The Second Quantum Revolution at school: teaching and learning Quantum Physics in the context of Quantum Technologies

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Abstract. The context of the Second Quantum Revolution, in which basic results of Quantum Physics are generating new technological applications, is exploited to devise teaching-learning paths for high-school teachers and students. The concepts of quantum state, superposition, entanglement and measurement are addressed introducing the qubit and the quantum logic gates.

1 Context

Since about twenty years we have entered the Second Quantum Revolution [1] where applications and technologies based on the principles of Quantum Mechanics are becoming increasingly available thanks to the capability of preparing, controlling and manipulating single quantum states and exploiting their nonclassical properties, such as superposition and entanglement. Among these technologies, the European Flagship on Quantum Technologies [2] focuses on quantum information and communication, quantum computing and simulations, and quantum metrology. Such newly developed quantum technologies will not only have fundamental social and economic implications in the next future [3,4] but also require changes in our epistemic perspective. The reason is that the properties of the physical systems underlying quantum technologies have no classical analogues and require a different logical approach: the classical propositional binary logic must be replaced by a new one to deal with the evolution of quantum systems.

On such basis, it would be important to familiarise new generations with these technologies so they be part, in the near future, of the workforce needed to fully implement the second quantum revolution [4]. However, usual teaching approaches of Quantum Physics at secondary school level does not empahsize current findings of in advanced quantum research [5-6] [6]. To bridge this gap, it is necessary to create new learning environments to support both teachers and students in tackling the conceptual difficulties related to quantum physics [7]. This can be achieved through the exploration of quantum technologies as a significant context to show how quantum superposition, entanglement, and other quantum core concepts can be used in the developoment of new technologies.

2 Activities

Introducing the qubit, the basic building block of quantum information, and approaching physical transformations from a computational point of view, as quantum logic gates, help reducing the level of the mathematical formalism required to describe the essential features of quantum physics. Moreover, relevant properties of physical systems, such as electron spin or single-photon polarization, can be seen as physical realizations of qubits and discussed keeping the argumentation rigorous enough to avoid distorting hyper-simplifications [8].

To address the above issues, during the past three years, we designed and implemented Continuous Professional Development (CPD) programs to support the development of teachers' pedagogical content knowledge in quantum physics. Combining the exploration of quantum concepts (i.e., quantum superposition, entanglement) and the development of physical models to interpret the result of electrons spin and single-photons experiments, teachers had the opportunity to reflect on the nature of quantum objects using an elemental and rigorous mathematical formalism.

We also organized extracurricular activities (Summer Schools and PCTO - Transversal Competencies and Orientation Program) to introduce students to quantum technologies. Using an interdisciplinary approach, we designed and implemented a teaching learning sequence for high school students about the core concepts of quantum physics and the tenets of quantum computation. The intertwining between logic and physics enables students to understand the way quantum computers manipulate information and how this could be used to develop cryptographic protocols and perform quantum teleportation. Extensive use of interactive simulations [9] and processing of quantum algorithms on real quantum computers [10], together with analytical calculations, supported students' learning process.

3 Conclusion

All the activities are the result of the joint efforts of the communities of researchers active in Italy the fields of Quantum Technologies and Physical Education.

Preliminary results of the evalutaton of activities carried out with small groups of students during the Summer Schools, show that using the quantum technologies, and quantum computing in particular, was effective in introducing foumding concepts of quantum physics: quantum superposition and entanglement, evolution of quantum states, quantum measurement and quantum probabilities.

Acknowledgements

M. Bondani acknowledges the essential contribution of M.L Chiofalo, E. Ercolessi, O. Levrini, C. Macchiavello, M. Malgieri, M. Michelini, O. Mishina, P. Onorato, F. Pallotta, L. Santi, S. Satanassi, A. Stefanel, C. Sutrini, I. Testa, G. Zuccarini.

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