Cultural understanding of quantum physics through a historical and pedagogical reconstruction of Old Quantum Theory and early Quantum Mechanics

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Abstract. In a society where technological applications risk overshadowing the true essence of physics, understanding historical and epistemological aspects becomes crucial for a meaningful and cultural introduction to quantum physics (QP). In this sense, we believe that exclusively presenting Quantum Mechanics (QM) when introducing QP (especially at high school) may prove insufficient, and we emphasize the importance of dealing also with the Old Quantum Theory, as it provides insights into the cultural relevance of QM, facilitates a deeper reflection on the Nature of Science, and aids also in understanding the physics-related QM problems. In this presentation we will discuss these aspects.

Historical aspects for a meaningful introduction of quantum physics

Most Physics Education Research (PER) groups consider that, for an effective introduction to quantum physics (QP) (at both school and university levels), starting with historical questions and aspects is not an appropriate choice and they believe that an approach that directly addresses the physical aspects is preferable as it is more effective [1]. On the contrary, in our PER group of the University of Milan, we believe that the historical and epistemological reasons underlying a profound conceptual shift – such as that brought about by Quantum Mechanics (QM) – should be highlighted [2]. We believe that such a reconstruction should be done not only for QM but for all topics, as it not only provides cultural significance to QM (and, more generally, to physics) in itself but also to facilitate a deeper reflection on the Nature of Science (NOS) [3]. In fact, the NOS refers to the understanding of the fundamental characteristics, principles, and processes that define and shape scientific knowledge and its development. Understanding the NOS is crucial for both scientists and the general public, as it promotes a more informed engagement with scientific information, fostering critical thinking and a deeper appreciation for the dynamic and evolving nature of scientific knowledge.

In this regard, we believe that there is a need and urgency to reconstruct the crucial role of physics as a cultural promoter of scientific knowledge in society. This need is clearly expressed also in the GIREP thematic group "Cultural Understanding of Physics" [4]. Notably, a cultural understanding of QM demands even more considerable and immediate effort. This urgency arises from a society increasingly reliant on scientific knowledge and quantum technologies, where the application of physical knowledge risks overshadowing the true essence of physics. Therefore, we believe that, for a cultural understanding of QP, discussing only QM may not be sufficient, and it should be complemented by a suitable presentation of the Old Quantum Theory (OQT) to provide a gradual, reasoned, and culturally meaningful introduction to the quantum aspects.

OQT, or not OQT, that is the (research) question

It is quite clear that a presentation of the OQT allows for a cultural understanding of QP in a broader sense. Specifically, through the reading of original texts, it highlights the intricate and lengthy path that led to the birth of QM. This process reveals how scientific knowledge is rooted in empirical evidence obtained through observation and experimentation (with empirical evidence serving as the foundation for scientific theories and explanations), how scientific inquiry is an

ongoing and dynamic process (with science characterized by its open-ended and self-correcting nature), and how scientific knowledge is influenced by social, cultural, and historical contexts. It is equally clear that these aspects also facilitate a deeper reflection on the NOS. Furthermore, not only does the OQT constitute a common starting point, being present internationally in various high school physics curricula [5], but an approach to QP that also incorporates the OQT could potentially lead to a better and more profound understanding of QM from a physical perspective.

The following research questions thus arise: 1) Is it true, then, that the OQT aids in understanding the physics related to QM problems? 2) In the case of an affirmative answer, in what aspects can it be particularly effective? In our view, the answer is affirmative, and to illustrate this point, in this presentation we will focus on two specific aspects: a) Why are the expressions of QM (such as energy and angular momentum) essentially the same as those found in classical mechanics? b) Why is QM a theory with complex values? In fact, as to us, the answers to both questions emerge in a natural way from the OQT.

Quantum physics for inquiring minds: an accurate historical and pedagogical reconstruction for enhancing a cultural and meaningful understanding

Starting from our research questions and from the analysis of the literature, to address these issues, in AYs 2022/23 and 2023/24 the PER group of the University of Milan has organised two editions of the educational laboratory "Old (but Gold) Quantum Theory" and the course "Principles and Equations of Physics III: Quantum Mechanics" with 210 high school students and 93 teachers overall. The primary objective was to deliberate on the significant cultural impact arising from the gradual birth of the OQT and the early development of QM through a multidisciplinary lens. The aim was to contribute to the establishment of a groundwork for fostering critical thinking skills as well as providing a cultural and reasoned perspective on QP [6], highlighting also the crucial disciplinary and learning knots. The same aspects were also discussed at a university level, with 59 students of master's degrees in physics and mathematics, during the courses of Preparation of Educational Experiences 1 and 2.

The foundation for all these activities is grounded in a wide and accurate historical and pedagogical reconstruction of OQT and early QM, based on a thorough analysis of primary sources, encompassing over 700 primary sources (papers, books, letters…). The historical account was enriched with pedagogical explanatory comments and notes tailored for "inquiring minds", at a university level (mainly, physics students and QP researchers). The inclusion of didactic considerations in the historical narrative served to illuminate prevalent conceptual misconceptions, offering a comprehensive cultural context that facilitated the contextualization and comprehension of the physics discussed. This approach aims not only to deepen understanding but also to captivate natural curiosity and the quest for comprehension regarding quantum issues. Moreover, it provides a tangible insight into the cultural significance of the quantum revolution.

References

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