Akdeniz Eğitim Araştırmaları Dergisi, Sayı 11, Yıl 2012, ss. 55-66
Mediterranean Journal of Educational Research, Issue 11, Year 2012, pp. 55-66

Pre-Service Physics Teachers' Understanding of the Photoelectric Effect: A Qualitative Study

Özgür ÖZCAN [*] **Serap ÇALIŞKAN** [**]

Abstract: The aim of this study was to investigate the students' interpretation of I=f(V) graph and electron's energy emitted by the photons on the photoelectric effect. The study was done at two different state universities' physics education department with pre-service physics students in Ankara and Izmir. A total of 35 participants took part in this study. The data collected by the open-ended questions were analyzed by using content analysis method. The results of the study revealed that there were students' learning difficulties regarding concepts of the photoelectric effect.

Keywords: Photoelectric effect; learning difficulties; pre-service physics teachers

Fizik Öğretmen Adaylarının Fotoelektrik Olayı Anlamaları: Nitel Çalışma

Öz: Bu çalışmanın amacı fotoelektrik olayda fotonlar tarafından sökülen elektronlara ait I=f(V) grafiğinin öğrenciler tarafından yorumlanmasını araştırmaktır. Çalışma Ankara ve İzmir'de bulunan iki farklı devlet üniversitesinde öğrenim gören fizik öğretmen adaylarıyla gerçekleştirilmiştir. Toplam 35 öğretmen adayı çalışmada yer almıştır. Açık uçlu sorular yardımıyla toplanan veriler içerik analizi yöntemi kullanılarak analiz edilmiştir. Araştırma sonunda, öğrencilerin fotoelektrik olay kavramlarına yönelik öğrenme zorluklarının olduğu tespit edilmiştir.

Anahtar Sözcükler: Fotoelektrik etki, öğrenme zorlukları, fizik öğretmen adayları

Modern physics courses mainly include certain subjects related to introduction to quantum mechanics and special relativity. Regarding mathematical structures they use and innovations they introduce, both classes' contents consist of the facts which classical physics is incapable of explaining. The leading facts are the models which are associated with the light and the subjects which examine various facts through these models. The facts such as diffraction, interference, black body radiation, photoelectric effect and Compton Effect are the significant facts that can be explained through using the light wave and light particle models. Surely, these facts usually contain notions and models which are contradictory to classical physics' accepted truths. In this study, we aim to explain one of these foremost facts that reinforce the idea of the light's photon model after the black body radiation and the difficulties that students have in learning. In other words, we will examine the students' learning difficulties regarding concepts of the photoelectric effect.

Most studies on modern physics have focused on quantization, electron diffraction, photoelectric effect, and light and atom models (Aubrecht, 2003; Thacker, 2003). In his study with the students who did not take quantum mechanics courses, Aubrecht (2003) determined the students' perceptions on photon concept. And, Thacker (2003) examined the students' perceptions on photoelectric effect, diffraction experiment and determination of e/m ratio. With the help of this study, the structures of students' preliminary concepts on modern physics subjects, the physical models formed in their minds before and during training were determined.

[*] Assist. Prof. Dr., Hacettepe University, Faculty of Education, Department of Secondary Science and Mathematics Education, Ankara, Turkey, ozcano@hacettepe.edu.tr
[**] Assist. Prof. Dr., Dokuz Eylül University, Faculty of Education, Department of Secondary Science and Mathematics Education, İzmir, Turkey, serap.caliskan@deu.edu.tr

According to the results of this study, students can have a better understanding of modern physics subjects easily by reinforcing them with daily life observations and examples. In other words, students can form the models from subatomic particles world in their minds more easily.

