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AN INVESTIGATION ON COLLEGE STUDENTS' CONCEPTUAL UNDERSTANDING OF QUANTUM PHYSICS TOPICS

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Abstract

Today, it is accustomed to investigate students who have difficulties about understanding quantum concepts and several findings indicated that they do face quite challenges about learning this difficult subject. In this study, we aim to explore students' conceptual understanding and knowledge of the topics of quantum physics. In order to achieve this goal we designed a questionnaire based on previous investigations and conceptual questions in different studies. Senior and junior college students enrolled at school of education and science department agreed to participate in the study. It was administered to 394 students at Erciyes University. Of them, 83 and 55 were senior and junior pre-service science teachers, 102 and 72 were senior and junior physics students, respectively. Rest of the participants was consisted of senior class chemistry students. At the end of this paper, we analyzed the results of questionnaire and observed that having more experience with the quantum concepts makes students to remember them easier. Results revealed that students struggle in understanding quantum physics and that was not a surprise because recent studies showed that these concepts were harder to learn than other physics concepts. In addition, the questionnaire designed for this study passed the reliability with KR-20 value of 7.83 and validity tests.

Keywords: Quantum physics, science teaching, physics education.

ÜNİVERSİTE ÖĞRENCİLERİNİN QUANTUM FİZİĞİNİ KAVRAMSAL ANLAMALARI ÜZERİNE BİR ARAŞTIRMA

Günümüzde kuantum kavramlarının üniversite öğrencileri tarafından hangi seviyede anlamaları üzerine araştırma yapmak yaygın olmakla beraber bu konudaki makalelerde öğrencilerin konuları anlamalarının diğer fizik konularına göre daha zor olduğu sonuçlarına varılmaktadır. Bu araştırmada öğrencilerin kuantum fiziğinde yer alan kavramların anlaşılmasının araştırılması amaçlanmıştır. Bu amaca ulaşmak için daha önceden yapılan çalışmalardaki veri toplama anketlerini kullanarak yeni bir anket oluşturulmuştur. Üniversitesinin fizik, kimya ve fen eğitimi bölümlerinde okuyan öğrenciler bu çalışmada gönüllü yer almayı kabul etmişlerdir. Erciyes Üniversitesinde okuyan 394 öğrenciye bu anketi uyguladık. Bunlardan 83 tanesi 3.sınıf ve 55 tanesi ise 4.sınıfta okuyan fen bilgisi öğretmen adaylarıdır. Ayrıca, 102 tanesi 3.sınıf ve 72 tanesi 4.sınıfta okuyan fizik bölümü öğrencileri idi. Diğer öğrenciler ise kimya bölümünde okuyan 3.sınıf üniversite öğrencisidir. Çalışma sonucunda ise elde edilen bulgular analiz edilmiştir. Elde edilen bulgularda öğrencilerin bu kavramları çok fazla öğrenemedikleri görülmüştür ve bu sonuç bizim için sürpriz değildir çünkü bu fizik dalı araştırmalar sonucunda daha zor olduğu elde edilmiştir. Ayrıca, kullanılan veri toplama aracının geçerlilik testleri sonuçları yeterli seviyede bulunmuştur.

Anahtar Kelimeler: Kuantum fiziği, fen öğretimi, fizik eğitimi

Introduction

The twentieth century is characterized by the prevalence of radically new scientific events (Kalkanis et al, 2002). In today's world, with the help of improvements in quantum mechanics (QM) or otherwise known as quantum physics (QP), we can manipulate and utilize technology in a better way.

To better understand QP at first we should understand the history of quantum mechanics (Isham and Linden, 1994). In 1905, Albert Einstein published his famous theory of relativity. Until that revolutionary moment, every natural event such as position of an electron and momentum was used to be explained with Sir Isaac Newton's Theory of gravity but this theory was not enough to explain objects like electrons, which orbits with high speeds, massive stars life circle and black holes (Pospiech, 2004). However, with Einstein's special and general relativity theories, it is currently possible to understand and explain such phenomenon. At the beginning, it wasn't easy to accept a new theory. To prove the theory, Einstein hypothesized that massive objects such as stars make a black hole around them and it causes refraction of light which make a misapprehend about the real position of the star. Sun, being as a massive star, must make true the hypothesis. After the solar eclipse application, there was nothing suspicious about Einstein's theory. With this natural event, Einstein showed that he was right about his theory.

