The historical transition from the Young's double-slit experiment to the Davisson-Germer experiment, as taught to undergraduate educators. The educational outcomes and implications.

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Abstract: In the present work a teaching method is presented, concerning the way that a sample of undergraduate students is instructed about two basic experiments in the history of Physics: The Young's double slit (interference) experiment and the Davisson - Germer experiment, which essentially proved that particles (electrons) do behave like waves(de Broglie hypothesis). The research question behind this research project is whether it is possible to teach students about the very important aspects of wave interference and wave properties of matter (Vokos et al., 2000) , by avoiding mathematical formalism and difficult Physics' concepts as much as possible. There have been similar efforts in the past, in the area of educational research (Baily and Filkenstein, 2010; Krijtenburg-Lewerissa et al., 2017), but these efforts usually refer to students with a good physics and Mathematics' background. The novelty here is that future educators - with weaknesses in Physics and with not an interest in Physics taken for granted - are addressed.

The students watch both the experiments in front of them; they have some level of interaction with what is happening and are interviewed, in semi-structured research interviews about: (i) what they predict that will happen, (ii) what they see happening and (iii) what they learned about it (meta-knowledge).

The first experiment is executed both in its original form with water waves with laser-light, but also in the alternative form with laser light. The second experiment is executed through computer simulations (https://phet.colorado.edu and others) (McKagan et al,. 2008) and animations.

Prior to the interviews with the N=6 students, N´ = 2 were interviewed on a pilot basis, in order to improve the interviews. Also the N=6 students were given a pre-test and a post-test questionnaire, so as to measure what they learned from this teaching and experimental sequence.
The results concerning the educational outcomes – given the limitations o the sample – are encouraging.

Keywords: Young experiment, Davisson-Germer experiment, interference, history of Physics, teaching, history of Physics.

1. Introduction

A very common methodology in teaching basic concepts of Physics, is teaching the historical evolution of it, especially through the presentation and discussion of historical experiments. Within this framework, situated knowledge about Physics priciples and discoveries is achieved, and – at the same time – it becomes possible to avoid tiring the learners with formulas and laws.
This is the main idea behind this paper and the research accompanying it. As in introductory step in order to teach wave-particle duality to prospective Primary School teachers, a method was chosen to teach two basic experiments of the history of Physics, avoiding heavy mathematical formalism and – then – research on the educational and learning outcomes. The two experimentrs chosen were Young's interference experiment and Davisson – Germer electron diffraction experiment.

Fig. 1. Left: Thomas Young (1773-1829). Right: Clinton Davisson (1881-1958) and Lester Germer (1896-1971)

2. The aims and scope of the research.

The central research question of this work was:

Is it possible to teach students about wave interference and about wave properties of matter (Vokos et al., 2000), avoiding mathematical formalism and difficult Physics' concepts as much as possible ?

A secondary research question was: *What is a way to do this?*

Similar efforts regarding these research questions have taken place in the past, in educational research (Baily and Filkenstein, 2010; Krijtenburg-Lewerissa et al., 2017), but these efforts refer to students with a strong Physics and Mathematics' background.

One novelty here is that future educators – with weaknesses in Physics and with not an *interest* in Physics taken for granted – are addressed.

Another novelty is considered to be: the software application used for teaching Davisson-Germer experiment (based on Phet- Colorado but simpler), created by Gkiolmas and Chatzichristos.

3. The sample and the methodology

The sample of the research consisted of N = 6 undergraduate students of the Department of Primary Education (5 female, 1 male).

Before them N΄ = 2 (female) students were used as a small pilot sample, in order to check and correct things in the interviews.

The first of the authors conducted ***semi-structured*** interviews (Drever, 1995) with each-one of the N students, each lasting about 50 minutes (masks and distance were necessary, due to Covid-19!).

Apart from recording, they were also delivered worksheets, to write or draw things on them. Each student – during the interview and the filling of the worksheet – could interact both with: a. the experimental setups (being set in front of her/him) in the case of Young's double –slit experiment. b. With the computer simulations (Phet-Colorado and the other one) in the case of the Davisson-Germer – simulated – experiment.

The interview process was mainly based in ***POE (Predict-Observe-Explain) techniques,*** and, in both the two historical experiments, the aim was triple:

(i) to investigate what the students ***predict*** that will happen and ***why*** they make these predictions**,**

(ii) to prompt them to ***describe*** what they ***see happening*** and explain this as much as possible and

(iii) to ***express in their own words,*** what they think that they learned – and how they learned it – about the phenomena, after interacting with the experiments (meta-knowledge).

