The development of simulation and game in 5E learning cycle to teach photoelectric effect for grade 12 students

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Received 22 Feb., 2017
Revised 18 Jul., 2017

Contents

Abstract

Photoelectric effect is regarded as one difficult topic in physics for science students because it is the abstract and multidimensional phenomenon. This study aims to develop the learning unit incorporated simulation and game with the 5E learning cycle for promoting the grade 12 science students' understanding of photoelectric effect and learning attitudes. The created learning unit was implemented with 31 grade 12 students in Bhutan. The students' pre- and post-understanding of photoelectric effect were measured by the Photoelectric Evaluation Conceptual Evaluation Test (PECE). In addition, the students' attitudes to the unit were explored by using the Multimedia Attitude Survey (MAS), individual interviews, and reflective journals. The quantitative data were analyzed by calculating for mean, standard deviation, and t-test. The qualitative data were analyzed by inductive analysis. The results from PECE revealed that the mean scores of students' pre- and post-tests were 12.94 (S.D. = 3.81) and 16.94 (S.D. = 3.12), respectively. The simulation and game based learning unit significantly helped the participating students improve their understanding of photoelectric effect ($t = 7.79$, $p < .05$). In addition, the students expressed their positive attitudes to the learning unit. The implications in teaching physics by game and simulation embedded in the 5E learning cycle are also discussed.

Keywords: Photoelectric effect, game, simulation, 5E learning cycle, science student

Introduction

Some phenomena in physics, such as the photoelectric effect, are not easy for students to comprehend because of their abstractness, complexity, and time-consuming to do experiments in classroom settings. Physics teachers need to help students concretize the abstract phenomenon. One solution is the utilization of simulation in teaching because good simulation can make many physics topics, which are abstract and difficult to teach, simpler and clearer for students (Bozkurt & Ilik, 2010). Game also help keep students' attention and makes students focus on the complex and abstract contents (Anderson & Barnett, 2013; Clark et al., 2009). Good games can create immersive environment and adaptive control for students to learn the contents embedded in them (Wernbacher et al., 2012).

Quantum physics is regarded as one important topic in physics for science students to learn because it can be applied in diverse fields such as science, engineering, technology, and so on. Cultivating deep understanding of quantum physics in science students is therefore demanded. Regarding this, the quantum physics concepts are included in secondary science curriculum worldwide. Among various topics in quantum physics, the topic of photoelectric effect is pivotal and accepted as a stepping stone entering the world of quantum physics (Hughes & DuBridge, 1932; Klassen, 2011; Knight, 2004) because it has historical importance and demonstrates the particle nature and properties of light as a photon (James, 1973; McKagan, Handley, Perkins, & Wieman, 2009). However, many students face difficulty to understand the photoelectric effect phenomenon because it is abstract and usually explained through mathematical equations, and demands multidimensional understanding and mathematical skill. Helping science students understand the photoelectric effect is therefore regarded as a big challenge for science educators (Steinberg & Oberem, 2000).

The current reform of physics education is moving towards student-centered teaching and learning, which has been proposed as a major way to prepare current generation of students, who need more critical thinking and problem solving skills. In student-centered teaching and learning, students are given more opportunities to interact with the scientific phenomena, to critically explore and solve problems embedded in the phenomena, and to create deep understanding about the phenomena (Rezaei & Katz, 2002). The student-centered approaches are based strongly on the constructivist philosophy. In constructivism, it is believed that students come to the classroom with prior knowledge and experience that can affect their learning. In learning the new topic, students link their prior knowledge and experience with the new ones and construct their own understanding about the topic. During this process, a teacher is regarded as a facilitator taking a role in promoting students to actively participate in learning activities and subsequently construct knowledge by themselves (Rias & Zaman, 2011). In the constructivist classroom, science learning is focused on the process rather than the product of learning and multiple perspectives are accepted (Rezaei & Katz, 2002).

Like other topics in physics, the photoelectric effect topic is widely taught by traditional, teacher-centered approaches such as lecture and rote learning (Steinberg & Oberem, 1996, 2000), which are not effective to help science students develop deep understanding especially in the abstract and multidimensional phenomenon as the photoelectric effect (Clark, Nelson, Sengupta, & D'Angelo, 2009). Instead, in learning the photoelectric effect students themselves must construct their own mental models to accommodate and apply the photoelectric effect concepts (Anderson & Barnett, 2013). Thus, the constructivist approaches should be employed in teaching photoelectric effect.

The 5E learning cycle is one of constructivist teaching approaches that is used around the world. Originally, this approach had been created by the Biological Science Curriculum Study (BSCS) program. The stages in 5E learning cycle are consisted of Engagement, Exploration, Explanation, Elaboration, and Evaluation. The combination of 5E learning cycle with simulation and game is seen as being interested especially in the high-technology world at present, which the computer applications and software are widely applied in education to facilitate self-learning environment (Bozkurt & Ilik, 2010). In history, the Computer Assisted Instruction (CAI) was established to represent the use of computer in helping teach students. CAI helps students visualize some abstract science concepts and phenomena and promote their learning achievement (Bakac, Tasoglu & Akbay, 2010). At present, simulation is widely used to simulate the complex or abstract concepts or phenomena, which are difficult for students to visulize and understand (Bayrak, 2008). Simulation can breakdown the complex science processes into the simple and easy-to-understand ones (Liu & Li, 2011). In addition, the use of education game is useful in making students learn science contents with enjoyment. Thus, good simulations and games can provide avenue for science students to learn complex, abstract concepts and phenomena with understanding and enjoyment (Anderson & Barnett, 2013). Simulation and game are presented as the appropriate tools to be applied with the learning cycle (Wankat & Oreovicz, 1993).

The photoelectric effect topic is included in the grade 12 science curriculum in Bhutan. Many Bhutanese physics teachers teach the photoelectric effect topic by describing the photoelectric effect experiments in the physics textbook to students and then requiring them to interpret relevant graphs. There is a lack of student-centered activities and learning materials and media to help students visualize and understand the abstract and multidimensional nature of the photoelectric effect phenomenon. The inclusion of simulation and game in the 5E learning cycle in this study present an initial effort in improving teaching and learning about photoelectric effect in the Bhutanese science education context in order to help grade 12 students visualize and understand the concepts of photoelectric effect within active and enjoyable learning environment.

The research questions guided this study are: a) What are the desirable characteristics of the simulation and game based learning unit of photoelectric effect for grade 12 students? And b) Can the simulation and game based learning unit promote the participating grade 12 students' understanding of photoelectric effect? What are the participating grade 12 student's attitudes to learning photoelectric effect by simulation and game?

This study aims to: a) develop the simulation and game in the 5E learning cycle for teaching the photoelectric effect for grade 12 students; b) explore the impact of the simulation and game in the 5E learning cycle for promoting the grade 12 students' understanding of photoelectric effect, and c) explore the grade 12 students' attitudes to learning with the simulation and game in the 5E learning cycle in the topic of photoelectric effect.