In the meantime with the help of Einstein's Relativity theory, there was a new way to investigate and to understand physical world. In between 1900 and 1930, there was another theory akin to similar to Relativity Theory there was a revolution named quantum mechanics. Max Planck put a major theoretical side of quantum mechanics forward; however, Einstein, Bohr, Schrödinger, De Broglie, Heisenberg, Born and Dirac evolved necessary mathematical explanations and applications of theory. (Rovelli, 2001)

In spite of worldwide success and reputation of quantum mechanics, even Einstein declared that he was not fully satisfied with the way theory was built upon (Akarsu, 2010) because he never accepted the concept of finding particles with probability distribution. Especially, the Heisenberg uncertainty, which basically suggests that it is impossible to measure a particle's real position and speed at the same time, was a major dilemma for him. Specifically, it was accustomed for scientists including Einstein to see the world through the idea of "possibility" when locating a particle. He then expressed his idea with this sentence.

"God doesn't play dice with the universe"

In spite of every against opinion to it, quantum theory managed to obtain a huge success and reputation all over the world (Wittmann et al, 2002). Twentieth century's technology mostly depends on the concepts and applications of quantum physics. Contemporarily, in computer technology, telecommunication and genetics technological applications of quantum physics is widespread and dominant. For example, light amplification by stimulated emission of radiation (LASER) devices was developed with the help of quantum ideas. Mechanism of LASER depends on three different principles (Serway and Beichner, 2005). The system of Laser must be in a population inversion, the system must be meta-stable and stimulated photons must be retained in the system until the other unstipulated atoms can be stimulated and emission of radiation. Since its invention in 1960, laser technology has been improving with a glory. (Lipshitz, 2002)

Nowadays, ultraviolet rays, infrared rays and visible rays are being used in laser technology and it is getting common to have different kind of laser lights. Coherent scattering and easily focusing on features of lasers make them more useful not only in science, but also in astronomy, geology, geophysics and medicine (Lipshitz, 2002). In geophysics, measuring the distance between two particular stars is possible with high accuracy in today's technology, and in medicine to heal the visual defects is now bloodless surgery and healing process is shorter than before for patients with the aid of Laser. In addition, lasers facilitate hologram technology and make better appearance of an object in three dimensions.

Although it's technological applications and success, educational aspects of quantum ideas failed to be learned by the students in classrooms. Several investigations have been undertaken to focus on main pedagogical issues in quantum mechanics (Singh, 2007). Bao and Redish (2001) published a study which aimed to help students building a model of how to visualize the probability in physical systems and developed a set of hands-on tutorial activities appropriate for use in modern physics and engineering courses and they demonstrate that three of the six students were able to develop an appropriate understanding of quantum probability. However, the remaining students used classical arguments in their reasoning and tried to associate the probability of finding an electron in a potential well with the velocity of the electron. Similarly, Wuttiprom et al. (2006) studied about developing a survey that includes the basic ideas underlying quantum physics and they practiced the survey with senior and junior college students and found that junior students scored lower than seniors.

Kalkanis, Hadzidaki and Stavrou (2002) presented a study that demonstrate in/pre-service teachers' misconceptions about Quantum Mechanics (QM) and showed that, simple, and relevant teaching approach towards QM into teacher education needed a reform of science education along the aforementioned line and they developed a model for it. For the same purposes, Ozdemir and Erol (2010) developed a hybrid model about double slit experiment, which contains tutoring, group and class discussion and homework activities with undergraduate students.

