Eurasia Journal of Mathematics, Science & Technology Education, 2015, **11**(4), 777-792

A Study Investigating the Effect of Treatment Developed by Integrating the 5E and Simulation on Pre-service Science Teachers' Achievement in Photoelectric Effect

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Received 17 December 2014; accepted 23 March 2015; published on April 27, 2015

The Current study investigated the effect of the 5E learning cycle in which the simulations were integrated on pre-service science teachers' achievement in photoelectric subject. Four sophomore level classes with their 140 students participated in the research and a quasi-experimental design was used. The classes were randomly assigned into one of the two treatment groups. The experimental group (n1=69, male=16, female=53) studied photoelectric effect with the developed instruction and the control group (n2=71, male=19, female=52) studied the same subject with traditional instruction. Achievement test and open-ended exam were administered to measure students' pre-and-post achievements. The main effect of treatment on post-tests scores was examined via MANCOVA with pre-achievement scores used as covariate. The analyses yielded significant treatment effect on the collective dependent variables. Follow up ANCOVA results indicated that the instruction developed for the experimental group affected participants' post-achievement and post-open-ended exam scores significantly. Extensive analyses of the open-ended exam items showed that some of the participants were considering the supplied potential as the preliminary condition for the current flow in photocell circuit. The instructors or researchers would develop their treatments by integrating scientifically well-developed simulations into 5E learning cycle and use them in their lessons to promote learners' achievements.

Keywords: Photoelectric effect, 5E learning cycle, simulation, achievement, science education.

INTRODUCTION

In recent years, researchers have focused their attentions to the students' understanding of quantum physics concepts at different school levels (Asikainen & Hirvonen, 2009; De Leone & Oberem, 2004; McKagan, Handley, Perkins, & Wieman, 2009; Steinberg, Oberem, & McDermott, 1996; Yıldız & Büyükkasap, 2011). Photoelectric effect is one of the important quantum physics topics that play a crucial role in understanding the photon model of light (McKagan et al., 2009; Wong et al., 2011). Unfortunately, the previous researches reported that most of the students from different educational levels have serious learning difficulties in understanding the basic aspects of photoelectric effect such as interpreting experimental set-up, predicting experimental results and its' relation to the photon model of light (De Leone & Oberem, 2004; McKagan et al., 2009; Sokolowski, 2013; Steinberg et al., 1996). Especially, the university level quantum physics courses

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doi: 10.12973/eurasia.2015.1367a

ISSN: 1305-8223

State of the literature

- Photoelectric effect is one of the important quantum physics topics that plays crucial role in understanding the photon model of light.
- Most of the students from different educational levels have serious learning difficulties in understanding the basic aspects of photoelectric effect.
- The related literature reported that applications of the 5E learning cycle and the simulation activities individually promote successful learning outcomes. Hence developing a treatment by inserting the simulation activities into 5E learning cycle and applying it successfully would result in higher achievement of sophomore level pre-service science teachers.

Contribution of this paper to the literature

- This study will make important contributions to the literature in terms of both identifying the development of a new treatment by integrating simulations into 5E learning cycle and defining the application of it in school environment for other researchers and instructors.
- The findings presented here denoted that some of the sophomore level pre-service science teachers were not aware of the basic aspects of photoelectric effect.
- This study will add to the literature about the effectiveness of treatment developed by the 5E learning cycle in which the simulations were integrated in increasing the sophomore level pre-service science teachers' achievement in photoelectric effect.

cover such topics so rapidly that most of learners cannot grasp the fundamentals of the concept (Asikainen & Hirvonen, 2009). Hence it is claimed that traditional presentation of photoelectric effect does not provide students with the sufficient functional and conceptual understanding (Steinberg et al., 1996; Uscinski & Larkin, 2011).

Steinberg et al. (1996) investigated sophomore level students' understanding of photoelectric subject via interviews and exam questions. They developed photoelectric tutor and the learners interacted with it after the lectures. Research results showed that the participants were unable to explain the photoelectric experiment in terms of the photon model of light previously and the learners who used the tutor made fewer errors and better explanations about the exam questions. Asikainen and Hirvonen (2009) conducted a case study to investigate the effect of treatment developed via Cyclic Teaching-Learning Procedure on pre-service and in-service teachers' understanding of photoelectric effect. Results denoted that application of the instruction led both groups attain deeper understanding and higher achievements. McKagan et al. (2009) developed a curriculum including computer simulation, interactive lectures with peer instruction, and conceptual and mathematical homework problems. They searched whether students can predict the consequences of photoelectric experiment and identify how the results are related to photon model of light. The researchers reported that the developed instruction helped students in predicting the results of experiment better than traditional instruction did. Yıldız and Büyükkasap (2011) studied the effect of writing activities on learning the photoelectric effect. They reported that prospective teachers had previously low levels of understanding for the concept but writing activities increased experimental group students' understanding more than that of control group. Sokolowski (2013) conducted a study to see the effect of inductively situated instruction on high school students' understanding of the photoelectric subject. The researcher used interactive simulation as the lesson activity. The results denoted that the students attained a better conceptual understanding level for the process of photoelectric effect.

As stated above, various methods were used to promote learners' understanding of photoelectric effect. In their study, Asikainen and Hirvonen (2009) developed a treatment which has certain similarities with the method suggested by Karplus and Their's three phases learning cycle method. They reported successful learning acquisitions in understanding key quantum physics concepts. Hence, it was expected that it would be better to develop a new instruction via learning cycle method as suggested by Asikainen and Hirvonen to satisfy high participation of learners into the teaching-learning environments and promote higher achievement in photoelectric concept.

Learning Cycle Method

Learning cycle method was originally formulated by J. Mayron Atkin and Robert Karplus in 1962 (Bybee & Sun, 1990). Later, Karplus and Their explained three phases teaching approach in 1967 (Lawson et al., 1989). Learning cycle is a teaching approach which was originally constructed on three distinct cycles of instruction; exploration, term introduction and concept application (Marek, 2008). As time goes by, different versions such as four faces, five faces and seven faces were developed. Each has the same inductive instructional procedures regardless of the quantity of phases (Settlage, 2000). For this study, five phases of learning cycle model (5E) was handled for the development of instruction.

5E Learning Cycle

In the late 1980s, Biological Sciences Curriculum Study began using a teaching model for the development of new curriculum materials and it was labeled as BSCS 5Es Instructional Model (Bybee, 2009). It is a theory based design for inquiry and consists of five distinct phases; engagement, exploration, explanation, elaboration and evaluation. Bybee reported the basic tenets of five phases of learning cycle briefly; at the engagement phase, students' attentions are attracted and their preconceptions are uncovered. For the exploration phase, students are provided with first-hand experiences related to science phenomena. In the explanation phase, teacher helps students focus their attention on previous engagement and exploration experiences and provides opportunities to explain their understanding. At the elaboration phase, students' understandings are extended with new experiences. Finally, for the evaluation phase, the learners are encouraged to assess their own understanding and teachers evaluate their development in achieving the educational objectives.