Literature Review

Physics education in Bhutan

Physics is generally regarded as a difficult subject in science because it deals mainly with abstract explanations through a mathematical format (Osborne, 1990). So, there is a belief that to understand physics students must be knowledgeable in mathematics. This is also evident in many physics textbooks, which presents lots of mathematical calculation. Physics contents, therefore, are delivered to students through memorization of physics equations and correctly apply them in solving problems with mathematical skill. Regarding this, teaching physics is teacher-centered, which places emphasis on lecture method. Students regard doing laboratory as for verifying the physics equations the teacher introduced to them. The consequence of mathematical calculation in physics is that the people have a notion of physics being accurate subject and do not have a room for speculative imagining. However, the use of mathematics to represent physics concepts should be the end point in teaching physics rather than the starting point (Mulhall & Gunstone, 2008; 2012).

In Bhutan, the Department of Curriculum and Research Development (DCRD) (2009a, 2009b) states the rationale of teaching physics for high school Bhutanese students as to equip students with basic knowledge of physics principles enough for using as a sound foundation to pursue a higher degree. Students are expected to comprehend complex scientific terms, facts, concepts, principles, theories, and laws related to physics. They should be able to apply such learning to solve the problems related to physics in real-life situations. Students need to acquire basic skills in conducting physics investigation such as handling apparatus, observing, recording, drawing diagrams and graphs, and interpreting and generalizing the results. Students should also have good mathematical skill for problem solving and reasoning and have scientific attitudes. Learning experiences in physics should provide an opportunity for students to investigate and do scientific enquiry. They should be able to pose questions and develop scientific hypothesis and discuss and recognize many faces of science. Students should make inference and generalization from the experiment and verify laws from it.

Photoelectric effect

Photoelectric effect plays a crucial role in presenting students about the photon model of light, which is a prerequisite in learning other topics in physics such as the interaction of light and matter, atomic energy level, and lasers. Although there is a general consensus in the importance of photoelectric effect phenomena among teachers and educators, only few hours devoted to teaching this topic. The minimal instructional time devoted to the photoelectric effect topic is based on the ground that this topic is straight forward and simple. Moreover, the photoelectric effect topic does not receive proper attention in secondary school teaching. The photoelectric effect is taught mainly through lecture mode, where a teacher describes the experiments and results without any laboratory practices. At the end, in most cases, student answers questions by reading the information given in the handout without deep understanding of the photoelectric effect phenomena (Steinberg & Oberem, 1996).

Although there were studies conducted in exploring the conception of photon model of light held by the students, a few studies were conducted with the photoelectric effect topic (Klassen, 2011). McKagan et al. (2009) found that many physics textbooks contain misconceptions related to the explanations of photoelectric effect and the students faced difficulties in understanding even the basic aspects of photoelectric effect. According to Steinberg and Oberem (1996, 2000), even though the university students who had completed a course on photoelectric effect, they attributed the Ohm's law (V = IR) to explain the photoelectric effect. They failed to understand the relationship between emissions of photoelectrons and intensity and frequency of light and had a misconception that a photon is a charged particle. Finally, the students failed to make prediction from the observation of photoelectric effect experiment.

5E learning cycle

The learning cycle was developed by Robert Karplus in 1960s under the Science Curriculum Improvement Study (SCIS) program. It is based on the constructivist philosophy, that is, a constructivist learner is conceived as one who construct their own knowledge by linking the new concepts with what they already knew (Applefield, Huber, & Moallem, 2000). The Karplus's learning cycle was consisted of three stages: Exploration, Invention and Discovery.. The Karplus's learning cycle was successfully applied in different educational settings, and consistently researched and revised over by many educators.

During 1980s, the Biological Science Curriculum Study (BSCS) developed the 5E learning cycle based on Karpuls's learning cycle and presented that the 5E learning cycle was effective in helping students improve scientific understanding and reasoning, interest in science, and attitudes to learn science. The 5E learning cycle consists of: Engagement, Exploration, Explanation, Elaboration and Evaluation. In Engagement, students are motivated to learn by exposing to a given problem or situation, which leads them to disequilibrium in their mental states. In Exploration, the process of cognitive equilibration is initiated. Students should be able to explore the targeted phenomena and subsequently establish the relationships or patterns in the observed phenomena with their own understanding. In Explanation, the concepts, processes or skills are made comprehensible and clear. At Elaboration, all of students' misconceptions are clarified and students are encouraged to transfer their learned concepts to a new but related situation. In Evaluation, students are given opportunity to evaluate their process and product of learning. To be remark, the informal evaluation takes place throughout the learning process not just at the Evaluation stage at all (Bybee et al., 2006).

The constructivist methods have been employed in Chang (2008) and found that the students taught using constructivist methods were found to have a deeper comprehension of the learning process and outcomes, and as a result, became more critical than those in traditional classes. In particular to 5E learning cycle, Ornek and Zziwa (2011) demonstrated the use of low-cost materials with the 5E learning cycle to show students ways to measure "gravity" by observing and analyzing the trajectory of projectile motion in 2D and study the relationship between different factors such as air resistance and friction. Also, students can learn to plan and conduct scientific investigations through studying the motion of a ball or a marble to measure "g". This allows students to realize there is not just one fixed investigation method to follow while conducting investigations. In addition, Samsudin, Suhandi, Rusdiana, Kaniawati and Costu (2016) developed an Active Learning Based-Interactive Conceptual Instruction (ALBICI) model through PDEODE*E tasks (stands for Predict, Discuss, Explain, Observe, Discuss, Explore, and Explain) for promoting pre-service physics teachers' understanding on electric field concepts. The ALBICI model consists of four phases; 1) Conceptual focus 2) Use of texts 3) Research based materials (PDEODE*E tasks) 4) Classroom interactions. The effectiveness of ALBICI model was evaluated by a Field

Conceptual Change Inventory (FCCI) and PDEODE*E tasks. The findings suggested that ALBICI teaching model enhanced pre-service physics students' conceptual understanding and reduced most of their misconceptions despite a few misconceptions still occurred.

Simulation based instruction

Some phenomena in physics are not easy for students to comprehend because of its abstractness, complexity, time-consuming to observe or too dangerous to do experiments in classroom settings. In similar, for the abstract phenomena in physics as the photoelectric effect, the difficulty for physics teachers is placed on helping students visualize the phenomenon. One solution is the utilization of simulation in teaching. Many physics topics, which are abstract and difficult to teach, can be made simpler and clearer with good simulation. Also, good simulation can help present the hard-to-conduct or dangerous experiments in physics (Bozkurt & Ilik, 2010).

Well-designed simulation incorporated with a constructivist teaching and learning environment can provide a platform for students to develop scientific understanding through active construction of concepts. Students can learn the targeted phenomena presented via the simulation by manipulating parameters in experiments until they discover relationships or patterns between variables and understand the targeted phenomena. It helps students link their prior knowledge with the new ones (Jimoyiannis & Komis, 2001). Not only turn an abstract phenomenon into concrete one, simulation can also speed up or slow down the phenomenon. It can promote students to learn actively and enhance their problem solving and higher order thinking skills (Smetana & Bell, 2012). Simulation can also help teach some laboratories that cannot be conducted in schools because of limited resource (Bozkurt & Ilik, 2010). A student-centered, inquiry based simulation has a potential to engage students in inquiry learning and scaffold them to more understandable and meaningful understanding about the scientific phenomena (Smetana & Bell, 2012). Students can actively engage with inquiry based simulation through formulating questions, developing hypotheses, collecting data to test hypotheses, and developing explanations or theories (Rutten, van Joolingen, & van der Veen, 2012).

