“The Elegance of Quantum Mechanics”: a didactic path for high school

Ester MELLI, Luisa LOVISETTI, Marco GILIBERTI

Physics Department, University of Milan, via Celoria 16, 20133, Milan, Italy.

Abstract. This paper describes the work of design, testing and evaluation of the effectiveness of a pilot Teaching-Learning Sequence on quantum mechanics presented to high school students and teachers. The experimentation consisted of 10 Zoom meetings, between October 2021 and January 2022. At the end of the first nine meetings, each student was given a form aimed at bringing out the reasoning used, and the level of understanding achieved. At the end of the course a satisfaction survey was also given. The effectiveness of the activity was assessed by means of all homework and interviews with 13 students and 6 teachers.

1. Introduction: the state of the art and open problems

Quantum Mechanics has been the focus of physics education research since the 90s. After an initial phase, characterized by a wide debate among those who believed it was too complex to be significantly presented at school, nowadays researchers no longer express doubts on the fact that it is fundamental for the culture and the awareness of the individual citizen and of the whole society [1-2]. The Quantum Technologies Flagship initiative, organized at a European level, also pushes in this direction, by financing projects that aim to give life to the second quantum revolution.

From surveys on teacher training [3-6], it emerged that most teachers - mainly with a degree in mathematics - often do not have a coherent framework of modern physics in general, and of quantum physics in particular. Furthermore, the didactic path presented on textbooks is limited to a pseudo-historical presentation, which provides a hyper-simplified explanation of the fundamental concepts, in an attempt to bypass the problems associated with students’ lack of adequate mathematical tools. One of the main results is that such an approach - which we can call "traditional" - is the cause of deep misconceptions [7], mainly due to the use of two different methodologies throughout the entire educational process.

To fulfill this purpose, the entire international scene, since 2005, has implemented profound reforms within the school system. In high schools the teaching of modern physics in general, and of quantum physics in particular, has therefore become one of the most actual - and at the same time debated - didactic topics. Recently, the European Union has invested heavily in the creation of the "Quantum Technologies Flagship" (QFlag), with the aim of increasing and disseminating the knowledge and development of quantum technologies. Various proposals (Feynman paths, Dirac "spin first" approach, wave mechanics, field theory, etc ...) have been put forward by various working groups, both in Italy and around the world [5-6,8-11], but the discussion on which is the most appropriate approach to follow is still open.

2. Our course: “The Elegance of Quantum Mechanics”

The course “The elegance of quantum mechanics” was organized in AY 2021/22, within the Scientific Degree Plan (SDP) of the University of Milan. The project was born as the development and the implementation for students of an educational course proposed to teachers in AY 2019/20.

The activity was offered to teachers and students of the last three years of high school (120 participants overall), from October 2021 to January 2022, through weekly appointments of one and a half hour each. The course was done online, integrating lessons with slides, questions with Kahoot! and graphic examples created with GeoGebra (https://www.geogebra.org/m/aqf2dgn3).

At the end of each of the first nine lessons, students received a Google form (https://forms.gle/Nr2umPc53FCCi3KZ9) with questions and exercises related to the topics covered, to be carried out before the start of the next meeting. The materials are available on the SDP page (https://pls.fisica.unimi.it/materiali/).

3. Evaluation and discussion

Course effectiveness was assessed by collecting and analysing different types of data deriving from an anonymous satisfaction survey, 9 Google Forms (with a total of 38 open questions and 24 exercises) and 19 individual interviews (with 13 students and 6 teachers), aimed at investigating strengths and criticalities. This analysis allowed us to identify the reasoning that students commonly use in facing some conceptual issues of quantum mechanics. Will be discussed:

- strengths of the activity: both students and teachers enjoyed the mathematical aspects; they like Kahoot!; the use of GGB was really appreciated; Kahoot!; therefore, these aspects and tools will be upgraded and improved;
- criticalities: students faced some difficulties is dealing with spaces with more than 3 dimensions; the concept self-adjoint operator was difficult to understand; there was often confusion between states and operators;
- work in progress: in surveys and interviews was also pointed out that the lack of course lecture notes was a crucial aspect; those materials are thus currently in the writing phase.

A new course, implemented with the aspects said above, is expected to start in October 2022.

References

[1] E.F. Redish, Who needs to learn physics in the 21st century and why?, *Plenary lecture, GIREP Conference Physics Teacher Education beyond 2000* (2000).

[2] U. Besson, *Didattica della fisica*, Carocci Ed., Rome, 2017.

[3] E.F. Redish., The influence of student understanding of classical physics when learning quantum mechanics, *Research on the Teaching and Learning of Quantum Sciences, NARST Annual Meeting* (1999).

[4] A. Stefanel, (2008) Impostazioni e percorsi per l'insegnamento della meccanica quantistica nella scuola secondaria, *Giorn. Fis.* **49** (2008), 15-53.

[5] G. Fera, S.R.C.P. Challapalli, M. Michelini, L. Santi, A. Stefanel, S. Vercellati, *Formare gli insegnanti all'innovazione didattica e all'orientamento*, Connessi! Scenari di Innovazione nella Formazione e nella Comunicazione (2011) 411-420.

[6] K. Krijtenburg-Lewerissa, H.J. Pol, A. Brinkman, W.R. Van Joolingen, Insights into teaching quantum mechanics in secondary and lower undergraduate education, *Phys. Rev.* **13** (2017).

[7] VV.AA., *Amer. Journ. of Phys.* **70** (2002) 199-367.

[8] R.O. Battaglia, L. Cazzaniga, F. Corni, A. De Ambrosis, C. Fazio, M. Giliberti, O. Levrini, M. Michelini, A. Mossenta, L. Santi, R.M. Sperandeo, A. Stefanel (2011) Master IDIFO: a community of Italian physics education researchers for a community of teachers on modern physics, *Selected papers in GIREP-EPEC & PHEC Book* (2011) 97-136.

[9] D. Zollmann, Research on Teaching and Learning Quantum Mechanics, *Papers presented at the Annual meetings NARST* (1999).

[10] K. Becu-Robinault, H. Chabot, F. Ferlin, J.-L. Heraud, P. Lautesse, P. Lo Bello, A. Vila Valls, Enseigner la physique quantique en Terminale scientifique en France. L'objet quantique, une référence problématique, *Huitièmes journées scientifiques de l'ARDIST* (2014).

[11] J. Castrillòn, O. Freire, B. Rodriguez, Fundamental quantum mechanics, a didactic proposal, *Rev. Ens. Fıs.* **36** (2014) 1-12.