In science education, the number of researches investigating the effects of the 5E learning cycle has increased rapidly in the last decades. They generally reported that application of it resulted in mastery of subject matter, better retention of concepts, greater science achievement, improved reasoning ability and superior process skills than obtained by traditional instructions (Açışlı, Yalçın, &Turgut, 2011; Ates, 2005; Bybee, 2009; Duran, Duran, Haney, & Scheuermann, 2011; Ergin, Kanlı, & Ünsal, 2008). It was also reported that the method is being constantly refined as new researches emerge to support its effectiveness (Duran et al., 2011).

In the last years, some researchers (Hırça, Çalık, & Seven, 2011; Nas, Calik, & Cepni, 2012; Sahin, Calik, & Cepni, 2009) embedded some of the conceptual change techniques such as creative drama, conceptual change text, worksheet and analogy within 5E learning cycle model. Sahin et al. conducted a hypothetical study to denote how to combine different conceptual change methods within 5E learning cycle model for teaching liquid pressure. Nas et al. investigated the effect of their model on remediating 6th grade students' alternative conceptions of heat transfer. They reported that the model was meaningfully effective in remedying students' alternative conceptions of concerning concept. Hırça et al. conducted a research to investigate the effect of their model on 10th grade students' achievement in and attitudes towards work, power and energy concept. The research findings showed that the model was effective for increasing students' achievement in and attitudes towards concerning concept.

Aside from the above, some of the studies initiated to integrate virtual laboratory environments into teaching learning environment in the last decades (Başer, 2006; Jaakkola & Nurmi, 2008; McKagan et al., 2009; Ronen & Eliahu, 2000; Sokolowski, 2013; Steinberg et al., 1996; Zacharia, 2005). They reported positive impacts on learning outcomes. The virtual laboratory environments were generally created by using simulations.

The Simulation

Simulation is a kind of computerized version of a model that is run over a period of time to investigate the implications of the previously defined interaction (Başer, 2006). Simulation based learning is generally considered as an alternative approach to expository instruction or to real hands-on laboratory exploration (Ronen & Eliahu, 2000). It allows students to arrange the independent variables and observe the impacts immediately (Zacharias, 2005). Hence use of simulations was suggested while teaching physics to make the contexts more easily understandable (Jaakkola & Nurmi, 2008) and to provide the learners with constructive feedback (Ronen & Eliahu, 2000). Most of the previous researches reported successful learning outcomes (Başer, 2006; Jaakkola & Nurmi, 2008; McKagan et al., 2009; Ronen & Eliahu, 2000; Sokolowski, 2013; Steinberg et al., 1996; Zacharia, 2005).

Purpose of Study

The success stories of the 5E learning cycle and simulations as virtual laboratory environments connoted that a new treatment would be developed by integrating both the 5E learning cycle and simulations within a new treatment. It was thought that developing such a treatment and applying it effectively would help students in understanding the highly abstract and difficult subject of photoelectric effect. The extensive literature review indicated that there was no study combining both the 5E learning cycle and simulations for photoelectric teaching and investigated its' effect on sophomore level pre-service science teachers' achievements in photoelectric effect. Hence, this study aimed first to develop a new treatment by inserting the simulation applications into the 5E version of learning cycle and second to investigate its' effectiveness on sophomore level pre-service science teachers' achievement in photoelectric subject.

It is hoped that the current study will make contributions to the literature by (1) identifying the development of a new treatment by inserting the simulation applications into the 5E learning cycle, (2) explaining the application of it in school environment for other researchers and instructors, (3) reporting the research findings and comparing them with those of previous ones. The research question of the current study is;

- What is the effect of treatment developed by inserting the simulation applications into the 5E learning cycle on sophomore level pre-service science teachers' photoelectric post-achievement scores (PSTT) and post-open-ended exam scores (PSTOEE) when their pre-achievement scores (PRET) and pre-open-ended exam scores (PREOEE) are controlled.

METHOD

Population and Sample

The population of the study consists of approximately 515 sophomore level pre-service science teachers in Akdeniz region of Turkey. In this region there are eight government universities but five of them are offering science teacher education program in their faculties of education. A convenience sample of 140 sophomore level pre-service science teachers in one of the five education faculties constituted the sample of study. Two classes (n1=69, male=16, female=53) were assigned randomly as experimental group and the remaining two (n2=71, male=19, female=52) were assigned as control groups, making the sample 27% of the population. Students' ages ranged from 18 to 24 years.

In science teacher education program, students study the photoelectric subject in the context of compulsory Introduction to Modern Physics course in their second years. The students studied some of the modern physics topics; structure of atom including atom models, energy levels, special relativity, photon concept including quant and black body radiation just before the research. They started to learn photoelectric subject with this study.

Design and Procedure of the Study

A quasi-experimental design was used for the research. The study started with a detailed review of the literature. The draft forms of Achievement test (ACT) and Open-Ended Exam (OEE) were developed and a pilot study was conducted. Meanwhile, all treatments and teaching/learning materials were developed for both experimental and control groups. Based on pilot study and expert opinions, the measuring tools and all instructional materials took the final forms.

After administering the ACT and OEE to all groups as pre-tests, the treatments were applied. The experimental group studied the photoelectric subject with the new treatment developed by inserting the simulation activities into the 5E learning cycle and the control group studied the same subject with traditional instruction. All instructional activities in both groups were conducted by the same researcher who has 15 years of teaching experience. After three-week treatment period, the ACT and OEE were reapplied to all groups as post-tests. All testing and instructional activities were conducted concurrently for both groups. Finally, the obtained data was analyzed via MANCOVA and follow-up ANCOVA.

Measuring Tools

The ACT was developed by the researcher to assess learners' achievement in photoelectric effect. It includes 40 questions; 10 items are true-false type, 10 items are fill-in the blank type and remaining 20 items are multiple-choice type. Thirty four of 40 items are conceptual and six are quantitative. Most of the questions were adapted from previous studies (Asikainen & Hirvonen, 2009; De Leone & Oberem, 2004; Özdemir & Aras, 2008; Steinberg et al., 1996; Uscinski & Larkin, 2011). The conceptual items seek to reveal students' understanding of the basic aspects of photoelectric effect, results of photoelectric experiment, interpretation of the graphs denoting photoelectric current versus applied potential (I-V) and kinetics energy of photoelectrons' versus the frequency of incident light (KE-f). The quantitative items are related with the calculation of threshold energy (or work function which will be used interchangeably throughout the study), threshold frequency, stopping potential and maximum kinetic energy of photoelectrons. Figure 1.a indicates a sample true-false type item, Figures 1.b and 1.c both show sample multiple-choice type conceptual and quantitative items respectively.

