpful if they could be more flexible and controllable in terms of adding or removing elements to or from the AR content (Kerawalla et al., 2006), and it has been reported that AR technology offers promise for transforming science learning. For example, Cheng and Tsai (2013) explored the effects of integrating AR into supporting science learning, and claimed that image-based AR would benefit learners' practical skills and conceptual understanding, while location-based AR is more helpful for inquiry-based scientific activities. Matcha and Rambli (2013) developed an image-based AR application, AR Circuit, to assist students in investigating the relationship of the elements in an electric circuit, and found that the physical AR objects promoted learners' discussion and collaboration during science concept learning. Chen et al. (2017) presented a blended learning environment through AR techniques to help elementary school students understand the growth pattern of leaves in a science course, and concluded that AR-based blended learning was helpful for outdoor exploration activities. Yoon et al. (2017) found that learners using the AR technique demonstrated better knowledge gain on science because AR affords greater ability to visualize details and hidden information. Studies have indicated that using learning technology sustains learners' motivation and learning engagement (ChanLin, 2008) and leads to effective learning (Chauhan, 2017). Despite the fact that many studies have revealed the positive learning effects of using AR techniques for learning, some have argued that learners with AR supports were less engaged than those using traditional learning resources because they were asked to watch an AR animation and describe it passively instead of having the chance to do the exploring (Kerawalla et al., 2006).

2.5. Summary of the literature review

After reviewing the related literature, the possible advantages of project-based learning and the features of technology-supported learning have been presented. The project-based approach enables learners to learn multiple disciplines and progressively build their own learning from basic level knowledge to higher order learning skills during the completion of the tasks. Besides, supporting teachers with diverse curriculum materials for conducting science project-based learning activities is also important. The technology tools would be helpful to support project-based instruction, and the use of game-based learning can arouse students' learning motivation, and the adoption of e-books and AR-based content creates more interactive environments for self-exploring activities. Hence, in this study, the e-learning materials were developed with the aim of combining the features of technologies to support teachers in designing the project-based science activities and to scaffold students in acquiring science knowledge from the basic cognitive process dimension to a higher order level.

3. E-learning materials design and development

Better design of learning educational applications could be achieved by having teachers and educational technology experts work together in a collaborative process of development to reduce the gap between system designers and practitioner teachers. Hence, science instructors were invited to participate in the co-design stage for structuring the project-based activities and learning materials according to various learning purposes. The co-design stage lasted for about half a year in which the research data from interviews from the science teacher and class observation were collected as a pilot study to understand the teachers' needs and students' learning problems (Figure 1).

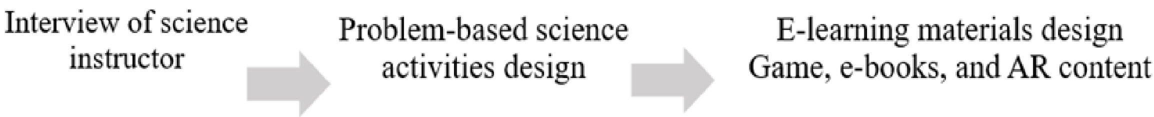


Figure 1. The process of content development

After analyzing the data from the co-design stage, it was found that the students' difficulties might include the concept of electric circuits or the characteristics of electricity such as comprehending or designing the real shapes of electric circuit diagrams. Hence, in order to assist students in adopting the learnt concepts into practice, the project-based activity and e-learning materials were designed and developed to help them acquire the concepts of basic electricity and then to implement the science concepts to produce a scientific electric current toy.

3.1. The structure of the materials

The learning content was designed for acquiring the basic electricity concepts such as electric circuits, the concepts of paths, open and short electric circuits and series and parallel, and the advanced knowledge such as combining the electrical elements and completing the scientific electric current toy. The learning content included two topics (Figure 2). Following Bloom's taxonomy, Topic1 was designed for acquiring the basic electricity concepts on the scales of the remember and understand knowledge dimensions, and Topic 2 was an advanced practical hands-on activity that asked students to apply learned science concepts in producing a scientific electric current toy for acquiring the scales of apply, analyze knowledge dimension. The game-based environment was created for Topic 1, basic concept learning, to provide learners with trial-and-error opportunities and to encourage them to do the learning inquiry through the game-based interaction. The e-books and AR-based interaction were created for Topic 2, the advanced practical hands-on activity, to give the students the necessary scaffolding to apply the previous basic science electricity concepts to complete the higher level cognitive learning tasks.

