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Teaching wave-particle duality using didactic materials to improve its conceptualization

Enseñanza de la dualidad onda–partícula empleando materiales didácticos para mejorar su conceptualización

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ABSTRACT

The purpose of this research is to study the impact of didactic materials capable of allowing students to approach the theoretical foundations for the conceptualization of abstract topics of Quantum Mechanics such as wave-particle duality. For the development of this research, a qualitative and applied methodology was used to collect data. The population consisted of 25 students of the 8th Semester of the Pedagogy of Experimental Sciences in Mathematics and Physics of the University of Guayaquil, who took a test to evaluate their knowledge about the Wave-Particle Duality topic, before and after using didactic materials in their teaching for their learning. They concluded that

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there was evidence of favorable changes at the moment of using didactic materials on the conceptualization of the wave-particle duality.

RESUMEN

La presente investigación tiene como propósito estudiar el impacto que tiene los materiales didácticos capaces de permitir a los estudiantes abordar los fundamentos teóricos para la conceptualización de temas abstractos de Mecánica Cuántica como lo es la dualidad onda partícula. Para el desarrollo de esta investigación se utilizó una metodología cualitativa y aplicada que permitió la recolección de datos. La población está conformada por 25 estudiantes del 8vo Semestre de la carrera de Pedagogía de las Ciencias Experimentales en Matemáticas y Física de la Universidad de Guayaquil, quienes realizaron una prueba para evaluar sus conocimientos sobre la temática Dualidad Onda – Partícula, antes y después de emplear materiales didácticos en su enseñanza para su aprendizaje. Concluyendo que se presencio evidencia de cambios favorables al momento de emplear materiales didácticos sobre la conceptualización de la dualidad onda – partícula.

Keywords / Palabras clave

Physics Teaching, Teaching Materials, Wave-Particle Duality, Quantum Mechanics

Enseñanza de Física, Materiales Didácticos, Dualidad Onda – Partícula, Mecánica Cuántica

Introduction

In 2017 Ecuador participated in the OECD's Program for International Student Assessment (PISA), in charge of internationally assessing the knowledge and skills of students in the areas of reading, mathematics and science. Obtaining worrying results, in which 43% of the students reached a minimum level of competencies in science, which covers the area of Physics. (Educativa, 2018). That is to say that 57% do not exceed the basic level of science creating a significant gap with the rest of the countries that participated in this test, demonstrating the low

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academic performance and educational deficiency that Ecuador presents.

The teaching of quantum mechanics faces several challenges; the fact that subatomic particles possess properties very different from those we experience on a human scale and those taught in classical mechanics creates many challenges in addressing these abstract topics with students. These concepts are counterintuitive and conflict with the classical worldview familiar to most students. A radical change in the student's thinking, and in the way these topics are taught, is needed for understanding. Students do not visualize the importance and application of Physics in the development and advancement of science and technology, as well as in their daily activities, which demotivates them and, therefore, reduces their interest in the learning process. They do not learn how to approach a real problem and any change, no matter how small, causes them difficulties. (Valenzuela, Villarreal, Lobo, & Terán, 2022)..

When thinking about the teaching-learning process, it is essential that we discuss the actions that make this relationship effective. Effective teaching cannot take place without functional didactic materials to enhance innovative production in modern fields such as science and technology, among others (Macanchi, Orozco, & Campoverde, 2020).. Physical phenomena can be vividly presented and correlations can be examined and analyzed. In addition, it is possible to simulate complicated content, simultaneously present different levels of abstraction, and help students gain a better understanding. These materials can be both physical and virtual, they assume as a condition, to awaken the interest of students, to adapt to the physical and psychological characteristics of the students, and to facilitate the teaching activity by serving as a guide; also, they have the great virtue of adapting to any type of content. With the help of these didactic tools, the relevant topic is sealed in the visual, auditory memory of students, which serve for the formation and development of skills, competencies, and abilities. (Khasanovna, 2021).. That is why in the teaching of Physics didactic materials are fundamental tools in the teaching-learning process, being an important and viable alternative in schools and universities of the public and private educational system.

According to Çaliskan (2009), cited in. (Pantoja, Moreira, & Hercovits, 2014). states that studies on how students approach conceptions about Quantum Physics are very scarce compared to

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research on how students reason in Classical Physics contents. This implies that there is also a lack of in-depth research on how to didactically approach these topics that become abstract when moving from classical mechanics with representations that can be observed and felt, to quantum mechanics.

Undoubtedly this is not a simple problem to address since the teaching of quantum mechanics not only requires the study of new phenomena and new methodologies, but also the development of alternative mental and conceptual models that better approach the behavior of nature in this context must be promoted. Thought must be given to the appropriate methods for these topics to be learned in a meaningful way and to the appropriate degrees at which they should be introduced within the curriculum so that the mental structures that Russell speaks of are still flexible (Arango, 2018). For all the above described, the purpose of this work is to improve the conceptualization of Physics undergraduate students through the use of didactic materials on the wave-particle duality topic.