In the development process of the ACT, first the learning goals were identified by preparing an objective list in the light of the curriculum. Then 40 items, measuring each objective, were developed. After that, a table of test specification was prepared to improve the validity of the test and check whether the items were measuring the content adequately. Finally, a draft ACT was obtained and given to one experienced college physics teacher and two instructors to investigate whether the test items are clearly readable, easily understandable and relevant to the teaching objectives. The suggestions were used to improve the test. After that, the ACT was administered to 17 graduate physics major students who were attending teacher certificate program as the pilot study. The obtained data was analyzed via ITEMAN. The findings denoted that the internal reliability coefficient of Cronbach's alpha was 0.92. The average difficulty index and average point-biserial correlation were 0.48 and 0.62 respectively.

Since all of the values were acceptable, no questions were removed and the ACT took the final form.

The OEE, given in Figure 2, consists of three open-ended items which were adapted from the study of Steinberg et al. (1996). They developed the items to reveal sophomore level students' understanding of photoelectric subject in the context of modern physics course. The items were translated into Turkish and then checked by an experienced college physics teacher and two experienced instructors whether they are easily understandable or not. The suggestions were used to improve the items. The main reason of administering the OEE was to obtain deeper and clearer picture of what the students are really thinking in the corresponding concepts.

Teaching/Learning Materials

For the conduction of treatment in the experimental group Photoelectric Simulation program was used. It was developed by Colorado University in the context of PhET Interactive Simulations Project. The program is free and downloadable (PheT Simulation, 2006). It enables users to set the experimental parameters such as wavelength, intensity, potential difference and cathode material and allows users to observe the impacts immediately. Students can construct the I-V, KE-f and

Read each of the following statements; if the statement is true, write T; if the statement is false write F in front of the statement.

4. …….. In a photoelectric experiment dim red light is projected on a photocell but no photoelectron is emitted. If the intensity of red light is increased then photoelectrons would be emitted.

Figure 1a. Sample True-False Type Item

24. A light beam whose frequency is greater than the threshold frequency falls onto the cathode surface of a photocell. If the intensity of this light beam is increased further then

I. the kinetic energy of the photoelectrons would increase.
II. binding energy of electrons would decrease.
III. the number of photoelectrons would increase.

Which of the above conclusion(s) are correct?

A) Only I B) Only II C) Only III D) I and II E) II and III

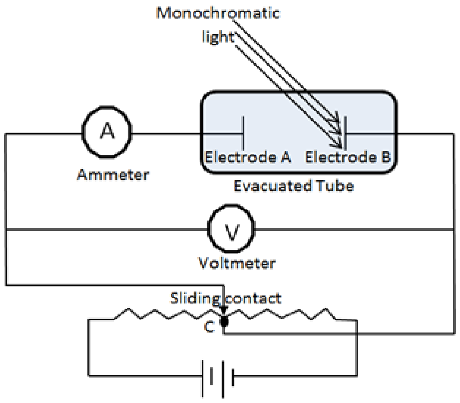
Figure 1b. A Sample Item for Multiple-Choice Type Conceptual Question

25. A light beam of wavelength of 2000A° is projected on metal surface whose work function is 4eV.

What is the cut-off potential for photoelectrons? (Take hc=12400eVA°)

A) 1.5V B) 2.2V C) 3.0V D) 8.4V E) 20.8V

Figure 1c. A Sample Item for Multiple-Choice Type Quantitative Question



Suppose that you are performing photoelectric experiment in which light of wavelength λ=250nm and a platinum cathode of work function 6.4eV are used. After you set the voltage across the photocell to zero, then no current flows through the circuit.

I1. Does photoelectric current flow in the circuit if the intensity of the light is doubled? Explain your reasoning.

I2. Does photoelectric current flow in the circuit if the voltage across the photocell is set to 6.5V? Explain your reasoning.

I3. Does photoelectric current flow in the circuit if the platinum cathode is replaced by the iron cathode whose work function is 4.5eV? Explain your reasoning.

Figure 2. The OEE Items

Part 1. Effect of Varying the Intensity of the Incident Light

Step1: Open Photoelectric Effect Simulation program, set the following parameters, and finally run the program. You can control the incident light either light beam or the photon beam by selecting the "show photons" box under the options menu.

Target cathode material	: Sodium
Wavelength of the incident light	: λ= 400nm
Battery voltage	: 0 volt
Intensity of the light	: 0 %

Question 1: Do you observe any current when the intensity of light is zero?

....
....

Step2: Increase the intensity of the light gradually from zero to 100% and observe the amount of current flowing through the circuit.

Step 3: Fill in Table A given below about the magnitude of current flowing through the circuit for the given light intensities.

Table A

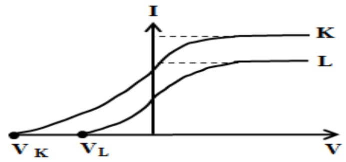
Light intensity (%)	Current ((I_0)
25	
50	
75	
100	

Question 2: What can you conclude about the effect of light intensity on magnitude of current when the frequency of light and the cathode material are fixed? Write your conclusion below.

....
....
....
....

Figure 3. Part 1 of the Experimental Manual

Question-2



A photocell is first illuminated by the light beam K and then the light beam L. The photoelectric current as a function of the potential difference across the photocell is shown in the graph. Based on this graph

a) Compare the intensities of light beams K and L.

Explain your reasoning

b) Compare the brightness of light beams K and L.

Explain your reasoning

c) Compare the frequencies of light beams K and L.

Explain your reasoning

d) Compare the wavelengths of light beams K and L.

Explain your reasoning

e) Compare the maximum kinetic energies of photoelectrons ejected by light beams K and L.

Explain your reasoning

Figure 4. Question-2 of the Homework Set

current-light intensity graphs. The program was used actively in the exploration, explanation and elaboration phases of the 5E learning cycle.

McKagan et al. (2009) claimed that viewing a simulation just passively is not effective for constructing mental models; the learner should interact with the simulation. Hence, four laboratory manuals were prepared for the experimental group to guide them in their interactions. They were developed for discovering the effects of (1) intensity, (2) frequency, (3) work function and finally (4) stopping potential on photoelectric current. Because of the limited space, only the first part of the manual, Part-I, was given in Figure 3.

A homework set was developed for the evaluation phase of the 5E learning cycle model. It consists of three items and each has sub-items. The questions were adapted from previous studies (Özdemir & Aras, 2008; Steinberg et al., 1996). Question-2 of the homework set is given in Figure 4.

Beyond the above, two power point presentation files, one for the experimental and the other for the control group, were prepared to conduct and deliver the course content. The files include explanation sections, questions and related figures. Both differ only in strategy of delivering contexts. Namely, the presentation of the subjects in experimental group was prepared according to the requirements of the stages (engagement, exploration, explanation, elaboration and evaluation) of the 5E learning cycle but the same topics were just presented traditionally in control group. For instance, the experimental groups' presentation file begins with Figure 5. The main purpose was to take students' attention towards the subject and reveal their ideas about the light (also photon) and metal interaction. The leading questions such as "what do you understand from the figure? or how do you interpret on it?" followed the figure to satisfy the engagement phase of the 5E learning cycle. On the other hand, the presentation file developed for control groups' just begins with the exploratory texts defining the concept. There were no leading questions or instructions to reveal students' ideas or take their attention toward light and metal interaction as in the experimental group. Of course, Figure 5 was placed within the exploratory text while presenting the concept but no special attention was given on it. In brief, different strategies were considered in the development process of the files for both groups. In both groups, the instructor opened them and followed the lectures over them. All materials stated above were checked by two experienced instructors for the content validity and suggested revisions were completed.