Topic 1: Basic concept learning (Remember and understand knowledge dimension)	**Topic 2: Advanced practical hands-on activity** (Apply, analyze, evaluate and create knowledge dimension)
1. To know the basic requirements of electric circuits 2. To recognize the concepts of path, open and short electric circuits 3. To know the concept of series and parallel 4. To recognize circuit diagrams, current, voltage, and resistance	1. To recognize the elements of buzzer, wire and breadboard 2. To combine the electrical elements and complete the scientific electric current toy

Figure 2. The topics and corresponding learning content

3.2. Topic 1

The purpose of Topic 1 was to acquire the basic science concepts of electrical circuits, series and parallel. There were three levels in the game. The first two were designed as multiple-choice interactions. The students explored the game-based environment with their own avatar. They had to follow the instructions and answer the questions correctly to overcome the challenges. The third level was a game-based examination, and the students had to use drag-and-drop interaction to fill in the blanks to complete the electricity diagram (Figure 3).

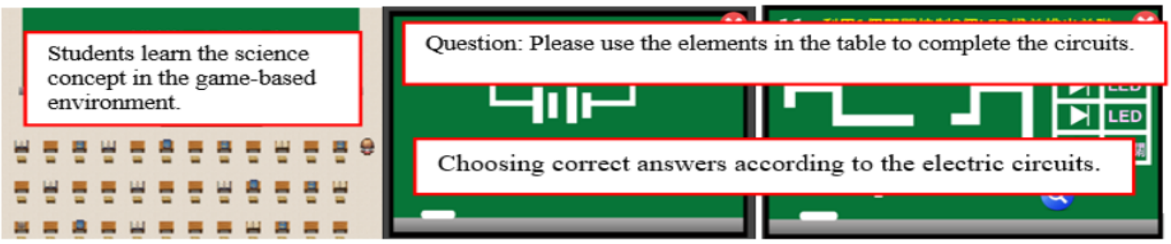
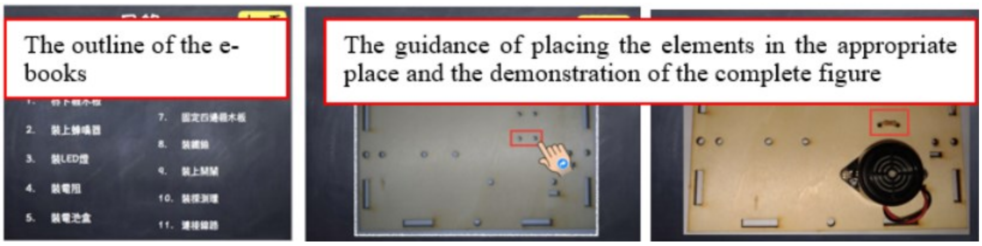


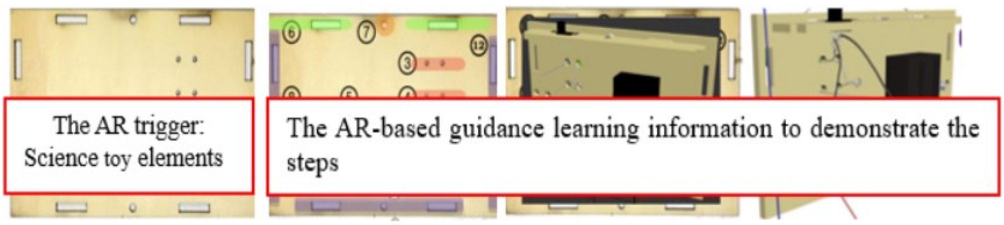
Figure 3. The game-based learning marerials