Materials and Methods

A quantitative approach was used for the development of this research, through the collection of quantifiable data and the use of statistical and mathematical techniques to explain the results of the data collected.

The study population is composed of 25 students of the 8th semester of a university located in the city of Guayaquil. Two tests were designed and applied, one input and one output, composed of 10 multiple choice items related to the wave-particle duality theory, valued on a scale of 1 to 10, with 1 being the expression of minimum satisfaction and 10 the maximum. In the process, a four-stage action plan was developed, the first stage being the investigation of methods and didactic materials that favor students' understanding by capturing their attention through visual materials; followed by the entry test to assess the students' previous knowledge, then the didactic materials were presented through virtual classes and a series of didactic activities to be carried out during asynchronous hours. Finally, to measure the results of this research, an exit test was conducted, which together with the results of the entry test, a comparison was made to determine the results and the students' learning.

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Results

Pre-test analysis

To determine the knowledge that the students possessed, an entry test was taken, to know their bases and concepts about the Wave-Particle Duality, this test consisted of 10 questions of which 9 were theoretical and 1 was a practical exercise.

Table 1. Survey

N	Ask	Percentage of incorrect answers	Percentage of correct answers
1	According to quantum mechanics, what is the photon?	52%	48%
2	Can the equation proposed by De Broglie be applied to all matter?	52%	48%
3	If a proton and an electron have the same speed, which has the longer De Broglie wavelength?	64%	36%
4	If a proton and an electron have the same kinetic energy which has the longer de Broglie wavelength?	48%	52%
5	Three observations on the behavior of electrons are as follows I. The emission of electrons as a consequence of the photoelectric effect. II. The diffraction of an electron when it interacts with an atom. III. The emission of radio waves as a result of electron oscillations in a conductor. What observations prove that the electron behaves like a particle?	64%	36%

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6	According to quantum mechanics, is light a wave or a particle?	68%	32%
7	Calculate the wavelength associated with a golf ball of mass 50 g moving at a speed of 500 km/h.	36%	64%
8	An electron and a proton moving with non-relativistic velocity magnitudes have the same de Broglie wavelength. Which of the following characteristics are also the same for both particles? A. Speed B. Kinetic energy C. Amount of movement D. Frequency	84%	16%
9	Which of the following answers provides evidence for the wave nature of the electron? A. The continuous energy spectrum in decay. B. The existence of atomic energy levels C. The existence of nuclear energy levels D. Electron diffraction in crystals.	68%	32%
10	Three historical breakthroughs in physics were: I. Wave-particle duality II. The kinetic model III. The equivalence of mass and energy. Which of these constituted a paradigm shift in scientific thinking?	56%	44%

Source: Prepared by authors, 2023

From the analysis of the data presented in Table 1, it is observed that there are weaknesses in the conceptualization, the definitions that the students have are very vague and tend totally to the classical definitions, some of them even do not know certain topics related to classical mechanics, visualizing that the percentage of totally theoretical questions answered correctly is below the average. However, the practical question was the one that had the most correct results, assuming that there are good mathematical foundations that facilitate that more than 50% of the students answer this question.

Post-test analysis

To evaluate if positive results were obtained with the use of didactic materials, an exit test was conducted, with the same structure as the entrance test, following the same tendency of the entrance test, without being similar.

Table 2. *Questions*

N	Ask	Percentage of incorrect answers	Percentage of correct answers
1	When does light behave as a particle? a. When absorbed, but not when emitted b. When emitted, but not when absorbed c. When absorbed or emitted d. d. Never, light always behaves as an electromagnetic wave.	28%	72%
2	In an attempt to reconcile the wave and corpuscular models of light, some people have suggested that the proton rises and falls on the crests and valleys of the electromagnetic wave. Why is this assumption wrong?	32%	68%

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3	Three phenomena associated with quantum physics are: I. Einstein's photoelectric effect II. De Broglie's hypothesis III. Rutherford alpha particle scattering. Which of the phenomena can be verified by firing electrons at a metal surface?	28%	72%
4	Three phenomena that can be explained as particle I. Photoelectric effect II. Bohr orbitals III. Compton effect IV. Electron diffraction V. Black body	16%	84%
5	A light is projected through two narrow slits. Suppose the intensity is reduced to the point where only a few photons per second pass through the slit. If one of the slits is covered, the individual photons would accumulate on the screen over time creating a pattern of _____.	20%	80%
6	According to quantum physics, electrons behave as waves or particles.	12%	88%
7	Matter has a wave nature, why is this wave characteristic not observable in everyday experience?	8%	92%
8	18. Determine the velocity of a neutron (m= 1.675X10-27 kg) having a De Broglie wavelength =0.200 nm, approximately the distance between atoms in many crystals.	12%	88%