Commonly, there are two objectives of teaching the photoelectric effect phenomenon in modern physics: a) to help students correctly predict the results of the photoelectric experiment, and b) to make students be able to use the results from experiment to explain the photon model of the light (McKagan et al., 2009). Some physics educators had tried to create the simulations on photoelectric effect to accomplish those learning objectives, but they faced the difficulty to accomplish the second learning objective as mentioned earlier. Steinberg and Oberem (2000) created and applied the interactive simulation called Photoelectric Tutor. This simulation was successful in achieving the first learning objective, but 60% of the students learned with the photoelectric tutor could not achieve the second learning objective. Mckagan, Handley and Perkins (2009) conducted the Physics Education Technology Project (PhET) and created the simulation based instruction within the Research-based Curriculum for Teaching Photoelectric Effect. This simulation was successful with the first learning objective, but the result for second learning objective was still ambiguous. Therefore, there is a room for improving the simulation on photoelectric effect to enhance students' ability to use the results from experiment to explain the photon model of the light.

Game based instruction

Many studies presented that a well-designed game can be an effective support for teaching and learning (Anderson & Barnett, 2013; Clark et al., 2009; Honey & Hilton, 2010). There are many advantages of using game in education. Hyvonen (2011) asserted that game could yield several positive impacts on students' cognitive, effective, social and physical development. Anderson and Barnett (2013) stated that game could promote students' higher order thinking and learning through interactive play. Regarding the affective domain of learning, interactive game helps promote student deep learning process with competence, autonomy, and relatedness, which is one requirement for intrinsic motivation (Przybylski, Rigby, & Ryan, 2010). One challenge for a game designer is to optimize the game players' intrinsic motivation and, at the same time, not to deviate from the learning goals. Game helps reluctant learners to engage themselves through tangible, experienced and non-textually mediated representations (Anderson & Barnett, 2013; Clark et al., 2009).

There are many desirable characteristics of a good game. The good game should keep students' attention and makes students focus on the complex and abstract contents (Anderson & Barnett, 2013; Clark et al., 2009). Students should play a game and learn contents embedded in the game with enjoyment (Wernbacher et al., 2012). The good game should create immersive environment and adaptive control for students to learn the contents embedded in it (Wernbacher et al., 2012).

In teaching science by game, students should be required to immerse themselves in the scientific phenomena presented in a game (Mohanty & Cantu, 2011). Corresponded with the constructivist theory, students playing a game should have the opportunity to link their intuitive knowledge with the new scientific knowledge embeded in the scientific phenomena in the game environment. The environments in the game, therefore, should let students observe and interprete the patterns hidden in the scientific phenomena in the game. Studenets, as the game players, must be able to construct their knowledge by themselves after played game.

This study incorporates of simulation and game with the 5E learning cycle into the learning unit for teaching the photoelectric effect for grade 12 students. The created learning unit aims to help students visualize the abstract scientific phenomenon as the photoelectric effect through the simulation. The simulation should help student understand the abstract scientific concepts through simulated experiments and appropriate visuals and media (Singh, Moin, & Schunn, 2010) and digital representation (Anderson & Barnett, 2013). Students learned with this simulation have an opportunity to visualize, explore, and formulate the potential scientific explanations for the photoelectric effect phenomenon. The simulation and game are sequenced and embeded in the the 5E learning cycle, which is a constructivist learning environment. In the constructivist learning environment, a teachers accepts a variety of students' hypotheses, ideas, and answers. Students are encouraged to actively interact with learning activities and materials and construct knowledge by themselves (Rezaei & Katz, 2002; Wankat & Oreovicz, 1993).

Methodology

This study is a quantitative research employed the one group pre-test post-test research design. The research process is consisted of three stages: a) Development of simulation and game on photoelectric effect, b) Implementation of simulation and game based learning unit to teach photoelectric effect, and c) Investigation of effectiveness of the learning unit in enhancing the participating students' understanding of photoelectric effect and attitudes towards the learning unit.

Development of photoelectric effect simulation

Macromedia Flash 8.0® was used to develop the simulation in this study because it is compatible with Windows®, which is the operating system commonly used in school computers in Bhutan, and gives a room for creating an animation and a configuration using action script 2.0. Figure I shows the structure of system used in designing the photoelectric effect simulation.

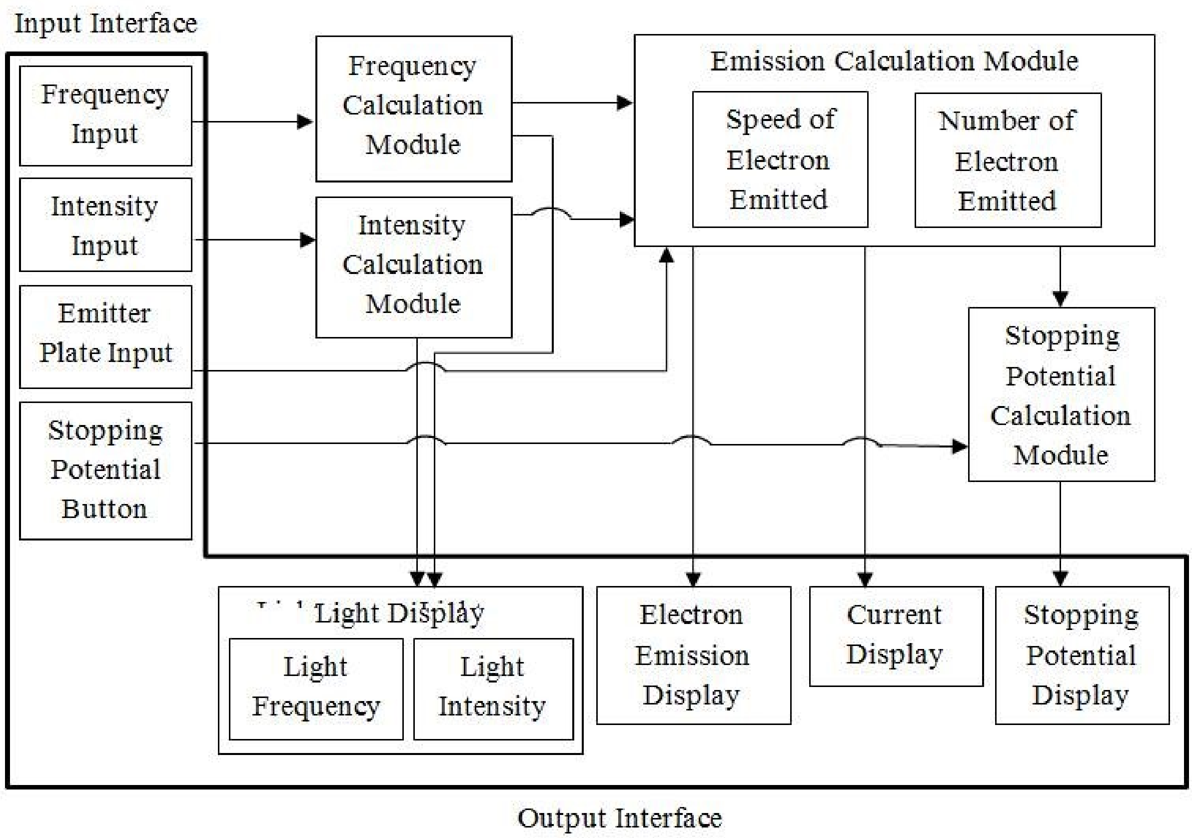

Figure I. Structure of system used in photoelectric effect simulation

The interactive simulation is developed to simulate the laboratory experiment on photoelectric effect. McKagan et al. (2009) suggest that, to increase the efficiency of learning, the subtle complications being irrelevant to the learning goal should be reduced or set as an assumption. Therefore, the following assumptions were made while developing the simulation in this study: a) the simulated photoelectric set up is 100 percent efficiency that every photon emits a photoelectron and the collector plate is large enough to collect all emitted electrons, and b) all photoelectrons will be emitted perpendicular to the emitter plate so that photocurrent remains the same even if the applied voltage is increased (Foong, Lee, Wong, & Chee, 2010).