3.3. Topic 2

The purpose of Topic 2 was to encourage inquiry and to create a science toy, also called an electric current avoider. After the basic concepts were acquired, the students had to apply the previous basic science electricity concepts to complete the higher level cognitive learning tasks. The requirement of the science toy is that when the toy was powered on, the learners moved the wire ring along the other wire, and when the wire ring collided with another wire (indicating that the path was connected), the buzzer would sound. The e-books and AR-based materials were used as scaffolding to provide the students with guiding steps when they produced the science toy (Figure 4). The content and guiding steps in the e-books and AR-based content were the same. The e-books provided the learners with figures and textual instruction, while the AR-based content provided them with more interactive instruction. The students could use the learning devices to scan the science elements, and then the instruction including textual guidance, video, and 3D animation would show up on the screen.



(a) The e-book learning content



(b) The AR-based learning content

Figure 4. Print-screens of the learning materials

4. Methodology

4.1. Participants

A total of 51 elementary school students participated in the study and were randomly separated into two groups. A general science concept test was conducted to confirm that the learners of the two groups had an equal learning starting point. Group A (GA) consisted of 30 students who learned with the game-based learning materials and e-books, and Group B (GB) consisted of the other 21 students who learned with the game-based learning materials and AR.

4.2. Research design and procedure

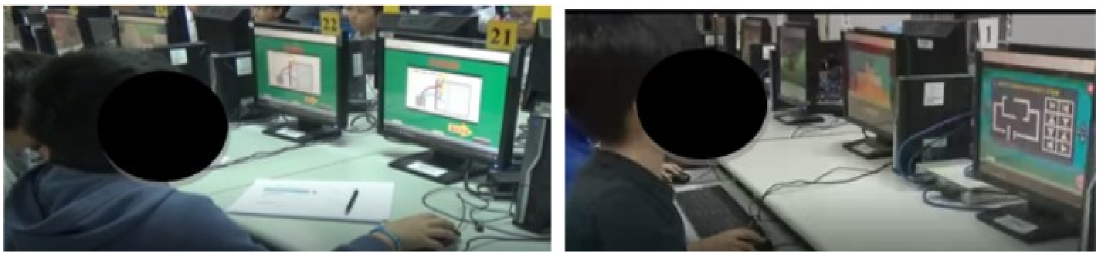
The duration of the experiment was 4 weeks, at 120 minutes per week, and the two groups were taught by the same science teacher (Figure 5). The Topic 1 activity took 2 weeks, and the students in the two groups learned the basic electricity concepts from the teacher's instruction. Both groups were able to practice with the game-based materials (Figure 6a) to acquire lower level knowledge (remember and understand).

Phase 2: Course Experiment

Weeks	Topic	Group A	Group B
1	Topic 1	Game-based learning materials	
2			
3	Topic 2	E-books	AR-based materials
4			

Figure 5. The processes and e-learning materials arrangement for the group in the experiment

Then, the Topic 2 activity took another 2 weeks in which the learners had to apply the learned knowledge to produce the scientific toy to achieve higher level knowledge (apply and analyze). During the Topic 2 hands-on session, the learners produced their science toy in the science classroom where there were several long rectangular tables, each occupied by four to five students. The teacher first demonstrated the complete version of the science toy to the students and briefly reviewed the basic concepts used in designing the toy. Then, each student got a material package including the components of boards, wires, buzzers, batteries and screws, and they had to make the science toy on their own. The students in GA were given e-books (Figure 6b) as their learning supports, while the GB students used the AR-based materials as supports (Figure 6c).



(a) Topic 1: game-based learning materials

(b) Topic 2:The e-books (c) The AR-based learning materials

Figure 6. The students doing hands-on activities with the e-learning materials

4.3. Data collection and analysis

The collected research data included students' pre- and post-tests, their hands-on activity scores, questionnaires and interview data.