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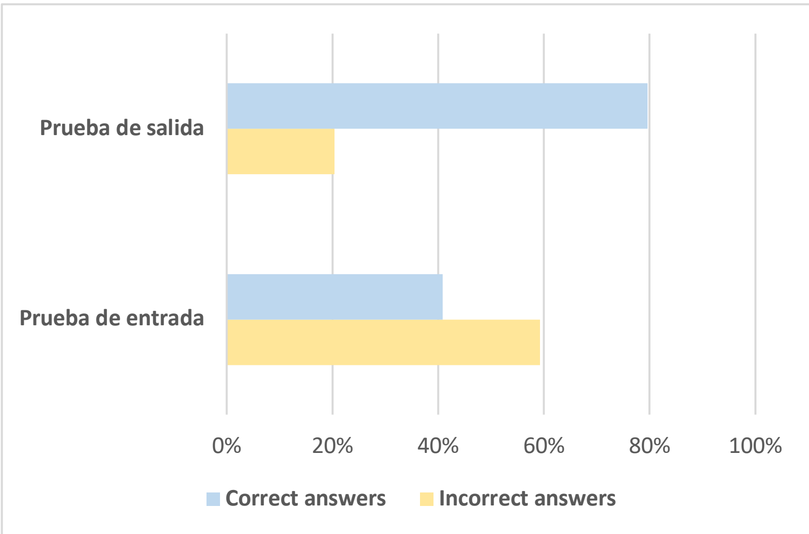
9	Consider a) an electron, b) a photon and c) a proton, all moving in a vacuum. Which one carries the amount of motion?	24%	76%
10	Can the equation E=hf be applied to any particle at rest?	24%	76%

Source: Prepared by authors, 2023

It can be observed that in the exit test there is a greater tendency to choose correct answers. A greater clarity and understanding is presented in the definitions and properties of light, matter and waves. With an average of correct answers higher than the average, we can assume that the students present a greater assimilation of the abstract topics.

Comparative analysis between the results of the input test and the output test

Graph 1. Comparison of responses.



Graph 1 shows the comparison of the results of the tests given to the students, showing a significant difference at the time of executing the research proposal. A divergence of almost twice as much is observed in terms of obtaining correct answers between the input and output test, being a favorable result for the output test. The errors in the

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understanding of the definitions decrease, thus reducing the choice of incorrect answers, since the students have a better understanding of the definitions of waves and particles.

Conclusions

This research project aims to establish a pedagogical reflection on the possibility of teaching quantum mechanics using didactic materials to generate meaningful learning, which will contribute to the cognitive development of students. The results of this teaching proposal can be a modest starting point to begin to promote a reflection on the guidelines and curricular standards of science, to propose a methodological strategy through the use of didactic resources that serve as input to support the teaching of the characteristics of the quantum world as opposed to those of the classical world, promoting tools to transform some practices within the school through critical reflection of the processes of knowledge construction associated with quantum mechanics.

It can be concluded that by means of the entrance test it was visualized that students show a classical vision of the basic concepts of quantum mechanics such as protons, electrons and photons, not establishing a dual particle or wave relation, presenting conceptual errors that derive in difficulties to advance with the topics. As far as the use of didactic resources for the teaching of these topics is concerned, a great positive impact on the acquisition of definitions and their comprehension was visualized, which was proved with the results of the exit test, being totally favorable results.

The major learning difficulties are linked to the theoretical incompatibility of classical mechanics with quantum mechanics. The problem is to abandon the deeply rooted (classical) idea and move to an abstract definition. Some students also have many problems with their prior knowledge, much of which is confused and poorly structured, vague or poor.

Quantum ideas are juxtaposed to classical ones. It is not that there has been a conceptual shift, but an alternative use of different theoretical schemes. Students need to have the theoretical foundations well rooted in order to understand quantum, only it must be disengaged that these definitions are inflexible. The problem is the way in which the theory is presented, the methodology used to reach the student;

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this means that a greater effort must be made to present a class that generates significant learning, which requires the use of materials that favor understanding. Thus corroborates (Arango, 2018) due to the differences between the conceptual nature of quantum mechanics and classical physics, research is needed on the misconceptions of students, on the correction of mental models, the teaching strategies implemented, the educational materials used.

Our proposal is not only the implementation of didactic materials in the teaching of particle-wave duality or quantum mechanics, but also to respond to a problem that has always involved the learning of physics, the understanding of all its natural spectrum. This research also aims to verify the effectiveness of didactic resources in the teaching-learning process of physics, from classical theory to quantum theory. Generating a feasible tool for teachers at both secondary and university level, encouraging the use of more resources in the classroom to generate greater learning.

With the results obtained in this research it is concluded that it is necessary for teachers to look for new didactic tools to obtain better results in education; didactic materials are a feasible and essential way that should be used in our classes.

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