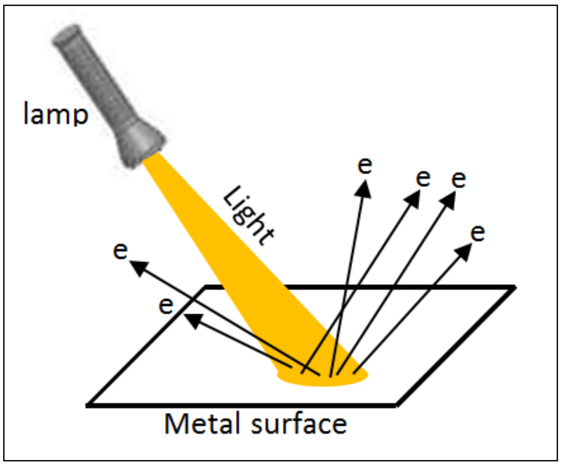


Figure 5. Ejection of Electrons from the Metal Surface

Treatment

The concerning topics of photoelectric subject were studied as a regular classroom activities in the context of Introduction to Modern Physics course. Both groups were exposed to same content. The lessons were two 40-minutes periods per week. Because of the limited space, only a small part of experimental group treatment was presented briefly without giving more detail to make the intervention more clear.

After introducing the lesson, Figure 5 was initially projected and students were asked to interpret on it to initiate the engagement phase of the 5E learning cycle.

Upon revealing learners' ideas, the schematic diagram of the experimental setup, given in Figure 2, was projected. Students were asked to identify the circuit and predict possible experimental consequences. Most of them identified the circuit as a kind of simple circuit consisting of variable resistor, ammeter, voltmeter, tube and a battery. They generally interpreted the evacuated tube as a kind of resistor. They couldn't explain the function of sliding contact as voltage divider. Most of the students stated that the potential difference supplied by the battery was the main reason for the current in the circuit. Some of them commented that the incident light would also lead to current flow but they could not explain the underlying idea of photoelectric effect satisfactorily. Interestingly, one or two students stated that the reflection of light from cathode towards anode lead to current flow in the circuit. When the students were asked about the conceptual meanings of intensity and frequency of light, they could not give clear explanations. Most of them were considering that the frequency and intensity are directly related with each other. If the frequency of light is increased, then the intensity also increases or vice versa. When they were asked about the effect of intensity and frequency on the photoelectric current, no satisfactory responses were obtained. They generally stated that increasing either the intensity or frequency would lead to current flow in general. For the exploration stage, students were taken to the computer laboratory for two hours to create a virtual laboratory environment. Most had one computer and only two learners shared one computer. The program was simply defined and previously developed manuals were distributed.

Students set up the experimental parameters as in the manual, given in Figure 3, and run the simulation (Step 1). Since the intensity of incident light is 0%, no light was send towards cathode and no current was observed in the circuit. They immediately noted their observations under Question 1. Then they increased the intensity gradually from zero to 100% and observed the impact (Step 2) even the applied external potential was 0 volt. They noted the magnitudes of current for different values of the intensity in Table A (Step 3). The foregoing steps indicated that increasing the intensity led to increase in the magnitude of photoelectric current when the wavelength was 400nm (for which the energy of photon is higher than the work function of sodium metal) and the supplied battery voltage was zero. After all, they reported their conclusions under Question 2. Upon the above, the next steps, which were not shown in Figure 3, were conducted. At this time, the wavelength of the light was set to 730nm (for which the energy of photon is smaller than the work function of sodium). This time students observed that increase of intensity neither produced current nor increased its' magnitude. They were confused why the increase of intensity led to increase in the magnitude of current when the incident wave length was 400nm and why the same increase of intensity did not produce any current when the wave length was reset to 730nm.

After engagement and exploration phases, the explanation stage was initiated. First of all, the instructor encouraged learners explain the photoelectric phenomena based on their previous simulation experiences. But students had difficulties in explaining the phenomena in terms of the conservation of energy between photon, work function and photoelectrons' kinetic energy. Beside they couldn't explain the ineffectiveness of intensity on the photoelectric current when the incident wave length was 730nm and there is sodium metal at the cathode. After all, the instructor opened the simulation and explained the fundamental concepts of photon energy, threshold energy (ϕ), threshold frequency (fo), photoelectric current. For the elaboration phase, students were asked whether they were aware of daily life applications of photoelectric effect. But they didn't render any opinion. Upon it, the instructor mentioned about the applications of it in photodiodes, phototransistors, image sensors and electroscopes briefly. Beyond this, in order to help students develop deeper and broader understanding, three activities were conducted. In these activities, drawing and interpretation of I-V graphs for the photoelectric phenomena was used. In each activity, true graph of the I-V was projected, and students were asked to draw new versions of it when (1) the intensity of incident light is decreased, (2) the frequency of incident light is increased and (3) the cathode metal is replaced with a new metal whose work function is greater than the energy of incident photons ($\phi > hf$). For instance, for the first activity, the true graph of the I-V, given in Figure 6, was projected and then learners were asked to draw new version of it in case of decreasing the intensity of incident light.

It was observed that, although some of the students predicted the result, most of them had difficulties in drawing the new version. Upon students try, the instructor guided them with leading questions such as; whether decreasing intensity lead to decrease in (a) photon energy, (b) photoelectron's kinetics energy, (c) threshold energy of cathode material and (d) stopping potential, sequentially. The questions helped students remind that any decrease in intensity leads to decrease in the numbers of photons and photoelectrons rather than individual photon and photoelectron energy. As a result, fewer photoelectrons flow through photocell and lesser photoelectric current is obtained. After all, they could draw the expected true graph. They also observed the

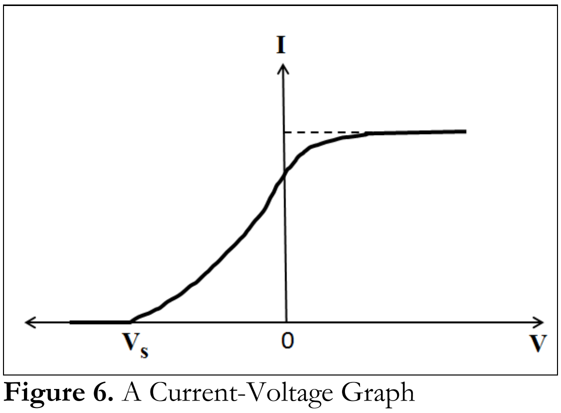


Figure 6. A Current-Voltage Graph

true graph over simulation program. Likewise for the remaining two activities, the similar strategy was followed as explained above. The last stage, evaluation, was conducted via previously developed homework set. It was distributed to the learners after the concept was studied. Students did them at home and delivered to the instructor at the next lesson. With this activity the learners had a chance of monitoring their learning. For the whole study, the experimental group students had four simulation experiences to explore the effects of the intensity, frequency, the work function and the stopping potential on photoelectric current. In each time, the same teaching strategy was used as explained above.