4.3.1. The pre- and post-tests

The pre- and post-tests consisted of multiple-choice questions for testing the learners' basic science concepts and an open-ended question for testing their understanding of circuit connections. The test questions were designed from the school's textbook organization and course materials, and the science teacher had reviewed and confirmed that the wording and the level of the items fulfilled the learning purpose. The test was a summative evaluation that helped the researcher to examine how much the students had gained through the experiment. The total scores of the pre- and post-tests were each 100. In the multiple-choice questions, the students had to choose answers from four items to demonstrate their learning acquisition of the basic science concepts. In the open-ended question, the students had to write down and distinguish the elements of an electrical circuit.

4.3.2. The hands-on activity scores

Each student also had a hands-on activity score according to the level of completion of the scientific toy. The evaluation of the hands-on activity was graded by the science instructor according to five criteria, namely installation of the Switch, LED, Buzzer, the correctness of the circuit diagram and their debugging analysis, and each criterion was graded individually as the quantitative results according to three levels: 3 points (Full completion), 2 points (Half completion), and 1 point (No progress). The total score of the hand-on activities was 15 points.

4.3.3. The questionnaires

The research questionnaires were administered and an interview was carried out after the experiment. The questions in the questionnaires included various subscales with items on a 5-point Likert scale (from 5 to 1: *strongly agree, agree, neutral, disagree, strongly disagree*) and open-ended questions to investigate how the learners perceived using the various learning materials for science project-based learning. The purpose of conducting the questionnaires was to understand how the students perceived using various technology-enhanced learning materials for science learning in terms of functions and interface design, and general feedback including learning stratification and motivation. The question items of the two groups were the same, but one more question was added for GB (the AR group) to understand the learners' feedback on the 3D object design in the materials. For the open-ended questions, the students were encouraged to write down their feedback on using the game, e-books and AR-based materials during the activity. The coefficient α of the measures of the questionnaires from GA and GB were .98 and .95, respectively.

4.3.4. The interview

The teacher and several students (5-7of each group) were invited to take part in an interview after the experiment so as to understand their perceptions and opinions of using the materials for learning. The teacher helped the researcher to pick the students for the interviews based on their performance during the course. Half of them were those who performed especially well and the others were randomly selected by the teacher. The interview questions for the teacher were: (1) How do you perceive integrating the various e-learning materials for the course? (2) After integrating the learning materials into the hands-on activity, do you have any preference for the e-books or the AR-based learning materials? Which might help the students better? The interview questions for the students were: (1) How did you feel when you practiced the science concepts with the game-based learning materials? (2) What did you do when you started to make the scientific toy? Did you follow the instructions in the materials step-by-step or did you try on your own first? Please share your experience. (3) Did the learning materials help you to conduct the science activity? Why or why not? (4) Do you have any suggestions regarding the design of the learning materials?

5. Results

The data were analyzed and are presented according to the research questions, and the quantitative and qualitative data, including the students' pre- and post-tests, hands-on activity scores, questionnaire and interview answers, were analyzed for methodological triangulation. Descriptive statistics were calculated to describe the means and standard deviations, and an independent samples t test and paired samples t test were adopted to compare the learning and questionnaire results between and within the two groups after the experiment. For the qualitative data from the instructor and students, each participant was given a code, group-sex-number, for example, GA-1-3 represents the data from learner 3 who is a boy in GA who learned with e-books and the game. GB-2-1 represents the data from learner 1 who is a girl in GB who learned with AR-based materials and the game. The researcher translated the feedback from the interviews into raw data files for each participant, and recoded the raw data according to different themes. The final qualitative data were organized and displayed as reduced data from which the findings for each question could be highlighted.

5.1. Learning performance

For answering research question 1 (Are there differences in the learning performance of the students who learn through the game with e-book learning materials and the game with AR-based learning materials?), the scores of the pre- and post-test were used for the paired samples *t* test in order to understand how the students improved before and after the experiment. The scores of the post-test and hands-on activity were adopted for the independent samples *t* test to examine whether there were differences in the learning performance of the students from GA and GB. According to the results of the paired samples *t* test (Table 1), it was found that the GA and GB learners all improved their learning after the course, and the statistical results achieved significant difference (GA t = -11.088, p = .00; GB t = -5.445, p = .00) which indicated that both types of e-learning materials helped their learning. However, the learning performance of the two groups did not show any difference according to the results of the independent samples *t* test (Table 2, t = 1.218, p = .229). When further analyzing the learners' hands-on activity scores, it was found that the total scores of the two groups were quite close, and the statistical results of the independent samples *t* test did not show a statistical difference (Table 3, t = 1.848, p = .071). However, it was noted that when analyzing the hands-on activity in more detail, the learners in GA with the e-books performed better on the sub-item of installation of the Switch (Table 3, t = 2.230, p = .030) and the correctness of the circuit (Table 3, t = 2.286, p = .61) than the learners in GB, and the scores achieved a significant difference.