There are four inputs presented in the simulation: a) Intensity slider, b) Frequency slider, c) Emitter plate list and d) Potential slider. These inputs aimed for adjusting the potential between the plates inside the vacuum tube as shown in Figure 2. The simulation allows a student to control the inputs such as the intensity and frequency of light and the electrodes used in the experiment.

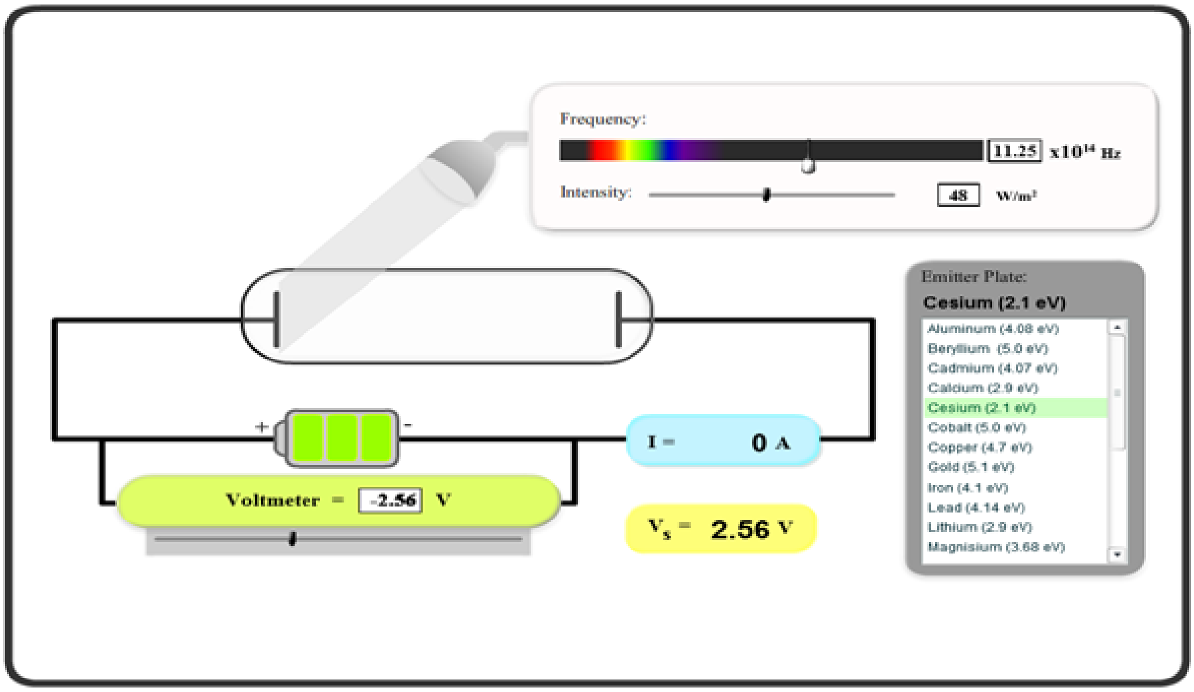

Figure II. Simulation on photoelectric effect

Based on the inputs, this simulation can give outputs like an amount of current produced by photoelectric effect and the simulation of emitted electrons in terms of numbers and speed, which might vary according to the input variables. The input variable of light consists of frequency of light in Hertz (Hz) and intensity of light in watt per square meter (W/m2). The student can vary the input regarding light either by moving a slider or punching the values.

Another input variable is electrodes used in the photoelectric effect experiment, which are consisted of 23 metals. The student can choose the lowest work function metal to the highest work function metal, which are Cesium with 2 electron volts (eV) and Platinum with 6.35 eV, respectively. The simulation of emitted electrons as per the input variables can help student deduce the relationship between the frequency of light and intensity of light with respect to the emission of photoelectrons. The potential of the cells can be varied and if the potential is reversed or negative, then at certain negative potential emitted electrons will be completely repelled by the collector plate, which will be at negative potential and the current will be reduced to zero. It is called stopping potential (Vs), which is equal to maximum kinetic energy of the emitted electrons. The data from simulation can be used to plot maximum kinetic energy versus frequency in order to find Plank's constant. This is particularly important since it gives a picture of how light interacts with electron on electrodes, which depends on the frequency instead of the intensity of light and thereby giving the concept of photons.

The salient feature of this simulation is that the student can input the value of intensity in watt per meter square (W/m2), unlike the previous works where an arbitrary value is given or is calculated in percentage (McKagan et al., 2009; Steinberg & Oberem, 2000). The simulation in this study can be correlated with the magnitude of output current. Similarly, when the intensity is kept constant and the frequency is increased, the magnitude of the current will decrease since the photon flux will decrease thereby decreasing the number of photoelectrons emitted (Angier, 2008; Khoon, 2011). This gives further evidence that particle nature of light call "a photon".

Another unique feature of this simulation is the way stopping potential is found. This simulation uses reverse potential slider to accurately find the stopping potential because the reading pops up when slider crosses stopping potential. In case of previous simulations, a student had to slide it with dexterity and very careful observation has to be made on the output current gauge to get an accurate stopping potential (McKagan et al., 2009).

Development of photoelectric effect game

The photoelectric effect game is developed on a board game framework by using Macromedia Flash 8.0®. Figure III shows the structure of system used in designing the photoelectric effect game.