In control groups the photoelectric subject was studied traditionally which includes just delivering the topics without considering the requirements of treatment developed for experimental group. The photoelectric effect was defined and the related terms such as photon energy, threshold energy, threshold frequency and metals' work function were explained. The graph of the KE-f was given and interpreted. Photoelectric current, saturation potential and stopping potential were defined. The graph of I-V was drawn and explained. Related quantitative questions, which were also held for the experimental groups, were solved. Meanwhile, students' preconceptions were not uncovered and they were not taken to computer laboratory to discover the effects of intensity, frequency and work function on photoelectric currents as in the experimental groups. Students were just passive listeners; they took notes and solved questions.

RESULTS

Descriptive Analyses of the ACT and OEE

Each correct response was coded by 1 and the rest was replaced by 0 for the ACT. Then, students' total scores were calculated out of 40 points; a higher score indicates higher achievement and a lower score indicates a lower achievement in photoelectric effect. Basic descriptive results for the PRET and PSTT for both

Table 1. Basic Descriptive Statistics for the PRET, PSTT, PREOEE and PSTOEE

Treatments	N	PRET		PSTT		PREOEE		PSTOEE	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Experimental	69	13.6	2.9	21.4	5.5	0.7	1.4	4.6	3.7
Control	71	12.2	2.8	15.8	2.8	0.8	1.3	1.4	2.1
Total	140	12.9	2.9	18.6	5.8	0.8	1.3	3.0	3.4

Table 2. The Proportion of Students' Responses for the OEE Items

	Experimental Group				Control Group			
	PREOEE (%)		PSTOEE (%)		PREOEE (%)		PSTOEE (%)	
Items	Yes	No	Yes	No	Yes	No	Yes	No
I1	38	30	16	59	28	42	30	31
I2	54	12	19	46	55	9	34	23
I3	29	28	54	20	27	20	28	11

groups were given in Table 1. As seen from Table 1, the average achievement mean for the experimental group increased by 7.8 points and that of control group increased by 3.6 points respectively from the PRET to PSTT. The internal reliability coefficient of the alpha was found as 0.78 for the PSTT.

Similarly, students' OEE scores were calculated out of 10 points via analytic scoring method. According to this method the rater assigns a score to each of the dimensions being assessed in the task (Jonsson & Svingby, 2007). Hence, a detailed answer key was prepared; each step in reaching the correct result was identified and graded. For instance, item 3 was scored out of five points and its' scoring procedure was as follows; reporting the equation for calculating photon energy ($E=hc/\lambda$) is one point. Translating the unit of wavelength into Angstrom ($\lambda = 250nm = 2500\ ^{0}A$) is one point. Calculating the energy of incident photon ($E=12400eV^{0}A/2500^{0}A=4.96eV$) is one point. Comparing the energy of incident photon with work function of iron (4.96eV>4.5eV) is one point. Finally deciding that the current would flow (since the energy of incident photon is greater than work function of iron, the photon is absorbed and some of the photons' energy (4.5eV) is used to eject electron and the remaining (0.46eV) is transferred into ejected electron as the kinetic energy) is 1 point. After grading other items, students' total scores were calculated. The grading process was conducted by the researcher three times in different times to limit the grading error. Basic descriptive values for the PREOEE and PSTOEE were given in Table 1. As seen from Table 1, average mean of the OEE scores increased by 3.9 points for experimental group and that of control group increased by 0.6 points from pre to post application. The internal reliability coefficient of the alpha was found as 0.79 for the PSTOEE.

Aside from general basic descriptive analyses, participants' responses were analyzed extensively for the OEE items by content analysis. The analysis was conducted by the researcher and all categories were created based on students' responses. Fraenkel and Wallen (2006) claimed that a researcher can do all coding by himself or herself, but it would be useful to know how the categorizations by the same researcher agree over a meaningful time period. Hence, to satisfy the consistency in the judgments and obtain reliable results, the analysis was conducted three times by the researcher in different time intervals. The consistencies of agreements between analyses were above 98%. The proportion of students estimating current and that of others estimating no current for the OEE items were calculated and the concerning results were given in Table 2. In the table, the term "Yes" means that "Current flow through the circuit" and "No" means that "No current flows in the circuit". The blank and nonsense responses were not considered. The analyses of the responses revealed various ideas, but the ones reported by at least 10% of the participants for the PREOEE and/or PSTOEE were considered and reported in Table 3.

As seen from Table 2, 38% of the experimental and 28% of the control group students initially estimated that doubling the intensity of light would result in photoelectric current at the PREOEE for the first item (I1). On the other hand, 30% of respondents in experimental and 42% of respondents in control group estimated no current.

As Table 3 presents, only 7% of experimental and 6% of control group students answered this question correctly. They explained the absence of current in terms of energy. These students noted that doubling the intensity does not affect the individual photon energy. Hence, neither the photoelectron is ejected, nor the photoelectric current is produced. After treatments, the proportion of students holding this idea increased up to 46% and 14% for the experimental and control groups respectively. Remaining others explained their reasoning in terms of ohms' law. 12% of experimental and 13% of control group students claimed that since the potential

Table 3. Response Categories for OEE Items

Items	Response & Reasoning	Experimental		Control	
		PREOEE (%)	PSTOEE (%)	PREOEE (%)	PSTOEE (%)
I1	No, doubling intensity does not increase individual photon energy*	7	46	6	14
	No, according to equation of V=I*R, the current is dependent on both the potential and the resistance. Supplied potential was zero	12	0	13	0
I2	No, supplied potential do not increase the incident photon energy. Hence no electron is ejected and no current is obtained*	1	29	0	6
	Yes, +6.5volts is greater than the threshold energy of platinum (6.4eV). Hence, The energy supplied from the battery is sufficient to release electrons.	12	10	18	13
	Yes, the equation of V=I*R implies that there would be current which is directly proportional with the potential.	17	0	14	6
I3	Yes, the energy of incident photon is greater than work function of iron*.	4	38	4	7
	No, the work function of iron is smaller than that of platinum.	14	6	9	3

* Students' Correct Reasoning

difference across the circuit was zero, no current is obtained based on ohms' law. Followings are some of their responses, verbatim

*No, according to equation of V=I*R, the current is dependent on both the potential and the resistance.*

No, increase of intensity does not produce potential difference.

No, there must be potential difference across the electrodes.

After treatments, nobody explained the formation of photoelectric current in terms of ohms' law at the PSTOEE in both groups. Besides, 6% of experimental and 1% of control group students reported that doubling the intensity lead to current flow in the circuit at the PREOEE. The most prevalent two of their responses were,

Yes, if the intensity is doubled, the energy exceeds the threshold energy.

Yes, increase in intensity also increases the frequency and hence the energy.