Photoelectric effect has a vital importance in understanding the particle nature of light. That is because; following the black body radiation, photoelectric effect is a physical fact which has the greatest contribution to the quantum mechanics. Photoelectric effect is an important helping tool for students to help them understand light photon model. Despite this significance, this subject is not given the value it deserves and it is not discussed in detail. As a consequence of this, most students have serious conceptual difficulties in comprehending photoelectric effect. Such difficulties revealed by these studies can be summarized as photoelectric experimental setup, experiment results and applications about the nature of light (De Leone & Oberem, 2004; Knight, 2004; Steinberg, Oberem. & McDermott, 1996; Steinberg & Oberem, 2000). Besides, via these studies, it was also determined that students had false conceptual understanding on classical light models which contradicts to the results of photoelectric effect. According to another study carried out by Knight (2004), many students stated that the discovery of photoelectric effect solely contributed to the increase of suspicions over the trust in correctness of classical physics and a few students stated that this subject, about which classical physics is incapable of explaining, the photon model of light could successfully be applied. In other studies carried out by Steinberg et al. (1996) and Steinberg & Oberem (2000), it was determined that many students had significant difficulties in understanding even basic concepts about photoelectric effect experimental setup and Einstein's theory based upon this experiment. The students' difficulties were grouped under four headings: (1) The belief in use of ohm law (V=IR) in photoelectric effect experiment (2) Not being able to distinguish the differences between light frequency and light intensity (3) Not being able to interpret the I-V graph drawn in photoelectric effect and (4) Not being able to express the definitions about photon and photoelectric effect.

To sum up, in studies regarding photoelectric effect, the lack of knowledge about circuits and the lack of knowledge about the particle model of light which is required to understand photoelectric effect hinder the understanding. Some of these obstacles were tried to be minimized by using the teaching materials prepared especially for the photoelectric effect (Steinberg et al., 1996; Mc Kagan et al., 2009; Oberem & Steinberg, 1999). However, how students perceive the graphs showing the results of experiments about photoelectric [for example I=f(V)] and the students' lack of knowledge about the physical meanings of the values stated on these graphs have not been studied. Since graphical displays have great importance in physics classes, precisely teaching the graphics about the subject of photoelectric effect, the theory of which is quite hard to be understood by students, have the quality to eliminate conceptual difficulties of this subject. It is because many conceptual and reasoning difficulties have their roots from the inability of interpreting the equations, diagrams, or graphs (McDermott, 2003). Considering the fewness of the earlier studies on photoelectric effect, this study is thought to have significant contributions to the physics education literature. Under the light of this information, within the scope of this study which is on the effective use of graphical displays and the difficulties arising from the use of these graphics, the answers to the following research questions have been sought.

- What are the alternative concepts developed by the pre-service teachers regarding photoelectric effect and related concepts (V_s: Stopping voltage, I_0: Photoelectric current, I_{max}: Saturation (maximum) current)?
- What are the difficulties that pre-service teachers encounter while using the graphical displays?
- What are the conceptual difficulties that pre-service teachers have regarding the relationship between the electrons emitting from the metal surface and the number of photons in the photoelectric experiment?

Method

This study was carried out using open-ended questions in a natural environment providing realistic and qualitative research method in order to determine pre-service teachers' understanding difficulties regarding the concepts of photoelectric effect which is one of the most important subjects of modern physics (Yıldırım & Şimşek, 2008).

Participants

For this study, accomplished by pre-service teachers' participations, the working group was determined by criterion sampling method among purposeful sampling methods. The criterion sampling method involves selecting cases that meet some predetermined criterion of importance. The criterion or criteria can either be determined by the researcher himself/herself or another predetermined list can be used (Yıldırım & Şimşek, 2008). While selecting the participant pre-service teachers, having taken all the theoretical and practical lessons on modern physics and quantum physics was the basic criteria. The study was done during the 2010-2011 academic year spring semester in two different state universities' physics education department junior students in Ankara and Izmir. A total of 35 participants, 18 male and 17 female, took part in this study. The age of participants ranged between 20 and 22.

Data Collection

In the study, in order to determine the understanding difficulties of students about photoelectric effect they learn in modern physics and quantum physics lessons, three different open-ended questions were asked. While preparing questions on photoelectric effect, the previous studies (Steinberg et al., 1996; Mc Kagan et al., 2009; Oberem & Steinberg, 1999) and related books (Bernstein, Fishbane & Gasiorowicz, 2000; Dereli & Verçin, 2000) were exploited. Following that, for the questions prepared, 2 experts in the field of physics and 2 experts in the field of physics education a total of 4 experts were consulted for the expert opinion. Considering the expert opinions, necessary changes were made, vague expressions cleared and a further expert consultation was conducted. Following this procedure, the questions were finalized. The adequate amount of time was allocated for the students to answer the questions in detail and the applications were done in the classroom environment by the researchers. All students completed the open-ended questions in 20 minutes.