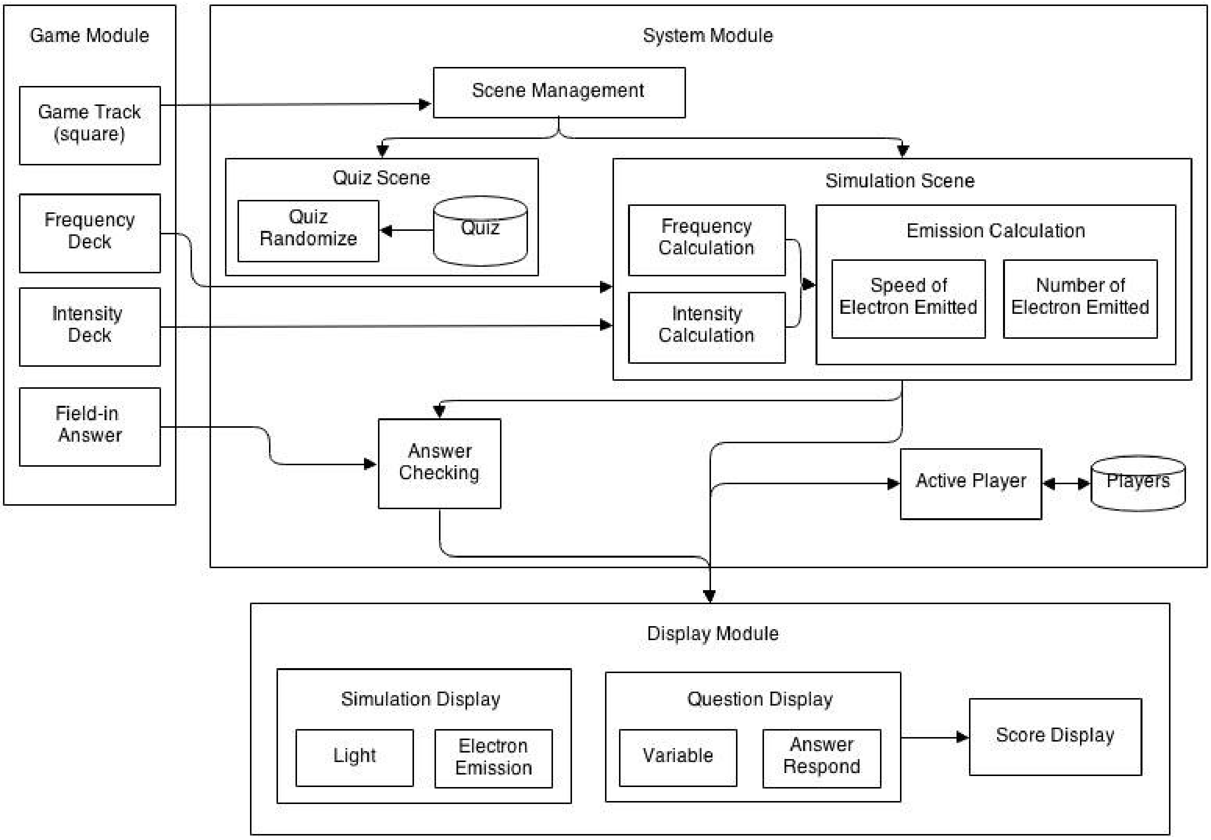

Figure III. Structure of system used in photoelectric effect game

The maximum number of players for the photoelectric effect game is two. To play game, Player 1 starts by rolling a dice and then the system will randomly generate one integer ranged from one (1) to six (6) and present on the dice face. The player's token then will move in clockwise direction to the rectangle block on the board as per the number appeared on the dice. Each block on the board has a specific type of metal presented with its work function in electron volt (eV). Next, Player 1 has to pick a frequency card, which will cause light wave with distinct color to strike on an emitter plate on the simulation panel of the game. On the frequency card, the players may be given the frequency of light or sometimes they will be given the wavelength and must convert it to the frequency. When Player 1 got the frequency card, he or she has to calculate the energy of photon in eV and put his or her answer in the box provided. Player 1 will get two points (+2) for the correct answer and minus two points (-2) for the incorrect one. Then, Player 1 will be asked whether there will be an emission of photoelectrons or not. To answer this, Player 1 has to compare the work function and photon energy and answer the question by pressing "YES" or "NO" button. Subsequently, two points will be awarded or deducted for the correct or incorrect answer, respectively. The emission of photoelectrons will be shown on the simulation irrespective of their answer; this will correct the player's understanding of photoelectric effect. Next, Player 1 picks an intensity card. Based on the magnitude of intensity, he or she has to calculate the number of electrons emitted. In this simulation, simulated apparatus is considered to be 100 percent efficient and hence one photon will emit one electron. When Player 1 puts the answer, he or she will be awarded or deducted two points as per the correctness of answer.

The speed and number of electrons emitted will depend on the frequency and intensity cards picked by the player. Subsequently, the intensity (represented by number of wave striking), frequency (represented by color of light wave), speed and number of electrons emitted will be displayed in the simulation panel. If the player's token falls into a quiz block, then a quiz will be popped up with four alternative choices. Player 1 will get +10 points for correct choice or -2 points for the wrong one. The answer with the explanation will be shown irrespective of their answer. This is the first round for Player. Next, Player 2 follows the same procedure and finish his or her first round. Two players will play this game with the same process until the winner has been declared.

This game is a new platform that is developed to motivate student to learn the concept of photoelectric effect. Game was used because by nature game can create immersive environment, where students' attention can be focused while learning the targeted concepts. For instance, even if the student picks the high magnitude intensity card but has low magnitude frequency card, it will not cause emission of photoelectrons. In this case, players cannot get 10 points for the calculation of number of photoelectrons emitted. Therefore, student would be eager to have high frequency card. This would reinforce the concept of emission of photoelectrons, which depends on frequency rather than intensity of light. It would be further reinforced by the simulation displayed and, at the same time, student would learn how to work through various calculations of photoelectric effect.

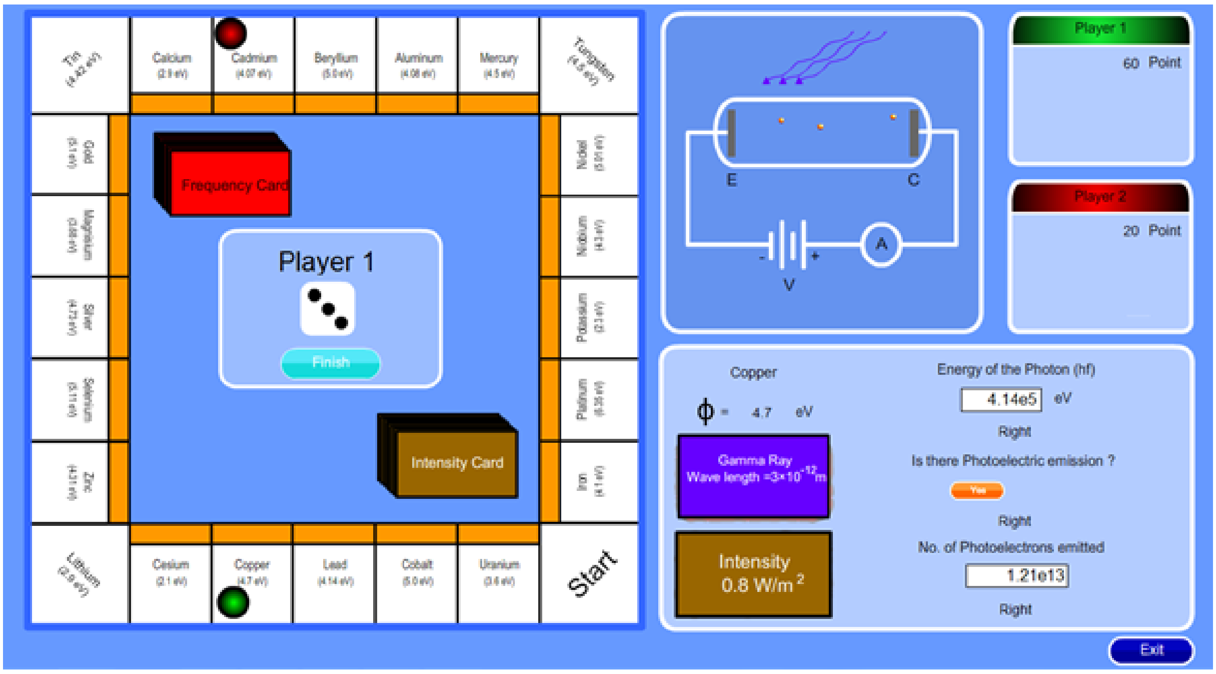

Figure IV. Simulation game on photoelectric effect

Five experts with physics and mathematics backgrounds validated content validity of photoelectric effect simulation and game. The index of item-objective congruence (IOC) (Rovinelli & Hambleton, 1977; Turner & Carlson, 2003) showed the experts' rating on the congruence of individual items with the objective intended by the developer. In overall, the IOC of these simulation and game ranged from .60 and 1.00, which were in the acceptance level.