After treatments, none of the experimental group students indicated this idea, but 7% of the control group students still hold the same conception. Since the rates of them were under 10%, this category was not reported in Table 3 as explained previously.

The analyses of second item (I2) also revealed significant findings. As seen from Table 2, although 12% of the experimental and 9% of the control group students estimated no current, the other 54% of experimental and 55% of control group students estimated current flow when the battery voltage was set to +6.5 volts at the PREOEE. As Table 3 denotes, only 1% of experimental group students subjected the absence of current to the insufficient energy of incident photon. But there was no scientific explanation in the control groups. On the other hand, the rates of students proposing no current increased up to 46% and 23% for experimental and control groups respectively at the PSTOEE (see Table 2). But among them, 29% of experimental and only 6% of control group students supported their responses scientifically (see Table 3). Investigation of the answers of other students, who were estimating current flow, revealed two alternative conceptions. The first one is that; according to these students the higher magnitude of the supplied potential than that of the threshold energy ($V>\Phi$) was the preliminary condition for the current. Namely, 12% of experimental group and 18% of control group students reported that since +6.5 volts of potential is higher than the threshold energy of platinum (6.4eV), the electrons can be released and the current would be obtained. Some of their responses were given below,

Yes, the supplied potential is higher than that of threshold energy of platinum.

Yes, +6.5volts is greater than the threshold energy of platinum (6.4eV). Hence, the energy supplied from the battery is sufficient to release electrons.

After treatments, 10% of respondents in experimental and 13% of respondents in control groups were still subjected the current flow to the higher magnitude of the supplied potential. The second conception for this question was that; the applied nonzero potential across the circuit was the main reason for the current flow as in I1. 17% of experimental and 14% of control group students reported that according to ohms' law, +6.5 volts was sufficient for the production of current. Since these students gave almost same reasoning as in I1, their sample answers were not reported again here. After treatments, none of the experimental group students related the current flow to ohms' law and potential difference, but 6% of control group students still believed that supplied potential was the main reason for the current at the PSTOEE.

Finally, for the third item (I3), as Table 2 denotes, 29% of experimental and 27% of control group students believed that replacing platinum with iron metal would lead to current flow at the PREOEE. But, among them only 4% in both groups explained their ideas by comparing the incident photon energy with the work function of iron as denoted in Table 3. They reported that since the incident photon energy (4.96eV) is greater than the threshold energy of iron (4.2eV), the electrons are ejected and the current is obtained. After treatments, although 54% of experimental and 28% of control group students estimated current (See Table 2), only 38% of the experimental and 7% of the control group students supported their ideas in terms of the incident photon energy and the threshold energy of iron as discussed above at the PSTOEE (See Table 3). Table 2 also denotes that 28% of experimental and 20% of control group students estimated no current for I3 at the PREOEE. Investigations of their responses, revealed a new conception. Namely, 14% of experimental and 9% of control group students explained their ideas in terms of the threshold energies of platinum and iron. The most prevalent two responses were,

No, 4.5eV is less than 6.4eV.

No, threshold energy of cathode was previously 6.4eV. If cathode is replaced by iron which has smaller threshold energy than that of platinum, no current is obtained.

Most probably, these students regarded the platinum as the stable cathode metal and the iron as a kind of material that would eject electrons from platinum. After treatments, although 20% of experimental and 11% of control group students estimated no current (See Table 2), 6% of students in the experimental and 3% of students in the control group still explained their ideas in terms of the above conception (See Table 3).

Inferential Analyses of the ACT and OEE

Initially, both of the experimental and control groups' PRET and PREOEE mean scores were analyzed whether they differ significantly from each other or not. Because possible any significant difference would affect the dependent variables of the study. For this, Analysis of Variance (ANOVA) was conducted. The result denoted a significant difference between groups' PRET scores favoring experimental group (F (1, 139) = 8.45, $p < .05$) and insignificant difference between groups' PREOEE scores (F (1, 139) = 0.11, $p > .05$). Then, the relations between the independent variables and dependent variables were investigated via Pearson Product-Moment Correlation. According to Cohen (1988), a medium and a small significant correlations were found between the PRET and PSTT (r = 0.38, $p < .05$) and the PRET and PSTOEE (r = 0.21, $p < .05$) respectively. Hence, the PRET was considered as the covariate of the study for the following statistical analyses.

Effect of instructions on dependent variables of the PSTT and PSTOEE was analyzed by conducting MANCOVA which equalizes the intervention groups on independent variables. The probability of rejecting true null hypothesis was set to .05. All preliminary checks for MANCOVA assumptions were conducted to ensure that there was no violation and no problem was encountered.

Initially, it was hypothesized that there were no significant effects of treatment on the population means of the collective dependent variables of the PSTT and PSTOEE when the independent variable of the PRET was controlled. Based on the MANCOVA results, the hypothesis was rejected (λ = 0.76, F (2, 136) = 21.49, $p < .05$). The power and the effect size (partial eta-squared) were found as 1.00 and 0.24 respectively. Then, effect of treatments on each dependent variable was checked via the ANCOVA. The results were given in Table 4.

Stevens (2002) suggested dividing alpha level (α=.05) by the number of dependent variables to limit the experiment-wise error while interpreting the ANCOVA results. Since two dependent variables exist in the study, α was divided by two and the results were interpreted based on this new value of .025. The findings denoted that, after controlling PRET, there was a statistically significant main effect of treatment on the PSTT (F (1, 136) = 32.3, $p < .05$) and PSTOEE (F (1, 136) = 33.6, $p < .05$). The effect sizes were found 0.19 and 0.18 for the PSTT and PSTOEE correspondingly. According to Cohen (1988) both values correspond to medium effect sizes and the treatment accounted for 19% of the total variance of the PSTT and 20% of the total variance of the PSTOEE respectively as given in Table 4.

Table 4. Test of Between-Subjects Effect

Source	DV	Type III SS	*Df*	*MS*	*F*	*p*	Eta Squared	Observed Power
Treatment	PSTT	754.0	1	754.0	32.3	.000	.19	1.0
	PSTOEE	298.6	1	298.6	33.6	.000	.20	1.0

DISCUSSION AND CONCLUSION

The current study investigated the effect of the 5E learning cycle in which the simulations were integrated on sophomore level pre-service science teachers' achievement in photoelectric subject. It presents development and implementation of the treatment and discusses participants' possible conceptions about the context. The results are compared with those of the foregoing studies.

The statistical results indicated that the treatment developed for the experimental group increased students' achievement significantly than the traditional instruction did. This overall result was initially expected before the study. Because the individual studies conducted on the 5E learning cycle (Açışlı et al., 2011; Ates, 2006; Bybee, 2009; Ebrahim, Coulson, as cited in Bybee, 2009; Ergin et al., 2008) and on simulation (Başer, 2006; Jaakko & Nurmi, 2008; McKagan et al., 2009; Ronen & Eliahu, 2000; Sokolowski, 2013; Zacharia, 2005) all reported successful learning outcomes. Hence, the higher success rate of experimental group would be ascribed first to the development of treatment and second to successful application of it. This result is consistent with the results of previous studies (Hırça et al., 2011; Nas et al., 2012) which embedded some of the conceptual change methods in 5E learning cycle.

