# Student Understanding of Some Quantum Physical Concepts

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**Abstract**

In spite of nearly a century, quantum physics and quantum phenomena seem to be having some difficulties to influence the human brain and logic hence some considerable effort has recently been spending to overcome such difficulties. As a part of the international efforts, we composed a questionnaire named as Quantum Concepts Questionnaire (QCQ) to investigate student ideas about some concepts in quantum physics and quantum phenomena. In this work, the concepts of electron, wave function, wave-particle duality and structure of atom are specifically investigated and obtained data are statistically analysed. The QCQ is administered to 71 undergraduate students all completed the quantum physics course at Education Faculty of Buca, Dokuz Eylül University in Izmir, Turkey. Finally some important outcomes of the research are presented, discussed and certain suggestions are briefly made.

**Keywords:** Physics education, Quantum physics, Understanding.

**Resumen**

A pesar de casi un siglo, la física cuántica y los fenómenos cuánticos parecen tener todavía algunas dificultades para influir en el cerebro humano y la lógica; de ahí el esfuerzo considerable que recientemente se ha estado realizando para vencer tales dificultades. Como una parte de los esfuerzos internacionales, se desarrollo un cuestionario llamado: Cuestionario de Conceptos Cuánticos (QCQ, por sus siglas en inglés) para investigar las ideas del estudiante sobre algunos conceptos en la física cuántica y fenómenos cuánticos. En este trabajo, los conceptos de electrón, función de onda, la dualidad onda-partícula y la estructura de átomo son expresamente investigados y los datos obtenidos son analizados estadísticamente. El QCQ fue aplicado a 71 estudiantes de licenciatura para completar el curso de física cuántica en la Facultad de Educación de Buca, Dokuz Eylül en la Universidad en Izmir, Turquía. Finalmente algunos resultados importantes de la investigación son presentados, discutidos y ciertas sugerencias son realizadas de manera breve.

**Palabras clave:** Educación en Física, Física Cuántica, Comprensión.

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## I. INTRODUCTION

Quantum theory is probably the most successful theory of the science history and it takes place in the centre of the micro world which can be defined as the world having physical sizes less than roughly $10^{-7}$ m. Although this theory is an excellent theory to explain the micro world, it is thought by many others as an unclear theory due to having no more than probabilities and uncertainties [1]. In addition, as Penrose states, the quantum theory helps us to understand many important events such as the colours of the stars, the structure and function of DNA, and super conductivity etc. [2]. In this sense, understanding of quantum theory is essential not just for physicists but also for chemists, engineers and medical doctors. Majority of the students find it extremely difficult to understand and internalize the quantum physics. The difficulty of learning quantum physics is primarily due to the following reasons: 1- The student is brought up in the tradition of classical physics, the fundamental concepts of which- determinism, causality, and etc- are very convincing. Having accepted the fundamental concepts of classical physics, they find it difficult to adjust to those principles of quantum physics- uncertainty, probability, etc. 2- The two standard mathematical approaches of quantum physics- Heisenberg's matrix mechanics and Schrödinger's wave mechanics- are so different that students find it difficult to understand how they can describe the same physics and 3- Quantum physics is usually taught historically, and the beginners find it difficult to connect the various stages in the evolution of the subject into a coherent whole [3]. Nevertheless, as learning and understanding quantum physics as includes difficulties teaching it. Thus, teaching quantum physics should aim to give students at least some understanding of how, fundamentally, this part of physics differs from classic physics [4].

In this context, understanding is the ability of reflecting the qualitative aspects of quantities [4]. Hence, what is meant by the topic of "student understanding quantum" in this research is to construct the quantum concepts and events in their minds and to build permanent knowledge traces by adding physical comment to a mathematical operation in quantum physics.