In addition, McKagan and Wieman (2006) published a survey which aims to measure student understanding of energy through the quantum mechanics conceptual like tunneling and barrier penetration and in the same year they use a simulation to teach quantum physics and published their study. Also, they presented results from a study designed to test students understanding Bohr model by developing a curriculum on models of the atom, including the Bohr and Schrödinger models. McKagan and Carr (2009) investigated improvement of graduate quantum education with course content, textbook, teaching methods, and assessment tools. They discovered that graduate students respond fine to research-based techniques that have been tested mainly in introductory courses and also found that students' ability to answer conceptual questions about graduate quantum mechanics is highly correlated with their ability to solve numerical problems on the same topics.

Baily and Finkelstein (2009) developed a survey and studied about students understanding quantum physics and they found that, after instruction in modern physics, many students are still exhibiting a realist perspective in contexts where a quantum-mechanical perspective is needed. They also conducted interviews with physics students and found that students possess analogous opinion with the physicist when quantum physics first appearing days. In the same token, Morgan et al. (2004) conducted interviews to measure students' understanding of tunneling and demonstrate students' misconception.

Calıskan et al. (2009) developed a diagnostic tool to measure students` conceptual understanding of some quantum physical concepts in university and suggests that creating an interactive class endearment. Similarly, McKagan et al. (2010) developed a survey, which contains 12 questions, and they also discussed about specific questions for other researchers. Also Akarsu (2010) studied with science and engineering college students and pre-service teachers to explore the percentages of quantum thinking, dual thinking and classical thinking of them.

A theoretical study was published by Hobson (2004). He studied quantum physics in introductory general physics courses but he didn't complete it as he commented:

"Because I am retired, I have been unable to test these ideas in the classroom. I hope that somebody will study the pedagogy of the field theory approach to quantum physics using the comparative methods of physics education research. I would be delighted to hear the experiences of instructors and physics education researchers who try this teaching approach"

Currently, we are even discussing about quantum physics as a philosophy and lots of people make decisions and shape their life with the ideas of this philosophy. Although in every part of social life quantum physics is so familiar, why students still have quite challenge with understanding quantum concepts and why do they believe that learning this kind of topics just for exams, not for life? In this study, we aim to inspect possible explanation of these negative ideas towards quantum physics. To execute this goal, at first, we must understand the major problems about this area and the challenges students face therefore we formed a questionnaire, which include main topics of quantum physics such as photoelectric, wave-particle dilemma, de Broglie wavelength and it's relationship with energy and speed, double-slit experiment, Heisenberg's uncertainty principle, wave packets, etc. The purpose of this study is to investigate college students' conceptual understanding of major topics in quantum physics according their genders, disciplines and faculties.

Methodology

It is acceptable for us to notice students who have difficulties of understanding various concepts of physics in every step of education system over in Turkey as well as all around the world. Especially, in high school and college, one of the most complicated disciplines for students is quantum physics. The aim of this study was to analyze these challenges and investigate students' understanding of quantum physics. To identify these issues, we improved a questionnaire, which was initially designed by Wuttiprom (2008) named Quantum Physics Questionnaire (QPQ). We administered it to 394 students in different disciplines such as Science education department, physics department and chemistry department at Erciyes University. All the attendees were chosen in departments randomly and the participants were students who take quantum physics lessons during a semester in the third or fourth year of college.

In this study, a questionnaire developed by Wuttiprom (2008) was adapted to Turkish educational conditions. The main intention of the study was to investigate students' conceptual understanding of quantum physics and also students' interpretations of quantum physics is important in our research purposes. In addition, we tested and analyzed the reformed data collection instrument. In addition, some important details of informal observations and small talks (interview) were noted.

After the process of preparing and adapting the QPQ, to determine the validity coefficient of the questionnaire, the questionnaire was sent to 7 different physics faculty members at science education and physics departments to analyze the QPQ's content, accordance and the way to determine the real aim.

Table 1: *Gender of the participants*

	Physics		Chemistry		Science education	
Gender	N	%	N	%	N	%
Male	78	44	40	46	56	41
Female	96	56	46	54	78	59
Total	174	100	46	100	138	100

At the beginning of the questionnaire we aim to know that if students have standard physics subjects such as Newton mechanic, magnetism and electric lessons along the education in collage before. Also we asked them if they have studied modern physics topics in high school.