Table 1. Paired samples *t* test of the pre- and post-tests

Group A (GA)	Mean	*SD*	*t*	*p*
Pre-test	16.33	15.34	-11.08	$.00^{***}$
Post-test	62.67	16.91		
Group B (GB)	Mean	*SD*	*t*	*p*
Pre-test	24.19	19.89	-5.44	$.00^{***}$
Post-test	56.19	21.00		

Note. $^{***}p < .001$.

Table 2. Independent samples *t* test of the pre- and post-tests

		Mean	*SD*	*F*	*t*	*p*
Post-test	Group A (GA)	62.67	16.91	4.46	1.21	.22
	Group B (GB)	56.19	21.00			

Table 3. Independent samples *t* test of the hands-on activity

		Mean	*SD*	*F*	*t*	*p*
Total score	GA	11.67	3.14	1.35	1.84	.07
	GB	9.90	3.63			
Sub-item	GA	2.60	0.72	2.68	2.23	$.03^{*}$
Installation of Switch	GB	2.10	0.88			
Sub-item	GA	2.27	0.90	0.41	1.03	.30
Installation of LED	GB	2.00	0.89			
Sub item	GA	2.60	0.77	0.10	1.65	.10
Installation of Buzzer	GB	2.24	0.76			
Sub-item	GA	2.20	0.76	0.84	2.38	$.02^{*}$
Correctness of circuit	GB	1.71	0.64			
Sub-item	GA	2.00	0.91	1.55	.581	.56
Debugging analysis	GB	1.86	0.79			

Note. $^{*}p < .05$.

5.2. Quantitative results from the questionnaire

The data from the questionnaires were analyzed to answer the second research question (What are the students' and teacher's feedback on using the game, e-books and AR-based learning materials for learning?). Descriptive statistics and an independent samples *t* test were conducted to analyze the two groups' feedback after the experiment. The questionnaire results are presented in Table 4. The average scores of the items revealed that the students of the two groups had positive feedback on learning with the assistance of the e-learning materials, and most scores were above 4 points (on a 5-point Likert scale from 0 to 5). It was noticed that the learners with the AR-based learning materials had higher average scores for most questions than the scores of the learners with e-books (Table 4, Q1-Q4, and Q6-Q10) indicating that the students liked to use the AR-based learning materials and reflected that the AR-based learning supports helped them understand the learning concepts and complete the hands-on work independently. GB also revealed that the instruction from the 3D demonstration helped them complete the hands-on activity (Table 4, GB-Q11). It was also noticed that the average score of Question5 was higher for GA (Table 4, Q5, GA *Avg.* = 4.5, GB *Avg.* = 4.19), showing that the learners with the e-books as technology-enhanced learning materials agreed more with the help provided by the learning technology for the hands-on activity.