As the field literature is scanned, various researches performed on students' understanding of many subjects such as electricity and magnetism [5, 6, 7], heat and temperature [8, 9] and most of all force and motion [10, 11, 12] in physics can be seen. A number of researches also focused on student understanding of quantum physics [4, 13, 14, 15, 16, 17, 18, 19, 20], the researches on student understanding of quantum physics is still quite few compared with the research carried out in the other areas of physics [15, 21]. These researches introduce many important results about how to teach quantum physics and present suggestions for changes in teaching materials [22].

Unfortunately the research on quantum physics education has recently been started in Turkey. In this manner, the present research is one of the very first researches on quantum physics. In this research, it is intended to reveal the point of view of the undergraduate physics students who had taken the quantum physics course at the undergraduate level and to determine their understanding of quantum concepts and events.

## II. METHOD

### A. Participants

The subjects of the study consist of n=71 students who contributed to the research as volunteers from 3rd, 4thand 5th grade students attending Department of Physics Education, Education Faculty of Buca Dokuz Eylül University in Izmir. All of these students had previously taken the Quantum Physics course. The Quantum Physics is one of the compulsory courses for the third-year undergraduate physics program of the Physics Education department. The course comprised of three 45 minutes lectures per week. Content of the course notes was parallel to the textbook "Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles, 2nd edition [23]."

### B. Quantum Concepts Questionnaire (QCQ)

Quantum Concepts Questionnaire (QCQ) was developed to investigate student ideas about some concepts in quantum physics and quantum phenomena. A preliminary literature search was carried out to determine the current inventories or surveys developed to measure students' understanding of quantum physics. In addition, research studies involving interviews with student about their view of quantum physics were also examined in this literature search [4, 13, 15, 16, 17, 25]. Based on this comprehensive literature search, the researchers in the current study developed survey items to determine students' ideas about quantum physics and some concepts in quantum physics. The first version of the items was examined by three physicists and they were revised in respect to expert suggestions. Finally, Quantum Concepts Questionnaire (Cronbach Alpha: 0.72) is made up of fivefold Likert type items. The choices are stated as "Strongly Agree", "Agree", "Undecided", "Disagree", "Strongly Disagree". The questionnaire contained 26 Likert-type items to provide information of student understanding of the quantum physics statements. In this work, the concepts of electron, wave function, wave-particle duality and structure of atom are specifically investigated and obtained data are statistically analysed.

### C. Analysis of the Data

The average point or mean value (M) and standard deviation (SD) of each item of the questionnaire were calculated.

Calculated mean value for each item can statistically be between 0 and 5. However the mean values can be read from the tables on the basis of the following classification: Mean value between (1.00-1.79) is read to be "Strongly Disagree", between (1.80-2.59) is "Disagree", between (2.60-3.39) is "Undecided", between (3.40-4.19) is "Agree", between (4.20-5.00) is "Strongly Agree". All the analysis was carried out by using SPSS for Windows, version 11.0.

## III. FINDINGS

Means and standard deviations for each item were calculated based on the answers of the students of each quantum physics expression existing in the questionnaire. The results are presented in the Table below.

Examining Table shows that most of the students partly agree with the statement that quantum physics is the world of probabilities and is a statistical theory (item 1 and 2). They also think that quantum physics is not independent from classical physics and exact behaviour of an electron can not be determined. Hence students do feel unconfident about quantum mechanical behaviour of an electron (item 3, 4 and 5).

A brief examination of means of the items 6, 7 and 8 indicates that students partly agree with the statement that quantum physics being the most fundamental resource of today's technology. They also believe that quantum physics is a superior theory containing some amount of classical physics. Nevertheless, most of the students disagree with the idea of quantum physics being just mathematics and not containing any comments.

According to the data, the students believe that position of electrons can not be determined exactly (item 9). They on the other hand strongly disagree with the following expression that the position of an electron in an atom is exactly clear (item 12). Nevertheless, they have an uncertain approach about the electrons being anywhere around the nucleus (item 13). The students believe that any measurement in quantum mechanics has natural limitations (item 10). They also strongly disagree with the idea that measuring the position of an electron with the same measurement instrument always gives the same results (item 11).