Implementation of simulation and game based instruction on photoelectric effect

The photoelectric effect simulation and game are embedded with the 5E learning cycle lesson plan (see Appendix). In Engagement stage, the teacher poses the questions related to energy of wave by using examples from everyday lives, for example, the similar impact of two waves with the same intensity originated from two sources located in different distances from an object. Also, the teacher asks students to determine the factor affecting the energy of two waves with different intensities. Next, the teacher presents the pictures of two light sources with different intensities and asks students to explain the difference of energy of those light sources. Then, the interference patterns of light and water waves is shown and students are asked to explain how interference is formed. These activities aim to engage and explore students' prior knowledge of wave and light as wave. At the end of Engagement, the teacher requires students to observe the photoelectric effect simulation in order to promote students' curiosity about an instantaneous emission of electrons despite the wave energy being distributed along the wave front. Students' understanding moves in various directions therefore at exploration phase, adequate and scientifically accurate concept should be initiated like giving concrete activities. The Exploration stage is suitable for using computer simulation to concretize their learning experiences (Bybee et al., 2006). Therefore, the photoelectric effect simulation is used to develop a common experience, which will be discussed in Explanation phase. There are two major activities to be carried out in exploring the photoelectric effect simulation. The goal of Activity 1 is to make students realize that the photoelectric effect phenomenon is not consistent with the wave model of light and it can be explained only when light is considered as a packet of energy (called photon). Activity 1 helps students understand about the relationship between the intensity of light and the frequency of light in the photoelectric effect phenomenon. Then, Activity 2 is used for students to find the magnitude of that packet of energy, which depends on the frequency of light and is integral multiples of Plank's constant. Activity 2 helps students derive the Plank's constant and understand the photon concept of light. In Explanation phase, the teacher probes students' understanding through various questions and asks them why the photoelectric effect phenomenon cannot be explained with the wave nature of light. Then, the teacher explains the concept in direct, explicit and formal manner. In Elaboration phase, Activity 3 is used and required students to use and generalize their learned concept from the previous phases in playing the photoelectric effect game. In Evaluation phase, students are evaluated for their conceptual understanding of photoelectric effect and their attitudes towards the photoelectric effect learning activities. However, informal evaluation is taken placed throughout all stages of 5E learning cycle.

Research participants

The participants of this research were 31 students in one grade 12 class in Bhutan. This is a typical class where all students share the same space, can identify each other, and interact with their classmates in daily classroom activity (McMillan, 2004). All participants were familiar with basic operation of computer. The photoelectric effect class took five hours.

Data collection and research instruments

There were four methods to collect data in this study: conceptual test, attitude survey, interview, and reflective journal. The data collected were both quantitative and qualitative. Before the photoelectric effect class, the participants were asked to respond to the Photoelectric Effect Conceptual Evaluation Test (PECE). This data served as a pre-test. At the end of the class, the participants responded to PECE again as a post-test and also the Multimedia Attitude Survey (MAS). One day after the class, all participants were asked to write their reflective journals according to teaching and learning in the photoelectric effect class. Also, the researchers interviewed the participants randomly. The instruments used in this study can be described as follows.

Photoelectric Effect Conceptual Evaluation Test (PECE)

This study adopted PECE developed by Sura Wuttiprom, Ratchapak Chiaree, Chernchok Soankwan, Kwan Arayathanitkul, and Naumon Emmarat (Cited in Wuttiprom 2008). PECE consists of 30 test items, which divided into seven constructs: a) Electromagnetic (EM) model of light, b) Photon model of light, c) Characteristic of photon d) Threshold frequency, e) Work function, f) Maximum kinetic energy, and g) Stopping potential. To check the reliability of PECE, the researchers administered PECE to one grade 12 class with 30 students, who were not the participants in this study. The reliabilities of PECE constructs ranged from .69 to .95.

Multimedia Attitude Survey (MAS)

The Multimedia Attitude Survey (MAS) is a multidimensional tool to assess student's attitudes towards multimedia-based instruction (Fco & Garcia, 2001). MAS consists of 25 items, which divided into eight dimensions. In this study, the five items in the dimension of "Students' attitudes toward the learner's control over the instructional process" were excluded. Consequently, there were 20 items of MAS used in this study. The reliability of MAS was established by the try out process with the same class of students as being occurred with PECE. The reliabilities of MAS dimensions ranged from .68 to .84, which were in an accepted range (Gliem & Gliem, 2003).

Interview

Of all participants, 20% were randomly interviewed after the photoelectric effect class by using the same interview protocol (see Appendix). The interview protocol was used as a guide for the researchers to maintain the focus of interview and as markers for the interview to follow (Dilley, 2000). The protocol was incorporated with the prompts to remind the interviewer to further probe for in-depth information from the participants, which was the focus of study (Jacob & Furgerson, 2012).

Reflective journal

After attended the photoelectric effect class, the participants were required to write their reflective journals to reflect upon contents, teaching, and learning in the class including the photoelectric effect simulation and game. The reflective journal can provide clues to important circumstances faced by the participants and their attitudes toward those circumstances (Jacelon & Imperio, 2005).

Data analysis

The quantitative data was analyzed by using the statistical package of SPSS®. The paired sample t-test was used to analyze the pre-test and post-test mean scores of PECE. The Cohen's d was also used to determine the effect size of the photoelectric effect class, which was measured by standardizing the difference between the means in terms of standard deviation (SD). Researchers identify that calculated value as 'estimated Cohen's d' (Wallnau & Gravetter, 2005). Thus, the estimated Cohen's d was used to measure the effect size of this study. The data from MAS was also calculated for mean and SD. In addition, a thematic analysis was employed to analyze qualitative data from interviews and reflective journals. The thematic analysis is started from intensive reading of qualitative data, then the important sections in the data are labelled and given a name or code. The similarly emerged codes will be grouped into a category. All emerged categories will be reviewed in order to find out the pattern or theme of findings. (Braun & Clarke, 2006).

Results and discussion

Students' development of understanding about photoelectric effect

The PECE revealed some common misconceptions of photoelectric effect held by the participating students as Table I.

