An approach to the Second Quantum Revolution: the case of the random walk algorithm

Sara Satanassi (1), Elisa Ercolessi (1), Olivia Levrini (1)

(1) Department of Physics and Astronomy, University of Bologna, via Irnerio 46, 40126, Bologna Italy

Abstract. The teaching of quantum technologies has now become a leading topic and is at the heart of numerous international programs.
In the contribution, we present an approach for teaching the second quantum revolution to secondary school students that Bologna's research group in physics education has developed in recent years. The approach and activity that we are going to present contribute to shed light on the potential that quantum computation and its interdisciplinary nature have both to introduce some quantum physics basic concepts and to reflect on the differences between the classical and quantum rational structures.

Introduction

The Second Quantum Revolution and the development of quantum technologies are now at the center of many national and international programs such as in Europe within the European Quantum Flagship initiative, in UK within the Unite Kingdom National Quantum Information Programme, in the US within the National Quantum Initiative.

Many programs have the pivotal objective to expand the number of students, educators, researchers, and practitioners, training and increasing the quantum workforce [1]. For this purpose, different programs have been already run both for a higher education level (with the institution of new master's courses, the organization of winter/summer schools, etc.) and for secondary school education level (through extra-curricular and curricular courses). Furthermore, pursuing the aim of innovating quantum mechanics teaching at school, some training courses for pre- and in-service teachers have been organized. Thus, a challenge that researchers and instructors are now addressing is the production of "educational modules for a variety of learners in the areas that traditionally do not get in touch with quantum physics (e.g., engineering, computer science, mathematics)" [2].

The research questions

The acceleration and the impact of the Second Quantum Revolution are very palpable today and we can run into those effects that some sociologists from the '80s and '90s have identified as due to the society of acceleration, such as a sense of loss and uncertainty [3]. In order to equip students with lenses to grasp the scope of the Second Quantum Revolution, the group in Physics Education of the University of Bologna, which has a quite long tradition in the research in teaching al learning quantum physics [4], tried to reconceptualize it as, first of all, a cultural revolution. The research questions that guided us are:

a) Which teaching approach and educational modules can be designed to value the potential of quantum technologies that can extend beyond technical training?
b) Which educational potential and principles can be carried out and for what purposes? [6].

We developed a course that aims, on one hand, to promote effective and fruitful learning by secondary school students of quantum physics and quantum technologies at an introductory level and, on the other, help them to orient and navigate the complexity of the present [5].

The methodology: the design principles and the random walk case

Starting from a previous research work [4], we pointed out a bunch of design principles that were implemented in the different activities of the module on quantum computing. The module was part of the project PLS (*Piano Lauree Scientifiche*) for secondary school students who voluntarily decided to attend extra-school activities. We identified four 4 principles:

1. To foster a close comparison between "classical" and "quantum" through an analysis of *the different logic* underlined in the physics of the hardware.
2. To reconceptualize the foundational experiments in terms of computation, that is to re-read the three main phases of an experiment - *state preparation, state evolution, measurement* - in terms of *input – processing – output information*.
3. To keep the quantum technicalities as simple/clear as possible and foster deep understanding of the *essential physical concepts that are needed*.
4. To make the module *inclusive* exploiting the intrinsic interdisciplinarity of the topic [6].

Among the different activities, the random walk activity, designed starting from [7], is particularly emblematic of the implementation of the principles. Firstly, the random walk proved to be an effective context to reflect on the differences between the classical and quantum rational structure and to investigate the potentialities of quantum computation. Secondly, the quite clear algorithmic and computational dimensions allowed us to focus on some key concepts (state and superposition principle, state manipulation/evolution, measurement, and entanglement) and that can help students to place them in a coherent and essential scenario. Finally, the algorithm proved to be suitable for an interdisciplinary reconstruction. The intertwining between mathematics, physics, and computer science in the random walk model can foster students with different interests and ways of thinking to choose and resonate with the dimension they feel closer to them.

Conclusion

The essentiality of the model underlying the random walk algorithm allowed us to design an activity that highlights the difference between classical and quantum rational structures and to reflect on the nature of probability. We believe that the design principles and activities such as the random walk one, based on the explication of the intrinsic interdisciplinarity of the topic, can be effective and fruitful also for non-physics students [2]. Furthermore, we believe that the reflection on quantum probability and its nature can play a key role to educate, as De Finetti discussed at the end of the 70ties, to the logic of uncertainty and to equip young generations with increasingly important skills such as the ability to manage the uncertainty and the probabilistic thinking.

References

[1] Deutsch, I. H. (2020). Harnessing the power of the second quantum revolution. PRX Quantum, 1(2), 020101.

[2] European Quantum Flagship (2020, February). Strategic Research Agenda

[3] Rosa, H. (2009). Social acceleration: Ethical and political consequences of a desynchronized high-speed society. In H. Rosa & W. E. Scheuerman (Eds.), high-speed society. Social acceleration, power and modernity. University Park, PA: Pennsylvania State University press, 77–112

[4] Levrini, O., & Fantini, P. (2013). Encountering Productive Forms of Complexity in Learning Modern Physics, Sci & Educ, 22:1895–1910.

[5] https://www.oecd.org/education/2030-project/teaching-and-learning/learning/student-agency/Student_Agency_for_2030_concept_note.pdf

[6] Satanassi, S., Ercolessi, E., & Levrini, O. (2022). Designing and implementing materials on quantum computing for secondary school students: The case of teleportation. Physical Review Physics Education Research, 18(1), 010122.

[7] Kempe, J. (2003). Quantum random walks: an introductory overview. *Contemporary Physics*, *44*(4), 307-327.