The following step was reediting the questionnaire to meaningful parts. The questionnaire contained 25 problems including the main topics of quantum physics and it is possible to fragmentize questionnaire in 9 different parts that depends on main topics.

Table 2: *Main topics of questionnaire*

Statement	Topics	Sub topics
1, 2, 3	Photoelectric event	Intensity of light Work function of surface Cut-off frequency
4, 5, 6, 7	Wave-Particle duality	Behavior of light Behavior of electron
8, 9, 10	De Broglie wavelength	Behavior of a particle in an electric field Behavior of a particle in an magnetic field
11, 12, 13	De Broglie wavelength and energy	
14	De Broglie wavelength and speed	
15, 16, 17, 18, 19	Double slit experiment	Spectrum of light
20, 21	Heisenberg's uncertainty principle	
22, 23, 24	Wave packets	
25	Double slit experiment with standard Physics rules	

The first three questions determine students' knowledge about photoelectric event and analyze their capacity of interpretation photoelectric. Questions 4 through 7 were based on wave-particle dilemma and we planned to demonstrate students' misunderstanding about wave-particle experiment when we add this question to questionnaire.

Questions 8, 9, and 10 were asked to measure students' knowledge about the topic "de Broglie wavelength." We expected from students that they can use their knowledge about de Broglie wavelength principles on a particle when a particle moving through an electric field in the same direction as the field, in opposite direction as the field and when a particle moving through a magnetic field in the same direction as the field. In questions 11 through 13, we wanted to observe students' knowledge about relation between a particle's wavelength and its energy. Question 14 was about the relation between a particle's wavelength and its speed.

Questions 15 through 19 were double slit experiment questions and indicators of misunderstandings we asked if a particle goes through the double slit, if marbles go through the double slit, if light goes through the double slit and at the end we asked if a slit was covered what will happen when a particle, light and marbles go through the double slit. Questions 20 and 21 were used in questionnaire to identify students' knowledge about Heisenberg's uncertainty principle. To determine misunderstandings we also asked students if one utilize uncertainty principle for large objects what will possibly occur. Last three statements measure students' knowledge about wave packets, true position of wave packets, and to determine their misunderstandings regarding double slit experiment. However, in the last question, we wanted them to make use of standard (Copenhagen) physics principles.

Results

Results of physics faculty members' opinions about items in the questionnaire are edited and demonstrated in the Table 3 under the below.

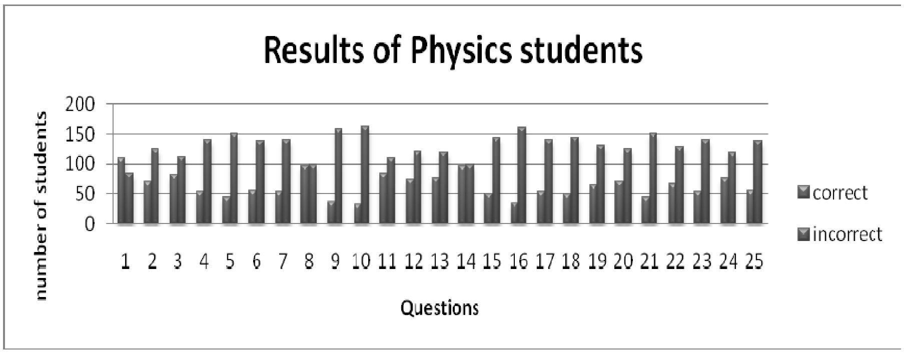
Table 3: *Validity coefficient of questionnaire*