Table 4. The results of questionnaires: Part one

Part one questions	Group	*Avg.*	*SD*	*t*	*p*
1. The learning material was easy to use.	GA	3.83	1.31	-.81	.41
	GB	4.10	0.76		
2. The design of the interface was clear.	GA	4.33	1.18	-.16	.87
	GB	4.38	0.80		
3. The instruction of the material was clear.	GA	4.10	1.34	-.27	.78
	GB	4.19	0.75		
4. The use of the materials helped me to understand the	GA	4.20	1.15	-1.34	.18
learning concepts.	GB	4.57	0.59		
5. The use of the materials helped me to know how to	GA	4.50	1.07	1.02	.30
use the science tools for the hands-on activity.	GB	4.19	1.03		
6. With the help of the materials, I could complete the	GA	4.07	1.28	-1.33	.18
hands-on activity without the teacher's assistance.	GB	4.48	0.68		
7. The use of the materials promoted my motivation for	GA	4.10	1.26	-.91	.36
conducting the hands-on activity.	GB	4.38	0.74		
8. The use of the materials promoted the effectiveness of	GA	4.13	1.27	-.03	.97
the hands-on activity.	GB	4.14	0.65		
9.With the help of the learning materials, the hands-on	GA	3.80	1.42	-.60	.55
activity was not so hard.	GB	4.00	0.63		
10. I like to use the learning materials for learning	GA	4.13	1.25	-.79	.42
	GB	4.38	0.80		
*GB 18. The instruction from the 3D demonstration	GB(only)	4.24	0.88		
helped me to complete the hands-on activity.					

5.3. Qualitative results from the questionnaires and interviews

The feedback from the open-ended questions and interviews are organized in Table 5 to answer the second research question (What are the students' and teacher's feedback on using the game, e-books and AR-based learning materials for learning?). In general, most students enjoyed learning with the game-based learning materials, and stated that they did not feel stressed even when they could not answer the questions since it was a game. They also reflected that the practice in the game could be transformed into hands-on activities to help them complete the scientific toy. However, it was noticed that some students felt that it was challenging to finish the work.

For the feedback from GA, the students gave positive feedback on the media elements of the learning materials, and revealed that the text and figures in the materials helped them to doubly confirm the processes of the learning information. Some students did a quick review of the content and once they got stuck on the processes they would watch the animation video to overcome the problem step by step. Some other students tended to discuss with their peers first, and if they still could not solve the problems, then they would follow the instruction of the materials in detail to complete the work.

The feedback from GB indicated that it was helpful to have AR-based guidance which provided instruction by showing colored blocks on the physical objects to facilitate assembly of the elements to complete the science toy. However, it was also noted that some students reflected that since it took time to scan and get the content from the AR-based materials, they would do the work on their own sometimes. Besides, the students suggested that when the AR triggers were removed from the lens of the learning devices, the learning information disappeared. The design of the mechanism of the AR content could be further improved.

In general, the feedback on using the AR-based and e-book materials indicated that the learners used the learning materials for the hands-on activity in various ways. However, it was noticed that one or two students stated that they would not think before doing the project but just follow the steps in the instructions if the materials provided them with very detailed guidance such as step-by-step instruction. The learners also shared the feedback of using the e-learning materials for project-based learning, stating that they needed teachers' aid before, but with the assistance of the learning materials they could complete the task independently. They were therefore able to complete the project at their own pace.

Table 5. The qualitative feedback from the learners

Items	Students' feedback
Impressive elements in the materials: Text, figures and video	• The figures in the book help me to understand the connection of the Circuit. GA-1-11 • The textual information is very clear. The figures in the content helped me to know the correct position of elements and the animation helped me to know the processes of operation. GA-1-11 • The textual information is better than the figures. GB-2-21
Impressive elements in the materials: 3D objects	• The 3D objects in the content helped me to know how to assemble the scientific toy. GB-1-3 • The 3D objects in the content showed clearly the steps of assembly. GB-2-4 • The figures and animation in the content helped me to know the correct position of the elements, and the 3D objects showed the back of the elements GB-1-8 • The 3D objects showed the information more clearly. GB-1-11 • The textual information helped me to know the steps, and with the 3D objects to present the information, it helped me to understand better. GB-1-20
Feedback on the game-based learning materials	• I understand the concepts more, and I could use the learned skills in the hands-on activity. GA-1-26 • If I did not practice in the game, I might not have finished the hands-on work. I liked the game-based learning, it is more fun. GA-1-24 • I like the game-based learning because it is not stressful and there were hints in the game. GB-1-11 • I think the hands-on activity is harder, because sometimes I did not know how to fix the problems when I got it wrong. GB-1-1
Feedback on the AR-based or e-book learning materials	• The course was not so hard for me, and it was really interesting. GA-1-33 • At first, I was not familiar with the content but I learned a lot in the activity. GB-2-5 • I think that this way (with the help of the e-materials) was good for me. GB-1-19 • With the help of the learning materials, I learned the processes of operation more easily. And it is more effective. GB-1-20 • The activity was very challenging, and I learned a lot. GB-2-23
Suggestions	• The speed of scanning (the AR content) should be faster.GB-1-3 • The learning materials were good, but the speed of scanning should be faster. GB-1-10

