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Quantum mechanics at high school: An online laboratory on wave-particle duality

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Summary. — The interest in studying quantum mechanics is always increasing in our society and schools. Especially in the latter case, this leads researchers to implement suitable actions to meet social needs of knowledge of quantum physics. We present an online laboratory on wave-particle duality for high school students (17–19 years old). The activity was carried out in the period December 2021–May 2022 at the Physics Department of the University of Cagliari, and more than 100 students from different high schools in Sardinia were involved. We will show the design of the activity and the experiments performed. We will show and qualitatively discuss results about a satisfaction questionnaire. A brief discussion about motivational issues will be presented.

1. – Introduction

Quantum mechanics is around us, and the interest in studying this subject is increasing in our society. For example, topics related to quantum physics are now part of high schools' programs. Newspapers, TV shows and science communication profiles on social media often talk about quantum technologies around us. Learning and being informed about quantum mechanics and its application in our research as well as in our everyday life is important for cultural reasons and to become citizens aware [1]. From this point of view, researchers play an important role in society, as they have to implement suitable actions to meet social needs of knowledge of quantum physics.

Starting from schools, many strategies can be used to face with the quantum world, focusing on technological aspects [2, 3] or on historical and informal ones [4]. The educational content of these approaches can focus on different subjects, from conceptual and linguistic aspects [5,6], where both natural and mathematical language is used as an instrument to introduce the peculiar features of the quantum world [7]. Another possibility can be focusing on one of the main conceptual issues of quantum mechanics, that is the wave-particle duality, and developing suitable learning strategies to highlight the manifestation of the dual nature of matter and light.

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In this paper, we present a laboratory on wave-particle duality for high school students (17–19 years old). The experimental activities were carried out in the period December 2021–May 2022 at the Physics Department of the University of Cagliari. More than one hundred students from different high schools in Sardinia were involved, whose participation was online due to the pandemic. The main aim is to show the design of the activity and the experiments performed. Inspired by previous research on this field [1], we also wrote a research questionnaire to understand how the online laboratory affected students' motivation and interest in physics, their vision of the scientific method and the influence of the laboratory on their understanding of physics and the concepts studied at school. A detailed analysis will appear in a forthcoming paper. Research methodology and a qualitative analysis of data are presented.

2. – Methods

The main topic of the laboratory was wave-particle duality. We focus on waves (mechanical and electromagnetic) and their properties, as well as on particular macroscopic properties and phenomenology of matter (such as scattering). Four different experiments dealing with the undulatory and particle properties of matter were shown and discussed.

The first experiment dealt with mechanical waves propagating in a fluid. In this case, researchers focused on diffraction as a key phenomenon to introduce the dual behavior of matter according to the experimental set-up and conditions. The second experiment was a flipper-like apparatus, with marbles hitting a screen passing through a slit. This was to explain and show the particle behavior of matter, that is that massive particles and, in general, macroscopic objects (with a length of the order of centimeters or more) do not diffract. Also in this case, researchers focused on the phenomenon of elastic scattering and the relationship between the dimension of marbles and the slit. The third experiment concerned the diffraction of light. A red light emitted by a laser (with a wavelength of about 650 nm) passed through some lenses and a slit to be coherently collimated in a beam. The slit can be opened or closed until its size becomes comparable with the laser wavelength. Then, diffraction occurs. Finally, in the fourth experiment, researchers showed electron diffraction through a suitable experimental set-up (the electron diffraction system built by Phywe). In this case, the diffraction manifests with rings on a fluorescent screen. This experiment shows that, under suitable conditions, that is an electron passing through a slit (graphite planes) of dimensions comparable with its wavelength, even what is typically thought as a particle manifests an undulatory phenomenology. Also to show that in this process the electron does not loose its charge, we used a magnet to move the diffraction figure along the whole screen.

The methodological structure of the laboratory was as follows. Firstly, an introductory game was proposed using the "Quizziz" platform to qualitatively measure students' expectations about phenomena showed during the activity made. Questions had no evaluation intent, rather they just measured their feeling or previous knowledge (especially for students attending the last years in high school) on the subject. This activity lasted ten minutes. After that, the experimental activities started (duration: 40 minutes). The laboratory ended with a general recap on the physics concepts dealt with and the results of the introductory game was discussed in the light of the phenomena observed. We left a detailed discussion on the pedagogical approach to a future paper, where further details will be given.