Data Analysis

The data collected by the open-ended questions were analyzed by using content analysis method, which is one of the qualitative research methods (Strauss & Corbin, 1990). The students' responses were analyzed in the following way. Firstly, the key concepts were determined by reading the participants' answers to the questions regarding photoelectric effect one by one. Secondly, categorization of their responses was carried out based on the particular characteristics of the answers (determined key concepts), and the main deficiencies and incorrect conceptions were identified. Thirdly, another researcher checked our categorization, and any disagreements were discussed until a consensus could be reached. In total, 231 responses were categorized and only 5 % of them led to disagreement between the researchers. After discussion, the description of the categorization and the categorization itself were slightly modified until both researchers agreed that the information provided corresponded with the students' responses.

Yıldırım and Şimşek (2008) explained the validation for the qualitative research by taking necessary precautions to reach the accurate information; and they explained the reliability by defining the research process and data clearly and in detail enabling another researcher to assess. For the purpose of increasing the internal validity of this study (Büyüköztürk et al., 2008), the findings obtained were examined by two different experts. By the end of this process, considering the expert opinions, the categories were redesigned. In order to support the findings, some responses from students were quoted.

Results

The findings obtained at the end of the application were presented with the categories formed for each question and the distribution of student responses. In addition to that, student concepts were defined in detail by quoting from their responses to the questions. Presenting the findings in this was would enable the reader to see the understanding difficulties of students about photoelectric effect concepts as a whole.

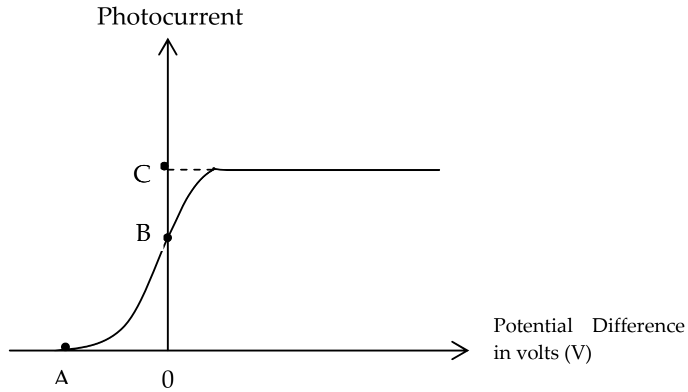

Figure 1. Graph of photocurrent vs applied voltage for a photoelectric cell

Question 1. *As a result of a photoelectric experiment, using the findings obtained from the measurements the I-V graph shown in Figure 1 is drawn. In this graph, what values about the experiment should be displayed in A, B and C?*

This first question in the study is based on widely used graphical displays used in high-school-level modern physics textbooks and college-level physics textbooks. In this question, the students were asked to identify the variables related to photoelectric effect suitable for the places represented by the letters A, B and C. The response categories in Table 1 are based on the information whether the students were able to put these concepts in their correct places on the graph and the alternative concepts they had. While the numbers in the table represents the number of students in each category, the first raw in the table represents the corresponding physics concepts for each letter in the graph.

Table I

Distribution of students' answers and the students' alternative conceptions (N=35)

Response Categories	*A (Vs)*	*B (I0)*	*C (Imax)*
Correct answer	23	23	28
Incorrect answer	7	7	3
Blank	5	5	4
Alternative Concepts	Threshold voltage (two students) First voltage (three students) Stopping voltage energy (one student) Initial voltage (five students) Initial current (two students)	The current of circuit when the threshold voltage was zero (two students). Initial current (one student) First current (three students) Threshold current (two students)	-

Vs: Stopping voltage, I_0: Photoelectric current, I_{max}: saturation (maximum) current

As it is seen in Table I, the majority of students (23 out of 35) determined the stopping voltage and I0 value correctly. However, while five students determined these two variables incorrectly, five students left this part unanswered. The 13 students out of 23 who answered the stopping voltage correctly used five different alternative concepts. The alternative concepts developed by students were shown in Table 1. As two students used the concept of "threshold voltage" the others used the following alternative concepts respectively "first voltage" (three students), "stopping voltage energy" (one student), "initial voltage" (five students) and "initial current" (two students). Eight students out of 23 who answered the I0 value correctly used four different alternative concepts to this concept. The alternative concepts expressed by students were respectively as follows: "the current of circuit when the threshold voltage was zero (two students), "initial current" (one student), "first current" (three students) and "threshold current" (two students). On the other hand, while 28 students out of 33 determined the saturation current correctly, three students answered the saturation current incorrectly and four students left this part unanswered by not indicating any comments.