5.4. Qualitative feedback from the science teacher

The feedback from the interview of the science teacher was collected and organized to answer the second research questions. The feedback was summarized and organized into three categories. First, the teacher stated that the e-books helped the students to connect the concept knowledge and hands-on processes through textual and image-based information. The students were able to read the text, to think (about the diagram of the circuit), then to complete the hands-on work. The teacher also mentioned that the 3D demonstration of the objects might be needed for assisting students with object assembly (Figure 6). Second, the teacher found that the students' learning motivation and concentration improved with the use of the AR-based materials. The clear step-by-step guidance of the AR information that connected visual learning information with physical objects was very helpful in terms of assisting every student in completing the hands-on work. However, it was also noticed that some learners tended to follow the step-by-step guidance directly without thinking, and the teacher indicated that the mechanical operation might not be a good thing for concept acquisition since they did not know the principles of circuits. Lastly, the teacher suggested that the AR-based content could be further improved through encouraging students to operate the 3D objects of the AR information. The teacher also revealed that since it took more time to prepare the AR environment, such as checking the Wi-Fi connection, better support of the equipment was also needed. Hence, currently, the science teacher had more positive perceptions of using the e-books to support science project-based learning in the classroom.

Figure 6. The learning scenario in the classroom

6. Discussion

After analyzing the quantitative and qualitative data, the discussion is presented according to the research questions (RQs).

6.1. RQ1

To answer the first research question (Are there differences in the learning performance of the students who learn through the game with e-book learning materials and the game with AR-based learning materials?), the results of the quantitative data analysis indicated that generally the GA had higher scores than GB in the hands-on activity according to the descriptive statistics results, but it showed no significant learning difference. Valuable research findings were found from the qualitative results of the interview and the learners' written feedback. The students revealed that the basic science concepts they practiced in the game helped them to complete the hands-on project, and it was noticed that the learning inquiry happened during the hands-on activities. The qualitative data from the interviews indicated that the learners had interaction and cooperation with peers during the processes of producing the scientific electric current toy. In sum, the students had discussions to exchange views and ideas when they met disagreement during the learning activities. These findings are in accordance with the previous research (ChanLin, 2008).

The study also found that the learners exhibited various behaviors when using the support of the e-books and AR-based materials. For example, students with the e-books tended to find out the answers on their own at the beginning of the activity and only when they got stuck would they use the learning materials to find out the answers, but some would like to have peer discussion during the whole hands-on activity and look up the answers when they could not reach agreement. It was also noted that some students with the AR-based learning materials would like to follow the instruction in the materials step-by-step during the activity.

6.2. RQ2

To answer the second research question (What are the students' and teacher's feedback on using the game, e-books and AR-based learning materials for learning?), the questionnaire results showed that both groups were positive about the technology-enhanced learning materials, and the questionnaire results also revealed that the learners with AR supports had better learning confidence in completing the hands-on work. The feedback from the teacher also confirmed the findings that the learners' motivation and learning concentration were enhanced during the whole project-based activity. These findings echo previous research which argued that integrating technology supported students' science learning motivation and engagement (ChanLin, 2008). However, the teacher also stated that well-designed AR-content might restrict students' creativity and hinder their thinking ability since some students followed the instruction and guidance of the AR content directly as soon as they got the materials, without thinking before doing. Despite the e-books not presenting very detailed assembly demonstration, the textual information with the figure as guidance made the learners think first then do the work. This reflection was quite similar to that in Kerawalla's et al. (2006) study. The study argued that the highly interactive technology might sometimes hinder learners' creativity, revealing that AR-based learning content gave students fewer chances to explore questions.