The total duration of the activity was about one hour. Contents where targeted: the younger the participants, the less technicalities and details were inserted in the discussion.

Despite the online environment, a certain level of interaction with the class through the mediation of the teacher was guaranteed.

Participants to the synchronous online session were 104 high-school students attending the last three years of Lyceums in Sardinia (in the metropolitan area of Cagliari, 1 "humanities" and 5 "scientific"). The total number of participants was obtained by summing the in-class counting made by teachers once the synchronous session started. Teachers and students attended the online laboratory from their classrooms and a Zoom connection was established, with cameras filming the researchers and the experiments connected to a laptop with a Raspberry system. Every class attended the laboratory separately, thus the total number of meetings was 6.

We wrote a satisfaction questionnaire to investigate students' feedback on their experience with the online laboratory (2 items); on the influence of the laboratory on their understanding of physics and the concepts studied at school (2 items); on their vision of science and of the scientific method (3 items); on the interaction with researchers (2 items). Students could answer by using a 5-point Likert scale, from 1 (completely disagree) to 5 (completely agree). For each class, data were collected from 15 days to one month after the end of the synchronous meeting. The questionnaire was written in Italian and imported in Microsoft Forms. The teacher distributed it as a link via email to students. Students' participation was voluntary, with no positive or negative inducements. The questionnaire was anonymous, no information on gender or class was obtained. The number of answers collected was 104.

In the following, we just show and discuss the qualitative results related to students' satisfaction on the 4 domains cited above.

3. – Results

Concerning students' feedback on their experience with the online laboratory, most of them (78.8%) affirmed that the topics of the lab were interesting. A half of them (51.1%) thought the lab fostered their curiosity on the topics of the lab, whereas one third of the sample (30.8%) remained neutral on this item. Concerning the influence of the laboratory on their understanding of physics and the concepts studied at school, 46.2% of students affirmed that thanks to the lab, they could explore the physics phenomena they were studying at school. 29.8% of the sample was neutral. The capacity of the lab to engage students in studying physics was rated as good by 66.3% of the students.

Concerning their vision of science and of the scientific method, 68.2% of the students affirmed that the lab helped them in understanding the importance of taking, analyzing, collecting, and interpreting data. Most of them (67.3%) affirmed that the lab helped them in understanding how to carry a scientific research on. The same happened when we asked students if the lab allowed them to think about and explain the observed phenomena: in this case, 57.5% of students agreed with this item. Concerning the interaction with researchers, the majority of them (78.8%) affirmed that the interactions with researchers were useful. Finally, the item: "attending the remote lab with the researcher helps me in understanding the experiment" was positively rated by the 65.3% of the sample.

4. – Discussion and conclusions

The qualitative results on students' interest and curiosity towards physics, as well as on their motivation in participating to the online activity are encouraging. Moreover, students appreciated to interact with researchers even in an online environment. Most of them also affirmed that the interaction with researchers was also helpful in understanding the physics behind the experiments. This result suggests that interaction is a key point in learning and in outreaching activities, too. Another interesting result is that students affirmed that our initiative helps them understand the scientific method. The laboratory seemed to have a certain influence also on students' understanding of physics concepts studied at school.

Some criticalities emerged: teacher-mediated interaction between researchers and students did not encourage a constant and active participation of the latter to the lecture. Students appeared to be scared by a possible judgement of their teacher if they were wrong in talking with researchers. This is a crucial point to be faced up in order to find strategies to implement online learning of physics in school in curricular timetable. A possible solution could consists in including teachers in the design of the activity, thus making them co-authors of the project. In this sense, if they already know what researchers will show, then, they can explain concepts to their class during synchronous activities, *e.g.*, when the internet connection arises or when they think this is needed.

For the future, we hope to increase the sample to improve statistics and to understand the efficacy of our methodology, possibly introducing a quantitative measure of students' learning of concepts proposed in the laboratory with a pre- and post-questionnaire. We are also planning to implement the laboratory in a proper education and learning platform allowing us to study all the steps of the participants' online learning. This platform will allow us to follow the students also in the asynchronous phase, when they re-elaborate the supplementary and learning material uploaded on the platform and focus on the content of the laboratory. All these activities are left for a future study.

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