Question 2. *Which value or values would change in A, B or C shown in Figure1 if a small wavelength light with the same intensity were used? Explain with reasons.*

With this question the students were asked to think about the value changes that would happen in A, B or C shown in Figure1 if a small wave light with the same intensity were used. Here, the students were supposed to determine the effects of the change in light wave on other parameters of the photoelectric cell. The students' conceptions obtained by analyzing their responses are present in Table 2, Table 3 and Table 4.

According to Einstein's photoelectric equation

$$eV_s = h\nu - \mathrm{W} \quad (1)$$

If the hv energy is smaller than the work function (W), there won't be a photoelectric current. On the contrary, that is to say, if the hv energy value of the incident photon is bigger than the work function (W), the electrons emitting from the metal will move at a certain kinetic energy and these electrons will make a photoelectric current. By increasing the frequency of light on metal, the maximum kinetic energy of the emitted electrons will increase. Since the increase in the maximum kinetic energy of photoelectrons means the increase in the cut potential, the stopping potential will increase in direct proportion to the frequency of light on metal.

Table II

Students' conceptions of the stopping voltage when the wavelength of the light was changed (N = 35).

Response Categories	A (Vs)	Correct Reasoning	Incorrect Reasoning	No Reasoning
Changing stopping voltage[a]	15	9	2	4
Unchanging stopping voltage	9	-	4	5
Blank	11	-	-	-

[a]Correct response, V_s: Stopping voltage,

As seen in Table II, only 15 students expressed that the stopping voltage would change, 9 of whom interpreted it correctly by attributing their answers to the mathematical expression stated by equation 1. Some quotations from these students' answers can be summarized as follows.

> **S8:** The stopping voltage changes depending on the kinetic energy of the emitted electrons. That's why; the decrease in the wavelength will cause the increase in the kinetic energy of the emitted electrons', in other words released electrons'.

S19: The small wavelength means the big energy. In that case, the stopping voltage potential will increase because the stopping voltage changes only with the wavelength of light.

S27: While the light intensity stays the same, the frequency has increased. The increase of the frequency means the increase of the photon energy. If the energy increases, the stopping voltage potential increases.

S29: According to the photoelectric equation, the type of the light changes only the stopping voltage potential.

What's common among the student responses above was the correct interpretation of the linear relationship between the frequency and stopping voltage given with equation 1. Similarly, the students who managed to interpret the relationship between these two variables correctly managed to answer the ones related to I_0 and I_{max} correctly. As seen in Table III and Table IV, the students were able to explain correctly how only these two variables (I0 and Imax) are affected for each context as well as providing scientific explanations in their responses. Four students out of nine, who stated that the stopping voltage wouldn't change, came up with a wrong reasoning. The quotations from these students' answers can be summarized as follows.

S5: This value will not change as it is already the initial intensity. In the photoelectric experiment the stopping voltage is connected to the battery and it isn't affected by the wavelength of light.

S9: The stopping voltage is already the initial intensity for the photoelectric effect to happen, that's to say, it is not affected by the changes coming along with the wavelength of light and its frequency.

S11: The photoelectric is connected to the battery of the circuit and the wavelength of light does not change the stopping voltage.

S33: The stopping voltage potential depends on the type of the metal. Unless the metal in the cathode is changed, the stopping voltage potential does not change because the stopping voltage is dependent upon the metal and independent of the wavelength of light.

Examining the students' responses, it is understood that their common explanation is the battery connected to the photoelectric circuit. The first three students (S5, S9, and S11) who had wrong reasoning about the stopping voltage potential believe that the change in the wavelength of light would not affect the stopping voltage since they think the battery connected to the circuit is an external parameter. However, one of these students (S33) relates the stopping voltage with the type of the metal. According to this student, as long as the metal is the same, the stopping voltage will stay the same and this value will be affected neither by the frequency of the incident light on the cathode nor the wavelength.