The treatment developed for the experimental group encouraged learners to participate highly in teaching-learning environments at all stages of the 5E learning cycle. During the instructions, the first step was taking learners' attentions to the subject matter and then alerting them what they know and would learn about the topics to satisfy the engagement phase. Second, the learners were enabled to test their preconceptions by conducting virtual experiments via simulations for the exploration phase. They were interacted with simulations by following guiding manuals rather than just observing passively. Third, students shared their simulation experiences and then discussed their ideas for the explanation phase. The discussions enabled instructor to capture learners' alternative conceptions. After all, the instructor explained the related concepts scientifically. For the elaboration phase, after mentioning about daily life application of photoelectric subject, the students applied their knowledge for drawing and interpreting various I-V graphs. These activities extended their' understanding. The final stage, evaluation was conducted with the homework set. Students made them and monitored their learning while solving the homework questions. All the steps mentioned above were conducted successfully throughout the study.

On the other hand, traditional presentation of photoelectric effect in control groups did not provide the learners with sufficient help to develop their conceptual understanding. The instructor delivered the lecture by using the power point presentation and whiteboard. The topics were explained verbally and the related questions were solved. Neither the learners' attention was taken to the subject matter and nor the preconceptions were uncovered. They did not interact with simulation and carry out virtual photoelectric experiments. Hence, these students had difficulties in visualizing the effects of varying the intensity of light, frequency of light, work function of metals and saturation potential on photoelectric current. The instructor mainly focused on the identification of terms and equations that require problem solving.

The extensive analyses of the responses given for the OEE items revealed that some participants in both groups were not clear about the effect of voltage on photoelectric current. The analyses indicated two alternative conceptions. The first one was that the participants initially related the absence or the flow of photoelectric current in the photocell to the ohms' law. After treatment, although all participants in experimental group recognized that the potential difference was not the preliminary condition for photoelectric current, some of control group students still related the formation of photoelectric current to the ohms' law. While conducting his study, Sokolowski (2013) first set battery voltage to zero and then run photoelectric simulation to show that formation of photoelectric current is independent of the supplied voltage. Upon this activity, most of his participants recognized that the supplied potential was not the main source of photoelectric current. Likewise, in the current study, the similar strategy was conducted as discussed previously and the findings showed that the strategy really worked for the experimental group. The second conception was that some participants subjected the release of electrons and hence formation of photoelectric current to the higher value of supplied potential than that of work function of metal $(V > \Phi)$. The findings indicated that even after treatments, some of experimental (10%) and some of control (13%) group students showed the same conception. The similar findings were also reported by McKagan et al. (2009) and Steinberg et al. (1996). It seems that this conception is prevalent and resistant. Hence a special attention should be given to remove it while designing further instructions. Students should realize that increasing potential difference does not produce any photoelectric current when the incident photon energy is less than the work function of metal; it can only affect the ejected photoelectrons' kinetic energy if there were. The third conception was discovered in the current study and it was not reported previously by any one of the foregoing studies. According to it, some of the students believed that work function of new metal, which will be placed on cathode, must be higher than that of originally placed one for the production of photoelectric current, otherwise neither electrons are ejected, nor is the photoelectric current obtained. Most probably these respondents couldn't comprehend the basic aspects of photoelectric subject throughout the study. A special attention should also be given to this one for the further studies.

Previous studies claimed that understanding the effect of intensity on photoelectric current is one of the most difficult aspects of photoelectric subject for most of the students (Steinberg et al., 1996; McKagan et al., 2009). Even after instructions, some of the students (5%) who experienced Photoelectric Simulation in the study of McKagan et al. and the others (15%) who used Photoelectric Tutor in the study of Steinberg et al. believed that proposed change in intensity provides sufficient energy for the release of electrons. But, in the current study none of the experimental group students indicated this conception after treatments. They realized that the release of electrons do not depends on the proposed change in intensity of light.

Many studies suffer from various threats for the validity of experimental studies. For this study, design of the research, standardizing the application of testing procedures and treatment conditions, and using the MANCOVA model for data analysis were held for controlling the internal validity. Namely, history and maturation were not problems because no extraneous events happened and the instructions were conducted over the same three-week treatment period for both groups. The treatment period seems to be short, but the content of the subject is limited. The previous researches (De Leone & Oberem, 2004; McKagan et al., 2009; Steinberg et al., 1996) also ended their studies less than three lecture hours. Instrument decay, data collector characteristics, data collector bias, testing and implementation were also controlled. All instruments were carefully examined and all alterations were corrected based on the pilot study and expert opinions before the main study. The administration of instruments and the conduction of all treatments were achieved by the same researcher. Regression was not a problem because the study groups were readily available and the participants were not assigned into groups on the basis of extreme scores. Although attitudes of subjects towards the photoelectric effect were not measured, no special attentions were given to treatments in both groups and teaching activities were conducted as usual instructional activities. Gender was not a serious problem; because, Fraenkel and Wallen (2006) reported that it does not lead to any problem if groups were homogeneous in proportion for each gender. In this study, the rates of males (23.2% for experimental group, 26.8% for control group) and females (76.8% for experimental group, 73.2% for control group) were almost similar in both groups. For the external validity, Fraenkel and Wallen suggest two concerns; population generalizability and ecological generalizability. Population generalizability refers to the degree to which a sample represents the population. As reported previously, the sample in the study constituted 27% of the population, hence it could be accepted that no problem exist for the population generalizability. The ecological generalizability refers to the degree to which the results can be extended to other settings or conditions. Pre-service science teachers follow almost the similar textbooks and same curriculum suggested by Higher Education Council in Turkey. The students were placed to science teacher education programs with the same placement exam and their scores were almost similar in these five universities. Environmental conditions of classrooms and universities, technological equipments and ecological conditions were almost similar to each other. Finally all students in the population were studying in government universities and hence their social and economic statuses were almost similar. To sum up, it could be accepted that the findings of current study would be generalized to other sophomore level pre-service science teachers in the population providing that they are instructed with same treatment and teaching materials used as in this particular study within similar ecological and environmental conditions.

There are some limitations for the study. First of all, the current study investigated the effect of treatment developed by the 5E learning cycle in which the simulations were integrated on pre-service science teachers' achievement in photoelectric subject. Hence it is difficult to differentiate whether the observed difference in achievements resulted from the learning cycle, or simulation, or combination of both. This problem should be handled in further studies. Second, the pilot study of the ACT and OEE were conducted with 17 graduate physics major students attending teacher certificate program. Although the reliability coefficient of alpha, average difficulty index and average point-biserial coefficients for the measuring tools were in acceptable regions, the sample size for the pilot study seems to be small to carry out reliable psychometric analyses. Third, since the researcher was implementer of the study, there was necessity for treatment verification to control the researcher's bias. But no instrument was used for treatment verification.