	Content		Logical		Convenience	
Question	M	SD	M	SD	M	SD
1	8,43	1,4	8,29	1,38	8,29	1,38
2	8,29	1,38	8,43	1,4	8,29	1,38
3	8,29	1,38	8,29	1,38	8,29	1,38
4	8,43	1,4	8,43	1,4	8,43	1,4
5	8,29	1,38	8,43	1,4	8,43	1,4
6	8,29	1,38	8,29	1,38	8,29	1,38
7	8,14	1,46	8,43	1,4	8,43	1,4
8	8,43	1,4	8,29	1,38	8,43	1,4
9	8,43	1,4	8,43	1,4	8,43	1,4
10	8,29	1,38	8,57	1,51	8,43	1,4
11	8,14	1,46	8,29	1,6	8,29	1,6
12	8,29	1,6	8,29	1,6	8,29	1,6
13	8,29	1,6	8,14	1,46	8,29	1,6
14	8,71	1,6	8,71	1,6	8,43	1,51
15	8,57	1,51	8,57	1,51	8,43	1,4
16	8,43	1,4	8,29	1,38	8,43	1,4
17	8,57	1,51	8,43	1,4	8,43	1,4
18	8,43	1,4	8,29	1,38	8,57	1,51
19	8,43	1,4	8,43	1,4	8,29	1,38
20	8,71	1,6	8,71	1,6	8,57	1,51
21	8,71	1,6	8,71	1,6	8,43	1,51
22	8,71	1,6	8,71	1,6	8,71	1,60
23	8,71	1,6	8,71	1,6	8,71	1,60
24	8,57	1,51	8,57	1,51	8,57	1,51
25	8,57	1,51	8,71	1,6	8,71	1,60

A total of 394 junior and senior students from the Physics department, the Chemistry department and the science education department were randomly chosen to practice this questionnaire. Subsequently, establishing the reliability coefficient of questionnaire, QPQ was performed as it was planed and to control the QPQ' the reliability coefficient, KR-20 formula was chosen. It is a common way to control questionnaire's reliability coefficient developed by Kuder-Richardson in 1937. KR-20 values can range 0,00 to 1,00. If KR-20 is close to 1,00 the questionnaire is intended the measure the real purpose of the questionnaire. The questionnaire used in this study has a KR-20 value of 7.83. Therefore, results of our data are considered reliable.

Preparing step of the questionnaire was accomplished with the suggestions of authors in Physics and science education department. And the results of QPQ were organized on the below. 174 junior and senior Physics student which were randomly chosen attended to response the questionnaire and the results of Physics students were given below as well.

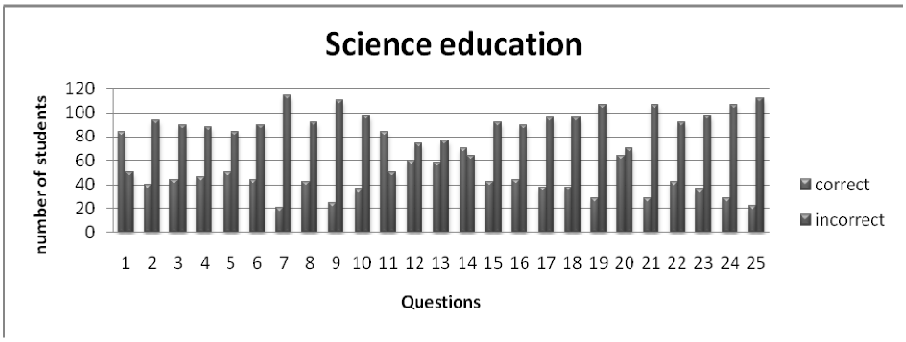
Figure 1: *Correct responses of physics students*



In the chart, physics students' answers show that students have problems about understanding the double slit experiment and explaining an electrons behavior in an electric field and magnetic field.

Maximum true questions percentages belong to questions 1 and 3 that aim to identify students' knowledge about photoelectric event, 11 and 13, which were asked to explore relationship between energy and de Broglie wavelength. And question 14 added to questionnaire to demonstrate students' interpreting a graphic of de Broglie wavelength and speed. 134 senior and junior science education students attended the study and the results of the students is under the below.