Table III

Students' conceptions of the I0 when the wavelength of the light was changed (N = 35).

Response Categories	B (Io)	Correct Reasoning	Incorrect Reasoning	No Reasoning
Changing photoelectric current[a]	18	9	2	7
Unchanging photoelectric current	7	-	6	1
Blank	10	-	-	-

[a]Correct response, I_0: photoelectric current

Some quotations from these students' answers who gave correct answers to the question related to I0 current value can be summarized as follows.

S17: If the wavelength is decreased, the frequency increases; and consequently, the energy of the photons will increase. Thus, the threshold frequency is exceeded and the photoelectric circuit current value (I_0) becomes higher than the initial state.

S21: The I_0 value increases due to the use of a greater light energy because the number of photoelectrons reaching the cathode will be more compared to the initial state.

Table IV.
Students' conceptions of the saturation current when the wavelength of the light was changed (N = 35).

Response Categories	C (Imax)	Correct Reasoning	Incorrect Reasoning	No Reasoning
Changing saturation current	11	-	6	5
Unchanging saturation current[a]	17	9	2	6
Blank	7	-	-	-

[a]Correct response, Imax: saturation (maximum) current

17 students managed to state that the saturation current would not change, nine of whom were able to provide correct explanations while two of whom failed to provide correct explanations. In addition to that, 6 students were unable to provide scientific explanations to their correct responses. The students who stated that the saturation current would not change and supported their answers included "light intensity" as the common concept in their responses. These students with correct reasoning (9 students) noted that the stable light intensities in both circuits were the reason for not changing current value in the photoelectric circuit. Some quotations from these students' answers can be summarized as follows.

> **S5**: Since the light intensity used in both cases is the same; there won't be any changes in the number of the emitted electrons. The decrease in the wavelength only causes the kinetic energy of the electrons. That's why, I_{max} won't change.

> **S7**: Because the intensity does not change, the number of the emitted electrons stays the same. This means the current stays the same. In the second case, the decrease in the wavelength changes the kinetic energy of the photoelectrons.

> **S19**: The metal used in the photoelectric circuit stays the same and the intensity stays the same. In that case, the saturation current stays the same.

Some quotations from these students' answers who gave wrong reasoning while stating there would be no change in the saturation current are as follows.

> **S31**: Saturation current depends neither on the frequency nor on the wavelength. That's why, Imax won't change.

> **S34**: Since the wavelength changes according to the $E=hc/\lambda$ equation, the only change that happens is the energy of the photon. This does not affect I_{max} the value.

11 students out of 35 who participated in the study stated that the use of the same intensity but a smaller wavelength would change the saturation current. Five of these students did not give any explanations along with their answers but two of them did. Some of these explanations are as follows.

> **S26**: Since the photon energy in the second case is greater; it will have a greater saturation current. As there is an increase in the energy of the photoelectrons, an increase in the saturation current is observed accordingly.

> **S26**: According to $hc/\lambda=h\upsilon$ equation, the photon with a small wavelength has a great energy. If we use a light with short wavelength, the energy increases. Accordingly, the I_{max} current value becomes greater when compared to the initial state.

As it is clearly seen from the quotations above that these two students have failed to interpret the relationship between the light intensity and saturation current correctly. The students' expressions are a clear proof of their understanding difficulties regarding photoelectric subject. These students are unaware of the fact that the saturation current changes solely depending on the intensity of light. That's why; these responses clearly present the lack of understanding regarding the linear relationship between current intensity and the light intensity.

Question 3. *In a photoelectric experiment, when a single photon with 3eV energy is dropped on the metal surface, one electron is emitted. Since it is known that this emitted electron has a zero kinetic energy, how much eV would the kinetic energies of the emitted electron or electrons is measured?*

With the help of this question, it has been aimed to find out the students' conceptions on how the kinetic energies of emitted electrons would be affected, on the condition of keeping the coming photon energy the same but sending more photons with the same amount of energy onto the metal surface. As it is known one photon is capable of emit only one electron. This means, there will be no difference between sending six photons instead of one. Each emitted electron's kinetic energy will be zero as expected. About this question, the students' conceptions obtained by analyzing their responses are present in Table 5.