In conclusion, I hope that the ideas and findings of current study will help other science educators, instructors and prospective teachers in preparing their teaching activities. Especially, implementation of the treatment in the current study may give hint for the future science teachers. Because, they will teach science and affect large number of science learners. The researchers would develop new treatments by integrating scientifically well-developed simulations with 5E learning cycle or other versions of learning cycle and investigate their effectiveness in increasing participants' conceptual understanding or in remediating learners' alternative conceptions for the photoelectric effect or other physics subject.

Author's Note

This study was presented at "1st National Physics Education Congress (UFEK2013).

REFERENCES

Açışlı, S., Yalçın, A. S., & Turgut, Ü. (2011). Effects of the 5E learning model on students' academic achievements in movement and for issues. *Procedia Social and Behavioral Sciences*, *15*, 2459-2462. doi:10.1016/j.sbspro.2011.04.128

Asikainen, M. A., & Hirvonen, P. E. (2009). A study of pre- and inservice physics teachers' understanding of photoelectric phenomenon as part of the development of a research-based quantum physics course. *American Journal of Physics, 77*(7), 658-666. doi:10.1119/1.3129093

Ates, S. (2005). The effectiveness of the learning-cycle method on teaching DC circuits to prospective female and male science teachers. *Research in Science and Technological Education. 23*(2), 213-227. doi:10.1080/02635140500266518

Başer, M. (2006). Effects of conceptual change and traditional confirmatory simulations on pre-service teachers' understanding of direct current circuits. *Journal of Science Education and Technology, 15*(5), 367-381. doi:10.1007/s10956-006-9025-3

Bybee, R. W. (2009). *The BSCS 5E instructional model and 21st century skills a commissioned paper prepared for a workshop on exploring the intersection of science education and the development of 21st century skills.* Retrieved from https://www7.nationalacademies.org/bose/1Bybee_21st%20Century_Paper.pdf.

Bybee, W. R., & Sun, B. R. (1990). *Piaget for educators (2nd edition).* Waveland Pr, Inc.

Cohen, J. W. (1988). *Statistical power analysis for the behavioral sciences (2nd edition).* Hillsdale, NJ: Lawrence Erlbaum Associates.

De Leone, C. J., & Oberem, G. E. (2004). Toward understanding student conceptions of the photoelectric effect. *American Institute of Physics Conference Proceeding, 720*, 85-88. doi: 10.1063/1.1807260

Duran, E., Duran, L., Haney, J., & Scheuermann, A. (2011). A learning cycle for all students. *The Science Teacher, 78*(3), 56-60.

Fraenkel, J. R., & Wallen, N. E. (2006). *How to design and evaluate research in education (sixth edition).* New York: McGraw-Hill.

Ergin, I., Kanlı, U., & Unsal, Y. (2008). An example for the effect of 5E model on the academic success and attitude levels of students': 'Inclined projectile motion'. *Turkish Science Education, 5*(3), 47-59.

Hırça N., Çalık M., & Seven S. (2011). 5e modeline göre geliştirilen materyallerin öğrencilerin kavramsal değişimine ve fizik dersine karşı tutumlarına etkisi: iş, güç ve enerji ünitesi örneği. *Türk Fen Eğitimi Dergisi (elektronik)*, *8*, 139-152.

Jaakkola, T., & Nurmi, S. (2008). Fostering elementary school students' understanding of simple electricity by combining simulation and laboratory activities. *Journal of Computer Assisted Learning, 24*, 271-283. doi:10.1111/j.1365-2729.2007.00259.x

Jonsson, A., & Svingby, G. (2007). The use of scoring rubrics: reliability, validity and educational consequences. Educational Research Review, *2*, 130-144. doi:10.1016/j.edurev.2007.05.002

Lawson, A. E., & Others. (1989). *A theory of instruction: using the learning cycle to teach science concepts and thinking skills.* Retrieved from ERIC database. (ED324204)

Marek, E. A. (2008). Why the learning cycle? *Journal of Elementary Science Education, 20*(3), 63-69.

McKagan, S. B., Handley, W., Perkins, K. K., & Wieman, C. E. (2009). A Research-based curriculum for teaching the photoelectric effect. *American Journal of Physics, 77*(1), 87-95. doi: 10.1119/1.2978181

Nas, S. E., Calik, M., & Cepni, S. (2012). Effect of different conceptual change pedagogies embedded within 5E model on grade 6 students' alternative conceptions of 'heat transfer'. *Energy Education Science and Technology Part B-Social and Educational Studies, 4*(1), 177-186.

Özdemir, M., & Aras, E. (2008). *12th Grade Physics (in Turkish).* Ankara: Aydın Publication.

PheT Simulation (2006). Photoelectric Effect (1.10) [Physics Education Technology Project]. Retrieved from http://phet.colorado.edu/en/simulation/photoelectric.

Ronen, M., & Eliahu, M. (2000). Simulation – a bridge between theory and reality: the case of electric circuits. *Journal of Computer Assisted Learning, 16*(1), 14-26. doi:10.1046/j.1365-2729.2000.00112.x

Sahin C., Çalik M., & Cepni S. (2009). Using different conceptual change methods embedded within 5e model: a sample teaching of liquid pressure. *Energy Education Science and Technology Part B-Social and Educational Studies*, *1*, 115-125.

Settlage, J. (2000). Understanding the learning cycle: influences on abilities to embrace the approach by preservice elementary school teachers. *Science Education, 84*(1), 43-50. doi:10.1002/(SICI)1098-237X(200001)

Sokolowski, A. (2013). Teaching the photoelectric effect inductively. *Physics Education, 48*(1), 35-41.

Steinberg, R. N., Oberem, G. E,. & McDermott, L. C. (1996). Development of a computer-based tutorial on the photoelectric effect. *American Journal of Physics, 64*(11), 1370-1379. doi:10.1119/1.18360

Stevens, J. (2002). *Applied multivariate statistics for the social sciences (4th edition).* London: Mahway.

Uscinski, J., & Larkin, T. L. (2011). Probing a deeper understanding of modern physics concepts. *41st ASEE/IEEE Frontiers in Education Conference,* S2H-1-S2H-6. doi:10.1109/FIE.2011.6143101

Wong, D., Lee, P., Shengan, G., Xuezhou, W., Qi, Y. H., & Kit, F. S. (2011). The photoelectric effect: experimental confirmation concerning a widespread misconception in the theory. *European Journal of Physics, 32*(4), 1059-1064. doi:10.1088/0143-0807/32/4/018

Yıldız, A., & Büyükkasap, E. (2011). The level of understanding of the photoelectric phenomenon in prospective teachers and the effects of "writing with learning" on their success rates. *Kuram ve Uygulamada Egitim Bilimleri, 11*(4), 2268-2274.

Zacharias, Z. C. (2005). The impact of interactive computer simulations on the nature and quality of post graduate science teachers' explanations in physics. *International Journal of Science Education, 27*(14), 1741-1767. doi:10.1080/09500690500239664