Table I. Students' common misconception of photoelectric effect expressed from PECE

Components of PECE	Common misconception	Correct conception
a) Electromagnetic (EM) model of light	Students use the photon model of light.	Students use the electromagnetic model of light.
b) Photon model of light	Students use the electromagnetic model of light.	Students use the photon model of light.
c) Characteristic of photon	The energy of the red light photon is greater than the energy of the yellow one.	The energy of the red light photon is less than the energy of the yellow one. (Energy of photon depend on frequency rather than intensity).
d) Threshold frequency	Students cannot relate conception of frequency light associated with emission of elections.	All the lights which has frequency greater than yellow light will emit electrons when shone to that particular metal.
e) Work function	Student cannot relate the conception of work function with energy of photon which in turn depends on frequency of light.	Potassium and sodium will be able to emit photoelectrons since the energy of ultraviolet is greater than the work functions of those metals.
f) Maximum kinetic energy	Student cannot relate the conception of work function with energy of photon which in turn determines the maximum kinetic energy of emitted electrons.	Potassium will be able to emit electrons since its work function is less than the energy of the light.
g) Stopping potential	Student do not have conception of stopping potential, which depends on work function of the metal.	Rank of the stopping potential from largest to smallest: Potassium > Sodium > Aluminum > Tungsten > Copper > Iron > Gold > Platinum.

In addition, the students' post-test scores were higher than pre-test scores in all constructs of PECE. The students gained more understanding specifically to the Threshold Frequency and the Work Function constructs.

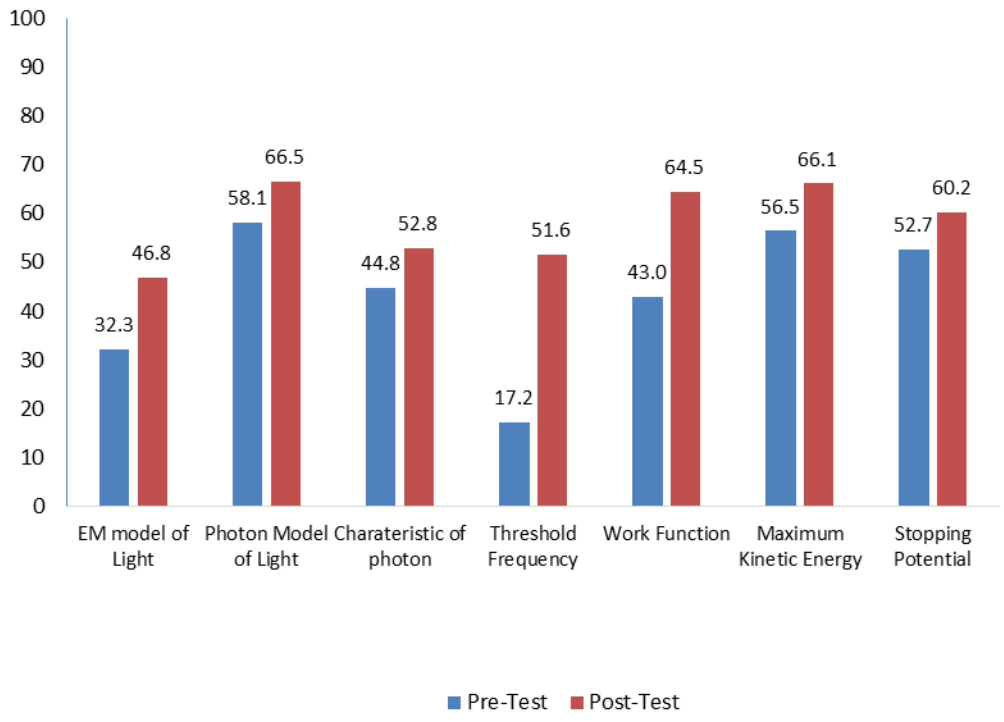

Figure V. Students' score in each construct of PECE

This finding showed that the photoelectric effect simulation and game helped concretize the abstract concepts of photoelectric effect, which otherwise would be difficult for the students to visualize. The students' highest post-test score was on the concept of photon model of light, which could be attributed to power of simulation created in this study in helping the students visualize the photon model of light. In overall, the students' post-test scores were higher than 50% except for the concept of EM model of light, which the students gained the lowest post-test score. This is because the photoelectric effect learning unit created in this study was not dealt comprehensively with the concept of EM model of light; the EM model of light was raised as one example to contradict the photon model of light. The mean of students' pre-test score was 12.94 (SD = 3.81) and the mean of post-test score was increased to 16.94 (SD = 3.12). The normalized gain analysis (Hake, 1998) revealed that the overall normalized gain score for the participating students was .352. In addition, the paired sampled t-test reveals that after attended the simulation and game based instruction on photoelectric effect the participating students significantly improved their understanding about photoelectric effect (t (30) = 7.79, $p < .05$). The paired sample correlations showed that the pre-test and post-test scores were statistically correlated ($r = .671$) at the .01 significant level.

Table II. Paired sample t-test of pre- and post-test of PECE

	Mean	Std. Deviation	Std. Error Mean	t	df	p-value
Post-test – Pre-test	4.032/p>	2.881	.517	7.793	30	.000**

** The statistically significant difference level at .01

In addition, the estimated Cohen' d was 1.40, which implied that the simulation and game based instruction improved the mean scores by 1.40 of the sample SD. Cohen (1988) suggested the criteria for evaluating a size of treatment effect and a magnitude of 1.40 was considered as a large effect size.

McKagan et al. (2009) used simulation to teach photoelectric effect but they did not mention about the teaching and learning approach used. This study shows the effectiveness of the simulation and game embedded in the 5E learning cycle in teaching the photoelectric effect concept. The simulation and game requires the students themselves to discover different aspects of the photoelectric effect phenomenon. The students can take advantage of the Exploration phase in the 5E learning cycle in generating various hypotheses to explain the photoelectric effect phenomenon and then testing those hypotheses (Blank, 2000). The simulation and game help the students to be able to deduce the relationship between the frequency of light and the emission of photoelectron as well as the relationship between the intensity of light and the number of emitted electron. The most important concept learned by the students is that the emission of photoelectrons depends definitely on the frequency of light irrespective of its intensity. Almost all students could predict the result of photoelectric effect phenomenon when altered various factors in the photoelectric effect simulation. The students could correctly state that the frequency of light must be above the threshold frequency to let the photoelectron emission to take place. Also, the threshold frequency is unique for a specific type of metal. The frequency of light is directly proportional to the energy of photon, which is considered as packets of energy. The students can accommodate the concepts of photoelectric effect phenomenon and use many evidences to build the photon model of light. The students could find stopping potential, which measures the maximum kinetic energy and used this data along with the frequency of light to plot the related graphs. These graphs give Einstein's photoelectric equation and the students knew the meaning of the equation, which otherwise would be presented directly to them in their regular physics class. The most important information from the graph is the slope of the graph, whose value is equal to the Planks constant. It means that energy of light is quantized and its magnitude can be an integral multiple of Plank's constant. The students were able to relate how light exist as packets of energy and what happens when the frequency of light is increased. While interacting with the simulation and game, the students take control of their learning and actively constructed knowledge by themselves. This is necessary for students' conceptual development and aligned with the constructivist philosophy (Duit & Treagust, 1998).

Students' attitudes toward the simulation and game based instruction in photoelectric effect

The analysis showed that the students gained not only understanding about photoelectric effect, but also positive attitudes to the simulation and game based instruction. In overall, the participating students had positive attitudes towards the simulation and game based instruction to teach photoelectric effect (mean = 4.43, SD = .72).

Table III. Students' attitudes towards the simulation and game based instruction on photoelectric effect

Dimension	**Mean**	**SD**
1. Students' views toward computer interaction	4.45	.72
2. Students' degree of involvement in the multimedia activity	3.70	.96
3. Students' views on individualize instruction	3.71	.81
4. Students' perceptions toward self-paced instruction	4.12	.84
5. Students' perceptions of application's user friendliness	4.23	.77
6. Students' level of anxiety when working with multimedia	4.11	.93
Total	**4.43**	**.72**

From MAS, the students had the highest and lowest attitudes towards the simulation and game based instruction regarding its interaction and degree of involvement with multimedia, respectively.