Table V

Students' conceptions of the electrons' kinetic energy when the intensity of light was increased (N = 35).

Response Categories	Correct Reasoning	Incorrect Reasoning	No Reasoning	Total
Changing the kinetic energy of the emitted electron	-	8	-	8
Unchanging the kinetic energy of the emitted electron[a]	19	-	4	23
Blank	4	-	-	4

[a]Correct response

When Table V is examined, it is observed that most students are aware of the fact that even the number of photons is increased; the kinetic energies of the emitted electrons won't change. While 19 students out of 35 correctly explained why the emitted electrons' energies should not change, four students did not comment on this situation. Although these students stated that the emitted electrons'' kinetic energies wouldn't change, they didn't put forward any theories why it was so. The common idea in the students' correct answers and correct reasoning was "one photon can emit only one electron." Some quotations from these students' answers can be summarized as follows.

> **S4**: It is (the kinetic energy) is zero. Since the energy for each electron is fixed, six photons' energy only goes to the (metal's) binding energy, which means 6 electrons were emitted but their kinetic energy is zero again.
>
> **S7**: Because W=3eV, six photons emit six electrons but their kinetic energy is zero.
>
> **S25**: 3eV=W+0, which means the kinetic energy is zero. Since each sent photon drops on the different area of the metal and emits an electron, the emitted electrons' kinetic energy will be zero again.
>
> **S22**: One photon will be corresponding to only one electron. When six photons with 3eV energy each is dropped on the same plate, they can emit six electrons and these emitted electrons' kinetic energies will be 0eV.
>
> **S16**: 6x3=18eV, kinetic energy can be thought as 18-3=15eV. However, one electron is emitted at first and this time six electrons are emitted. But again the kinetic energy will be zero.
>
> **S32**: When a 3eV photon is sent to the metal surface, we know that the kinetic energy is zero. When six photons with 3eV energy are sent, the emitted six electrons' kinetic energy will be zero again, because one photon will be corresponding to only one electron.

As seen from quotations of the students' responses, the common idea is that one photon emits only one electron, so six photons will emit six electrons and these six electrons' kinetic energy will be zero again. On the other hand, eight students stated that depending on the increase in the number of the photons, the emitted electrons' kinetic energy would increase accordingly. All of these students calculated that six photons' with 3eV energy would make a total of 18eV. These students stated that the

3eV of the total 18eV energy would be spent on the threshold potential, and the remaining (15eV) would be transferred to the emitting electrons as kinetic energy. Some quotations from these students' answers can be summarized as follows.

> **S28**: The coming light emits one electron; the rest of the energy is used to accelerate the emitted electron. This means the kinetic energy of emitted electrons is 15eV.
>
> **S23**: Since the threshold potential of the metal is 3eV, six photons' 3eV of its total 18eVemits electron, and because the rest is 15eV, it is transferred to the electron as kinetic energy.
>
> **S15**: When six photons come, the total energy becomes 18eV. According to 18=3+Ek equation, the kinetic energy of the emitted electron becomes 15eV.
>
> **S3**: The binding energy of the metal is given as 3eV in the question. Since six photons will have an energy as 18eV, according to Ef=Eb+Ek equation, it will be Ek=15eV.
>
> **S1**: The total energy of six photons would be 18eV. Since the 3eV energy would be used to emit the electron, the remaining 15eV would be transferred to the electron as kinetic energy.

Examining the quotations above, it can be concluded that, instead of taking each photon's energy individually, the students tend to their answers on taking six photons' energy as a whole. These students tried to find the answer by applying the photoelectric equation on the total energy of the six photons rather than considering the photons individually. This situation is quite significant to understand the fact that students fail to understand the physics logic behind the photoelectric equation.

Discussion

In this study, the conception of the university students who have studied modern physics and quantum physics courses on the photoelectric effect have been identified by two open-ended questions about the interpretation of I=f(V) graph and one open-ended question examining the electron's energy emitted by the photons. The answers given to the first two questions intend to determine whether the interpretation of this graph (Figure 1) presenting the photoelectric event visually correctly or not; and also, the very same question has the quality to show whether the students can define the event within the physics context correctly or not.