Examining Table shows that the students disagree with the idea of electrons being always a particle (item 14).

However they surprisingly think that an electron is a spherical particle with a negative charge on it (item 15).

**TABLE.** Means and standard deviations results for the QCQ items.

| QCQ item | M | SD |
|---|---|---|
| 1. Quantum physics is a statistical theory. | 3.59 | 0.99 |
| 2. Quantum physics is the world of probabilities. | 3.51 | 0.93 |
| 3. Quantum physics is totally independent from classical physics. | 2.47 | 1.16 |
| 4. Knowing the position of an electron one can estimate the behaviour of an electron. | 2.71 | 1.04 |
| 5. The behaviour of a bound electron at any event can be estimated in advance. | 2.78 | 1.01 |
| 6. Quantum physics is a theory just consisting of advanced mathematics and not containing any comments. | 2.47 | 1.28 |
| 7. Quantum physics is the most fundamental resource of today's technology. | 3.47 | 0.92 |
| 8. Quantum physics is a superior theory also comprising of classical physics. | 3.94 | 0.98 |
| 9. Position of an electron can not be determined exactly | 4.21 | 0.84 |
| 10. A limitation always exists in measuring physical variables in quantum mechanics. | 4.01 | 0.81 |
| 11. Measuring the position of an electron by the same measurement instrument always gives same results. | 1.62 | 0.78 |
| 12. The position of an electron in an atom is exactly clear. | 1.70 | 0.86 |
| 13. An electron around the nucleus can be anywhere at any time. | 2.81 | 1.41 |
| 14. Electron is always a particle. | 2.59 | 1.26 |
| 15. Electron is a spherical particle with negative charge moving in a cloud. | 3.76 | 0.78 |
| 16. Light always behaves as a wave. | 1.71 | 1.00 |
| 17. If an electron is passed through a narrow enough split and projected to a photographic screen, a diffraction pattern is always observed. | 4.05 | 0.75 |
| 18. Electrons moving around a nucleus behave as a wave. | 3.15 | 0.80 |
| 19. Being wave or particle for an electron depends on the type of the experiment. | 3.87 | 0.87 |
| 20. An electron can be assumed as a wave and a particle at the same time. | 3.47 | 1.06 |
| 21. Movement of an electron in an atom is similar to the structure of planets moving around the sun. | 3.73 | 0.90 |
| 22. Stability of an atom comes from the balance between repulsive and attractive electrical forces acted on an electron. | 3.70 | 0.90 |
| 23. Wave function represents a physical object. | 3.34 | 0.98 |
| 24. Wave function defines physical state of a motion and interaction with surroundings. | 3.85 | 0.72 |
| 25. $\|\psi\|^2$ expresses probability density. | 4.38 | 0.59 |
| 26. $\|\psi\|^2$ has no physical meaning in quantum mechanics. | 1.80 | 0.99 |

A brief examination mean of item 16 shows us that light is not always a wave. The students also agree with that the electrons can give a diffraction pattern assuming minimum diffraction conditions are set (item 17). They, on the other hand, seem to be unclear about the electrons moving around a nucleus having a wavelike property (item 18).

As can be seen from the Table the students agree with the idea that being a wave or a particle for an electron varies according to the experiment performed (item 19). They also think that an electron can be assumed as a wave and particle at the same time (item 20).

The Table clearly shows that the students agree with the first and second items. In other words, they are aware of the similarity between planetary and atomic systems and they also know that the atomic balance comes from the repulsive and attractive electrical forces (item 21 and 22).

According to the data of given in the Table, students have an uncertain approach about the subject that the wave function represents a physical object. The Table also indicates that the wave function defines a physical state. They seem to disagree with that the square of wave function has no physical meaning and they nearly totally agree with the idea of wave function expressing the density of existence probability (item 23, 24, 25 and 26).