It has to be noted that: The first experiment, Young's double slit interference, was executed ***both*** in its original form with light (based on small lasers), but also in the alternative form with water waves, through a "ripple tank" experimental arrangement.

The latter, shown in Figure 2, has been provided to our Department by the Polytechnic School of Athens and we thank them from here, too (Professor Emeritus Roza Zanni-Vlastou). In Figure 3, the typical laser arrangements used for the interference experiments are depicted.

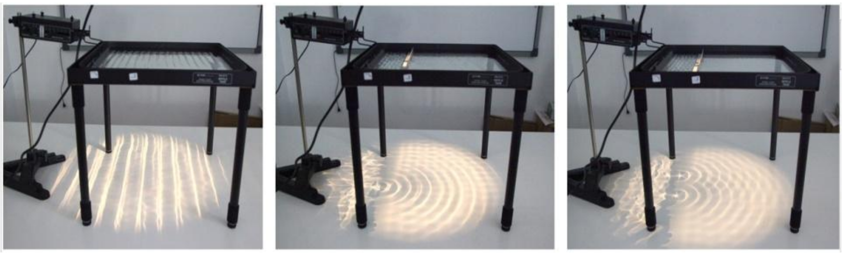

Fig. 2. The ripple tank device with water on top (on glass), being used to ask students some things about plane waves and wave interference (Photo courtesy: Panagiotis Lazos)

Fig. 3. Types of Laser arrangements, used for the Young’s double-slit experiment (we had various laser colors).

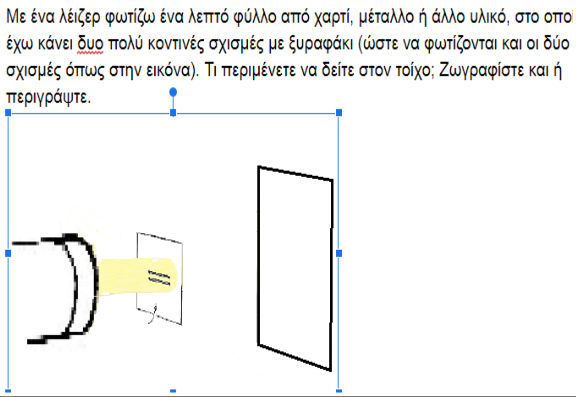

Fig. 4. An example of question provided to the student on the worksheet, asking him/her to write what will happen when light is incident on the double-slit.

In Figure 4, an example of the questions asked on the worksheet delivered to the sample of the students is presented. And in Figure 5, we are showing a screenshot of the phet.colorado simulation, where the students are taught – by interacting with it in the computer – things about the Davisson – Germer Experiment.

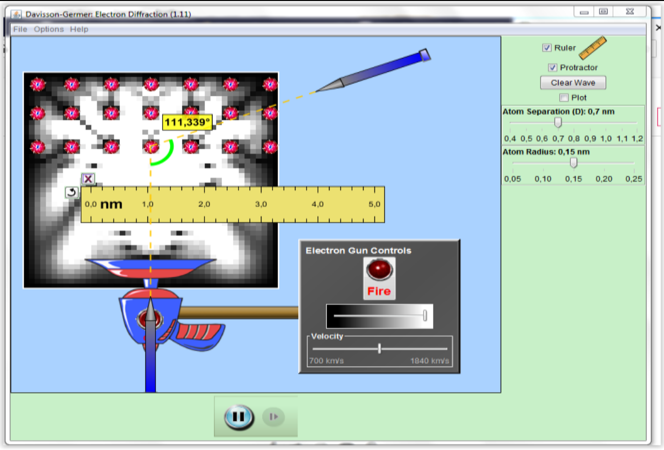

Fig. 5. A screenshot of Phet Colorado's educational simulation of the Davisson-Germer experiment, used in the interviews. The version used was in the Greek language.

4. Results and Discussion

Content analysis of the interviews and the completed worksheets of the (N=6) students was performed.