Upon examining the responses given to the first question, it is clearly observed that most students can correctly identify the significant parameters (stopping voltage (Vs), photoelectric current (I0) and saturation (maximum) current (I_{max}) between the current and intensity on the graph. However, some of the students' expressions of these concepts using their own alternative expressions like "initial or first voltage/ current", and similarly like "threshold voltage/ current" show us that they perceive this event's graph mathematically rather than within the physics concepts. In this regard, on the graph, the students perceive the stopping voltage as the minimum threshold voltage or the intensity that should exist at the very beginning of the event in order to make the photoelectric event possible. Depending on this, it is thought that students have difficulties in understanding the fact that cross-connecting the end of the battery which is connected to the voltage source positively (the voltage gaining a negative value), the emitted electrons being pushed by the negative plate, showing the stopping effect on the photoelectrons, the photoelectric current is decreased to zero. Besides, most of the students pointed out C on the graph as the current's reaching to a maximum value on the major values of the intensity.

When the responses to the second question of the research - interrogating the value or values that would change in A, B or C shown in Figure 1 if a small wavelength light with the same intensity were used- were examined; it was observed that only 15 of the students could say that the stopping voltage would change and increase; however, only 9 of whom could make reasonable comments on the event. While a few students excluded interpretations in their answers, some students with correct answers but incorrect interpretations said that the increase in the stopping voltage is solely related to the change in the wavelength but not the frequency. 11 students left this question unanswered, and 6 students stated that there would be no change in the stopping voltage. The students who managed to give the correct answer to this question mainly based their answers on Einstein's photoelectric equation showing the linear relationship between the stopping voltage and the frequency (inversely proportional to the wavelength). In this question, the students who concluded that the stopping voltage would not change based their answer on the relation that the smaller wavelength of the photon causes the greater energy (E=hν). But they did not use the photoelectric equation showing the relationship between the stopping voltage and the photoelectrons' kinetic energies.

As there were students who had the conception that, the I0 photoelectric current value like stopping voltage, there was a relationship between the increase in the coming photon's energy with a smaller wavelength light bearing the same intensity; some students explained the photoelectric current by the idea of the increase in the energy of the coming light, the number of photons increases and accordingly the number of photoelectrons reaching the cathode increase. Surely, this misconception concluded by the students is one of the most significant findings of this research. Different from this finding, however, the previous studies (Mc Kagan et al., 2009) also revealed that there were some students who thought the change in the light intensity would cause an increase in the photons' energies. The students who came to this conclusion could not establish an accurate connection between the parameters like the intensity and the number of photons and the wavelength and the photon energy. While the decrease in the wavelength of the coming light increases the photons' energies, the unchanging intensity would not cause any changes in the number of emitted electrons. Thus, the increase in the I0 photoelectric current value should directly connected with the decrease in the wavelength but not with the increase in the number of the photons. Similarly, almost half of the students gave no or incorrect answers to the question related to the stopping voltage. While nine students out of 17 who gave the correct answer by stating that the light with the same intensity but with a smaller wavelength would not change the saturation current were able to provide the correct reasoning, two students had incorrect reasoning. In addition to that, six students could not provide any form of reasoning to their correct answers. "The light intensity" was the common concept used by the students who managed to support their answers by stating that the saturation current would not change. These students who had correct reasoning (nine students) for the unchanging current value in the photoelectric circuit based their answers on the idea of using the same current value in both cases. Here, it is also a noticeable finding that the student who had the wrong reasoning tried to based his/her answer by one photon's energy (E=hν) on the photoelectric event, similar to the stopping voltage potential.

Examining the responses given to the third question which aims to find out the conceptions on how the emitted electrons' kinetic energies would be affected on the condition that the coming photon's energy stays stable (unchanging) if more photons with the same energy are sent onto the metal surface; it is found that most students could correctly explain the idea that one photon emits one electron. However, eight students miscalculated the emitted electrons' kinetic energies by adding up the photons' energies. All of these students misinterpreted the idea of one photon's emitting one electron. This finding from the study is an interesting finding since it presents a different result from the previous studies.