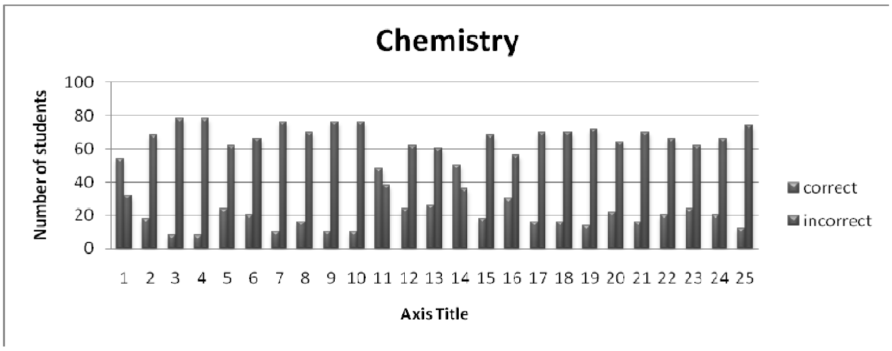
Figure 2: *Results of science education students*



Results of science education students show that students face a challenge about interpreting about a particle's behavior in an electric field and magnetic field. Also, it can be seen on the chart that science education students have difficulties about Heisenberg's uncertainty principle in normal life situation. Similar to physics students, science education students also possess difficulties concerning the double slit experiment.

Their best results belong to photoelectric event, determining a particle's speed using de Broglie wavelength and relationship between energy and de Broglie wavelength. 86 senior and junior chemistry students, which were chosen randomly, attended the study and the results of students are given below.

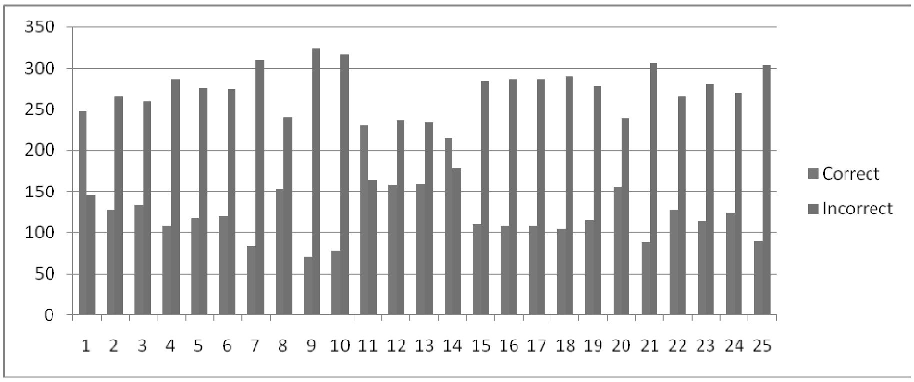
Figure 3*: Results of chemistry students*



The results also illustrated that chemistry students have difficulties about quantum physics concepts such as double slit experiment, Heisenberg's uncertainty principle, and electron's behavior in an electric and magnetic field. Besides, it must be mentioned that there appeared a challenge about a particle's wavelength.

On the other hand, chemistry students showed quite success about understanding photoelectric event and relationship between a particle's de Broglie wavelength and its speed. Totally, 394 students from physics, science education and chemistry depertmant answers are edited in the figure below.

Figure 4: *Results of the questionnaire in all disciplines*



In figure 1, students who participated in this study hold real challenge about understanding and interpreting quantum physics. In the result chart, maximum true answers belong to question 1 which aims to demonstrate students understanding of photoelectric event. 65% of students answered the question correctly.

Question 11 aimed to discover students' understanding of a particle's de Broglie wavelength in an electric field with the same direction and it was answered by 58% of the participants correctly. Question 14 was asked to understand how students use wavelength graphics to locate a particle's speed, and it was answered correctly by 58% of the students.

The lowest percentages of correct responses in the questionnaires belong to question 9 and question 10, which were asked to understand how students could utilize a particle's energy to calculate changing of particle's de Broglie wavelength. Question 9 was responded correctly about 18% of students and question 10 was answered correctly only 20 %.

In addition, question 25 aimed to investigate students' conceptual understandings of double slit experiment with the rules of standard physics. 23% of the students answered this question correctly.

Findings

As it was hypothesized at the beginning, most of the students revealed some degree of difficulties about quantum thinking and employ their previous knowledge in different question types especially interpreting graphics.