Certain questions in the interviews were characterised as Key-Questions (denoted KQ). In order to help present the results through bar-charts (which are easier to watch), the following chromatic code was agreed upon:

1. "Green": "Scientifically correct" answers and explanations.
2. "Yellow": Answers partly "correct", containing some correct aspects.
3. "Blue: "Scientifically wrong" answers.
4. "Black": Unable to answer it / did not answer at all.

In the following bar charts (Figure 6 to Figure 10) the research results from the answers to 5 key-questions are summarized.

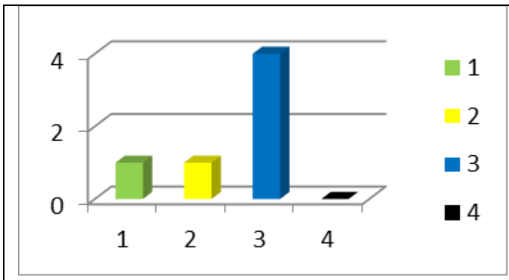

Fig. 6. **(Concerning KQ1:)** What do you expect to see at the screen behind, when light from the laser is incident to the two-slit formation?

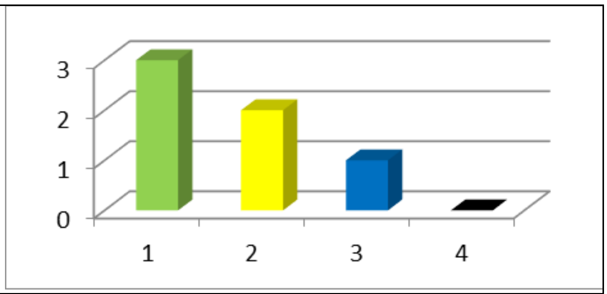

Fig. 7. **(Concerning KQ2:)** Comparing with the water waves that you saw, what can you say about light?

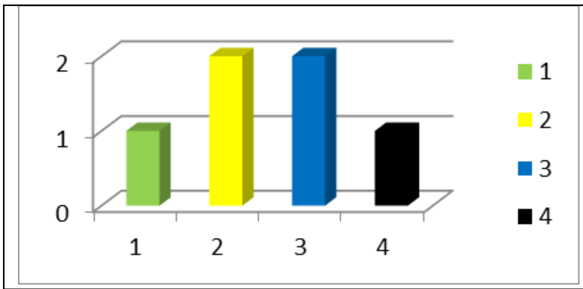

Fig. 8. (Concerning KQ3:) What do the dark areas and what do the lighted areas correspond to? How is this explained?

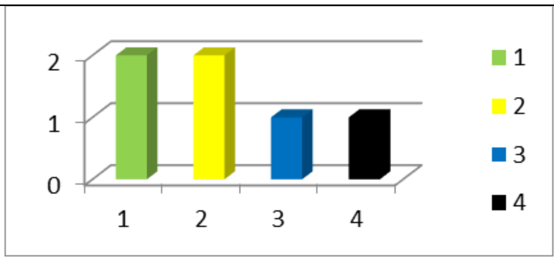

Fig. 9. (Concerning KQ4:) How would you describe the behavior of the electrons in the Davisson-Germer (simulated) experiment? Compare with what you saw previously with waves.

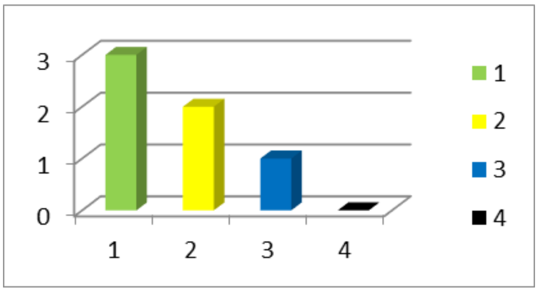

Fig. 10. (Concerning KQ5:) Based on your descriptions before, do you reach a conclusion about electrons? Feel free to explain.

5. Conclusions

This is part of a broader research, aiming to teach the dualism of matter (wave-particle). Obviously, we should never forget the limitations of this research which are: the very small sample, the fact that the sample consisted mainly of volunteers, restrictions in the interaction due to covid-19 measures etc.

There are also some other subtle things to point out about educational research such as the notion of “bias”, of “guidance” and of the sample members’ “ways of interpreting”.

However: the results in KQ2 seem to indicate that they deduce the wave nature of light Similarly, from KQ5 it could be assumed that they can – in some way – reach to the wave nature of electrons..

This is an ongoing large research and future studies are coming.

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