Conclusions, Limitations and Suggestions

Considering the findings the research provided, the research can be regarded as an important asset as it shows the fact that students have conceptual difficulties in comprehending a graphic visual about a photoelectric event within the physics context. Thus, this study is also considered to have great contributions to the literature since it draws attention to the student conceptions on a physics event explained through a mathematical visual, in other words, a graphic drawn by using numerical data.

In the literature, few studies (Steinberg et al., 1996; Steinberg & Oberem, 2000) that could be considered similar to this one came up with similar findings but this very research reached significant findings since it shows how students perceive the graphs [like I=f(V)] presenting the results of the experiment about the photoelectric effect and the knowledge or the lack of information that he students have about the meanings of values on the graphs in physics context. In addition to that, it is a snap shot type study. For this reason, if the same survey is repeated at another time, one might obtain different results. Apart from that, this research is limited to the students who had courses on quantum physics and modern physics in two Turkish state universities. From all the reasons stated above, the results of this survey may not be generalized. On the other hand, another survey supported by larger samplings and interviews can be carried out. Furthermore, within the resource possibility; letting the students perform a similar experiment, draw the graphs themselves and assess the results can provide significant and positive contributions to the research results.

As it is known, modern physics is an area which is quite difficult to understand because of its abstract course coverage and its complicated mathematical structure. For this reason, the pedagogical researches related to the modern physics concepts should be designed in a way that it brings the visual teaching methods into prominence, creates an educational environment eliminating the mathematical and conceptual difficulties that the students encounter and facilitate the students to understand such subjects more easily.

In this sense, teachers should put more emphasis on the physical meaning of graphic visuals about the photoelectric event and also they should correlate the variables, such as formulas and definitions that explain the event, with the graphics. While doing this, the teacher should use the real numerical data on the graphics. Besides, considering that laboratories for photoelectric event are too costly for schools to afford, the use of some certain interactive programs that allow monitoring and trying out the event on the computer environment and the analogies that can correlate the event with concrete should be put into use.

References

Aubrecht, G. (2003). Do students have any quantum-related ideas prior to study in college classes? In Teaching Physics for the Future, ed. Moltô, E. Havana, Cuba: Proceedings of the VIII IACPE, 574-580.

Bernstein,J., Fishbane, P.M. & Gasiorowicz, S.G. (2000). *Modern physics.*(1th ed.), Prentice-Hall,USA.

Büyüköztürk, Ş., Kılıç Çakmak, E., Akgün, Ö. E., Karadeniz, Ş. & Demirel, F. (2008). *Bilimsel araştırma yöntemleri* (1. baskı). Pegem Akademi, Ankara.

De Leone, C.J. & Oberem, G. E. (2004). *Towards understanding student conceptions of the photoelectric effect,* in 2003 Physics Education Research Conference Proceedings, edited by J. Marx, S. Franklin, and K. Cummings (AIP, Melville, NY)

Dereli, T. & Verçin, A. (2000). *Kuantum mekaniği 2*, METU Press, Ankara.

Knight, R. (2004). *Five easy lessons: Strategies for successful physics teaching*. Addison-Wesley, San Francisco.

McDermott, L.C. (1993). How we teach and how students learn-A mismatch?.*American Journal of Physics,* 61(4), 295-298.

Mc Kagan, S.B., Handley, W., Perkins, K.K. & Wieman, C.C. (2009). A research-based curriculum for teaching the photoelectric effect. *American Journal of Physics,*77 (1), 87-94.

Oberem, G.E. & Steinberg, R.N. (1999). *Photoelectric tutor physics academic software*, American Institute of Physics, College Park, MD.

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

Steinberg, R.N. & Oberem, G. E. (2000). Research-based instructional software in modern physics. *Comp. Math. Sci. Teach.*, 19, 115–136.

Strauss, A. & Corbin, L. (1990). *Basics of grounded theory methods*. Beverly Hills, CA.: Sage.

Thacker, B. A. (2003). A study of the nature of students' models of microscopic processes in the context of modern physics experiments. *American Journal of Physics,* 71(6), 599-606.

Yıldırım, A. & Şimşek, H. (2008). *Sosyal bilimlerde nitel araştırma yöntemleri* (7. baskı), Seçkin Yayıncılık, Ankara.