## IV. CONCLUSIONS AND DISCUSSION

In the light of the outcomes of the tables following conclusions can be underlined. Majority of the students assume that the principles of quantum physics based on the probability. Nevertheless they believe that today's living technology is fundamentally quantum physics dependent. They have the idea that quantum physics does not consist of just advanced mathematics but it also contains essential physical comments. The students seem to be well aware of the correspondence principle. In spite of being a complicated theory quantum principles can surprisingly be applied to analyse the classical behaviour of physical system. Therefore it seems to help us to obtain the following result that the quantum physics is the most fundamental theory defining behaviour of the physical universe [24].

The other important point student's underlined that the position of an electron is not clear and can not be determined exactly. The information of not being able to know position of an electron complies with the information of probability of finding a localized electron only in a certain area. Quantum theory only defines the probability of finding an electron at a certain point in space not its definitive position; this is known as Heisenberg Uncertainty Principle [25]. Most of the students have the information that square of wave function has physical meaning and it describes the probability of a particle existing in a certain position. The other important outcome of investigation is so called measurement problem that is the measurement in quantum mechanics makes change on the measured object and has some natural limitations. Heisenberg, as the requirement of quantum theory, starting from interference event with two splits, displayed that the measurements have limitations such as not being able to perform the measurement of position of electron on the screen and the interference observation (momentum) at the same time, and explained this with his famous uncertainty principle [24].

In reality electrons have either wavelike property or particle like property as a quantum mechanical object, whereas majority of the students agree with the idea that electron is a spherical particle in a cloud. Similarly, Masshadi and Woolnough [25], in their research about students' comprehension related to visualization of quantum objects, obtained that the majority of the students visualize the electron as a kind of particle and the sense of quantum objects' being “particle like” is more dominant. Interestingly enough students know the dual nature property of electron, they still continue to visualize electron as a small rigid ball. When the origin of this trend was traced back, it is concluded that both cases namely, the quantum and classical particles, were internalized as point objects [14].

The students believe that light does not always behave as wave, and being wave or particle depends on the experiment performed. This result is related to a general property of quantum physics, expressed as, the nature of a model to define a system depends on the nature of the instrument interacted [24].

Students assimilate the planetary system model of an atom and they agree with the idea that stability of an atom is resulted from the balance between repulsive and attractive electrical forces acted on the electron. Hence, they still tend to keep thinking classical physics to interpret quantum mechanical phenomenon. According to Fischler [26], the reason for this idea is that, most of the students' trying to explain the particle world by using macroscopic properties and the existence of planetary model of an atom in the introduction part of text books. The planetary model of the atoms, although students know that the electrons are not in orbital, is a thinking way strongly impressed in their minds and very difficult to change [16].

It is on the other hand obtained that the students are undetermined whether the wave function corresponds to a physical object or not. However, they seem to have the information evidences such that the wave function determines the state of motion of the physical object. The dimension of wave function in quantum physics varies with the physical case but never happens to be length dimension (L) like classical wave function in physics. The wave function in quantum physics is related to probability amplitude of a quantum object in a certain position, and also called as probability waves. In this case, when it is thought that the physical object is dependent to probabilistic laws, being its motion and interaction probabilistic, appears as the dynamic property of the physical object, though wave function can not be representing a physical object.

Under the light of these outcomes, one could suggest the following;

-Firstly especially upper secondary school curriculum should be revised in accordance with recent developments in science and technology to increase interaction between society and science and scientist.

-Secondly, the problems mentioned above may also be relating to the used textbooks and lecturers personal limits and misconceptions. Teaching methods, techniques and tools are inevitably important to reach specific goals. Creating an interactive classroom and using active learning techniques and interconnecting new concepts and principles with the environment and daily life experiences would surely reduce the amount of problems and would make an enjoyable and beneficial quantum physics classrooms.

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