At first we must mention about the students' background of quantum physics. All of the students in the study graduated from high school before 2006. Until last year, students who started to study in physics, chemistry and science education departments must answer questions of the modern physics concepts in the University Entrance Exam (UEE) such as waves, wavelength, frequency, energy of a wave and theories about light in high school. Nevertheless, 74% of them claimed that they did not study these subjects in high school. It is important for our study, because students, who already studied quantum physics courses in high school, do not remember that they took the subject before or they forgot about taking it. Possible reason of this dilemma stems from the high school system. Because of poor education system, students do not pay attention to quantum physics concepts, which didn't appear in university exam before. In 2010, physics curriculum and system of university entering exams was transformed and quantum concepts take their places in the UEE.

Conversely, correct responses of question 1 shows that, both of physics, chemistry and science education students' entrance behaviors are well built (63%) about photoelectric event, but when the photoelectric event was asked in a different way (in question 2), correct percentages fall around 32%. It perhaps indicates that most of the students hold knowledge of photoelectric concept but they don't know how they can make use of its rules in the observed macroscopic world. This result was somewhat different than Wuttiprom's *et al*. (2008) findings as they concluded that students possess particular problems with these questions. On the other hand, as mentioned in result section, Wuttiprom *et al*. (2008), also, reached same results of third year students being more successful than forth year students in overall scores.

When responses to questions 5 through 9 were analyzed, it was observed that students' way of thinking is deterministic as it was found in Sign (2010) study. Interpreting wave-particle duality is still a complex problem about students. Especially choosing when an electron behaves like a particle or behaves like light or behaves both like particle and light.

It must also be discussed that it wasn't surprise for the goal of our study, especially after analyzing question 5 through 9, that if students don't know concept of wave-particle duality, they couldn't understand double slit experiment. Besides, responses to questions 15 through 19 indicate that interpreting an electron's spectrum graphic or using larger objects other than electrons, such as marbles, in the double slit experiment revealed conceptual understanding difficulties for students.

In the same way, question 25 about interpreting double slit experiment with standard physics rules wasn't answered correctly.

Furthermore, students' way of thinking about Heisenberg's uncertainty principle must be discussed. In question 21, we asked students "Uncertainty principle is used for electrons but we don't use this principle for large objects, why?" The answer of students was really important. They claimed that uncertainty principle is used for small particles such as electrons, but for large objects we must use Newton's physics rules. This implements most of the students didn't grasp true essence of the principle and only focus on microscopic world. However, it can also be applied to macroscopic world.

The last important result, which must be mentioned, is as it was expected physics students hold best correct responses of the questionnaire, science education students are behind them. The lowest correct results belong to chemistry students. In fact, it proves that having more experiences with this kind of topics make students' understanding easier since physics students usually take 4 quantum courses and the others take only one in college.

Conclusion and Discussion

The goal of this research was to investigate students' conceptual understandings of quantum physics such as Heisenberg's uncertainty principle, photoelectric event, de Broglie wavelength, and double slit experiment. Questionnaire was purposefully designed to investigate these topics. This purpose play an important role in both students' academic life and real life environments because most of the physics course in college are dominated by quantum physics concepts and many technological devices have structures that are mostly depended on these fundamental quantum, too. Without knowledge of quantum concepts, students tend to fail in understanding basic mechanism of high technological devises and further physics courses.

It is obvious that students from all discipline have a huge presumption about quantum physics. During the time of the study, some of them were taking the same courses second time and it makes them feel more uncomfortable about the concepts. Besides, in informal interviews with them, it is revealed that imagining light both wave and particle at the same time is not realistic for students. Also, thinking about probability of an electron's place is so unreal for them too.

For changing students' misconception about quantum physics, simulations of uncertainty principle or making experiment about double slit experiment can be used in faculties such as simulations, which were developed by McKagan et al. (2008). The other point is that the ways of learning quantum physical concepts with the classical concepts make more challenges for students (Ozdemir and Erol, 2010)

In conclusion, from high school to university, educators must pay more attention and be very careful about prejudges against to quantum topics and try to rebuild correct ideas about concepts. After investigating and maybe development of university entering exam, this study may be repeated and results of the next study can be compared with it.

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