After finished the photoelectric effect class, the participating students were asked to write their reflective journals. The thematic analysis revealed five themes emerged as being shown in Table 7. Most of the students (n = 26) reflected that the simulation and game based instruction helped them understand the concept of photoelectric emission. In addition, more than a half of the students reflected that the simulation and game based instruction was enjoyable and attentive.

Table IV. Summary of students' reflections from reflective journal

Theme	**Statement**	**Frequency**
Photoelectric emission	Emission of photoelectron does not depend on intensity of light but on frequency of light.	26
Being enjoyable and attentive	Simulation and game was fun to explore and drew my attention	17
Threshold frequency	Light should have minimum threshold frequency for the emission	16
Visualization and Understanding	Students could visualize the concept and had better understanding	10
Student Centered	Students could explore by themselves	4

After completion of the whole learning unit, six students were randomly selected for interview to provide further evidence for supporting the results from PECE, MAS, and reflective journal. The students' comments on the photoelectric effect learning unit were:

Table V. Summary of students' reflections from interview

Topic	**Summary of students' reflection**
Photoelectric effect class	The lesson was well designed unlike our regular class where theories were directly described from the test. Students could observe and do the experiments therefore learning was easier and spontaneous without any rote learning.
Photoelectric effect phenomenon	Students could correctly describe the photoelectric phenomena and predict the result when various factors affecting the phenomena were altered.
Photon model of light	Students could describe the photon model of light using the result from the photoelectric phenomena but description of some relation was not that vivid.
Simulation and game	Simulation and game were interesting and fun to explore, and they could learn many new things related to photoelectric phenomena without much guidance from the teacher.

Photoelectric effect class

Some students said that the photoelectric effect lesson was not monotonous like their regular physics classes where they had to learn the theoretical concepts from the textbooks and did not have much room for visualizing the concepts. In this class, they could visualize the photoelectric effect concept and could explore by themselves with little guidance from the teacher.

We enjoyed a lot; it was not monotonous as a regular class we used to have. In our regular class, we use to have black and white image from the text, we were unable to visualize the exact concept. We were unable to conceptualize what is being taught. From the simulation and game we were able to perform by ourselves without the aid of our teachers, we were able to perform just simply by reading the questions (Student 21).

While learning from the text book, we have to go line by line, each and every detail had to be referred but in case of simulation, as soon as we see the question, we can perform in the simulation. In simulation we need not go line by line or read every detail of that because whatever question is asked, we are able to visualize in front of us, we can easily comprehend what is there (Student 27).

Photoelectric phenomena

Students could correctly state the factors affecting the photoelectric phenomena and predict the results that accompanied when various factor were varied. They were able to state that emission of electron is directly proportional to the frequency of light but independent of the intensity of light. The number of photoelectrons emitted depends on the intensity and the kinetic energy of the emitted electron depends on the frequency.

With the help of simulation we can see with our eyes and we knew that intensity does not play role for the emission whereas frequency is more important, since frequency is required to overcome the work function of the metal in order to emit the electron from the surface of the metal. The frequency of a light should be more than the threshold frequency of the metal for the emission to take place, if it is less then no matter how much is the intensity, electrons will not be emitted. The emission of photoelectron depends on frequency but is independent of intensity of light (Student 05).

I learned the energy of electrons emitted is related to frequency. How the wavelength and frequency differ, and how it relates to emission of electrons.

Intensity is directly proportional to number of electrons emitted from the surface of the metal. In case of frequency, if the frequency is higher, energy of electron emitted will be higher. Frequency is the factor which is the key for the emission of electron from the surface. For the emission, frequency is required but number of electrons emitted will depend on intensity of light (Student 09).

Photon model of light

The students were able to state that the in photoelectric phenomena, the transfer of energy between light and electron take place between packets of light energy and the electron. Therefore, there is instantaneous emission at very low temperature.

We know that diffraction and refraction can be explained by wave nature but due to particle nature, there is an emission of electron in photoelectric effect. This emission of electron will not be possible if there is no transfer of energy from particle to particle. The electrons ejected are at low temperature which shows that energy is transferred from particle to particle (Student 05).

When we expose the metal to the light with certain frequency and intensity, it is knocking the electron from the orbital, so in order to knock something, something has to have momentum and that momentum is the property of particle nature. That is why I came to know it is a particle nature (Student 02).

Simulation and game

The students were satisfied with learning outcome using simulation and game. They stated that simulation could bring theory to reality where they observe and learn. Also, game was fun to play and at the same time there was learning.

It is a new idea, before it used to be just only text book, and learning was theoretical one. But this simulation helps to bring theory into reality and we can see and observe experiment. Students used to learn directly from the text and students did not have opportunity to deal with this kind of experimental simulation. I knew the theoretical aspect of photoelectric effect from my regular class, but I did not know how it works in reality? How emissions of electron take place from the metal surface? How frequency and intensity of light affects the emission of electron. Before, I by hearted the phenomena and the factors affecting it. After doing a simulation in the class, I found that learning was easier and spontaneous without having to by heart (Student 01).

MAS shows that students are satisfied with the simulation and game instruction to teach the photoelectric effect concept. Most of the students reflects that the simulation and game based instruction is student-centered and they can learn with little guidance from the teacher. The students are enjoy and able to comprehend the photoelectric effect concept through visualization. The students like the interface of the simulation and game since they can carry out the activities with ease. They interact with the simulation and game by simply following the direction given. This is why the attitude mean score of the Interaction scale is highest. However, the students had low attitude mean scores on the Involvement and the Individualize Interaction scales. This might be because of the rules and knowledge required by the students for playing game. The students commented that it was interesting only after knowing certain rules and how to solve the problems. The students interact with the photoelectric effect simulation individually and they reflected that it would be better if they could perform in pair. The attitude mean scores for the Self-paced Instruction, User Friendly and Individual Anxiety scales were 4.12 (S.D. = .84), 4.23 (S.D. = .77), and 4.11 (S.D. = .93), respectively. It implies that students like the simulation and game, and they are comfortable to the learning unit. The photoelectric effect game was used in the Evaluation phase since it has an attribute of self-motivation and reward. In addition, the simulation and game activities were designed to fit into the constructivist philosophy (Amory, Naicker, Vincent, & Adams, 1999; Klassen & Willoughby, 2003).

Conclusions and Implications

This study shows that the simulation and game can be incorporated in the 5E learning cycle context and are able to significantly help grade 12 students improve their understanding of photoelectric effect and have positive attitudes towards learning photoelectric effect. Specifically, the created simulation help concretize the abstractness of photoelectric effect and the created game help make learning photoelectric effect with enjoyment. There are many other topics in physics, especially abstract ones, that can be and/or should be taught by simulation and game. This study also shows that the 5E learning cycle can be employed as a learning context for incorporating the well-constructed simulation and game in. The stronger experimental research design may be needed for further studies in order to make more stronger claims. The audience who is interested to get and use the simulation and game created in this study can contact and ask for the permission from the correspondence author via e-mail.

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