In sum, technology is a good tool to help transform the classroom into a suitable environment for science project-based learning and to achieve the practice of science for knowledge construction. The findings of the current study have revealed that using learning technology for assisting science learning is effective in terms of improving students' active participation as well as science learning motivation. When integrating technology into scientific project-based learning, whether the instruction and detailed guidance provided in the e-learning materials would be helpful or would hinder learners' exploration and creativity ability still needs to be further explored.

7. Conclusion

The study intended to integrate the value of the convenience and accessibility of e-books, the features of interactive demonstration and the combination of visual information with physical AR objects, and the enjoyment brought by game-based learning to create an integrated e-learning model for scaffolding students in acquiring different cognitive knowledge levels through a science project-based activity. Despite the quantitative data not presenting any learning differences between the two groups, the qualitative results showed that the e-learning materials with multimedia content (both the e-books and AR materials) were helpful in scaffolding students while completing the science hands-on activity, and triggered learners' peer discussion to achieve concept agreement.

Following the findings of the current research, I propose a revised e-learning integration model (Figure 7) to further support science project-based learning. In the revised design, the roles of the learning technology tools were adjusted according to various learning objectives of the learning content. The game-based learning environment is designed for factual and conceptual knowledge acquisition, aiming to give students basic concepts of electric circuits, paths, series and parallel, and to recognize circuit diagrams, current, voltage, and resistance. Besides, the revised version of the game-based learning content was improved through adding a new learning unit as scaffolding between basic conceptual learning and practical hands-on activity. The learners can simulate the processes of hands-on activities in the game-based environment and after they are familiar with the steps, they can then transfer their learning to the physical hands-on practice.

Since the core value of project-based activities is not to give students full guidance but to encourage them to think before starting the work and to give them more opportunities to be independent and to engage in self-regulated learning, the e-books with partial AR functionality were used in the revision model to support higher level knowledge acquisition and practical hands-on activities. The revised e-books used text, figures and animation for scientific toy assembly guidance, and the AR model would function only when learners needed further 3D demonstration such as demonstration of objects flipping or location guidance. The aims of the revised e-books tended to combine the advantages of e-books and AR techniques to create more easily accessible e-learning materials to assist students in applying the comprehensive conceptual knowledge at more advanced learning levels.

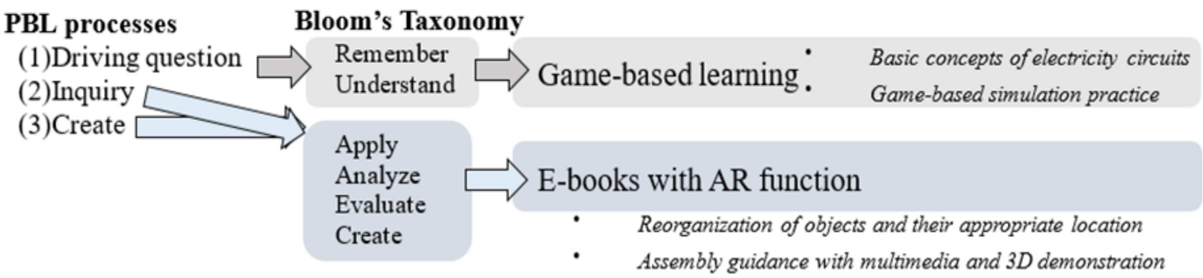


Figure 7. The revised e-learning model to support science project-based learning

The limitations of this study are that firstly the participants were elementary school students and the learning topic is for science education; secondly, the course duration was only 4 weeks due to consideration of the real classroom learning scenario and the teacher's routine instruction. Besides, the current game-based learning materials did not record the students' logging data; hence, the students' learning profiles and records were not analyzed in the current study. The future work will firstly be to revise the design of the e-books according to the findings of this study, and to further improve the game-based learning materials by constructing the database to further record learners' practice processes such as scores for further reference. Furthermore, it is suggested that teachers could consider the roles, affordances and features of various media when integrating them into supporting teaching and learning. Moreover, a longer experiment should be conducted and a delayed test is suggested to further confirm whether the learning technologies truly support science learning in the long run.

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