Comparing the two quantum revolutions: development of a teaching module to value their cultural and conceptual scope

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Abstract. We are in the midst of the Second Quantum Revolution, which succeeded the First in the early 20th century. The First revolution revolved around the wave-particle duality and led to the emergence of technologies like transistors and lasers. The Second heralds a new technological epoch encompassing quantum sensors, communication, computers, and simulators. This current revolution is changing the research and our political, societal, and educational landscape, calling educators to promote quantum literacy and prepare the forthcoming quantum experts. We present a module for high school students and teachers, which stimulates reflections on the cultural and conceptual implications of the ongoing revolution.

Introduction and research questions

In the contemporary technological landscape, quantum technologies represent a frontier of innovation with vast potential across diverse domains. The research and the development of these new technologies shed light on the importance of science education research as a catalyst for unlocking the transformative capabilities of quantum technologies. This research field has the potential to address multifaceted challenges through the development of training initiatives, fruitful learning and teaching sequences, pedagogical strategies as well as methodologies to promote inclusion. In particular, science education research has been involved to i. facilitate the creation of new ecosystems in which universities, enterprises, and schools can dialogue; ii. prepare a well-prepared and interdisciplinary workforce to realize its potential fully; iii. attract new generations of quantum experts and iv. promote quantum literacy [1,2].

The ongoing revolution, as Gisin [3] stressed, is also a conceptual revolution that “completely overturns our previous pictures of nature” giving rise to “new technologies that will simply look like magic”.

A further role of physics education research, at the intersection of scientific disciplines, epistemology of science, history of science, learning sciences, and sociology, can be to contribute to the understanding of the world we live in and the cultural potential of science, ensuring that individuals are equipped to comprehend the historical context, scientific principles, and societal implications underlying these groundbreaking advancements.

In light of this framework, the research questions that guided our work are: What characterizes the Second Quantum Revolution with respect to the First one? What is its cultural and educational potential? How can we design educational materials able to value the Second Quantum Revolution also beyond the technical training?

In the present contribution, we aim to unpack the Second Quantum Revolution from a cultural perspective in relation to the first one, focusing on how the technological landscape we are developing is changing the vision of quantum physics itself.

Theoretical Framework and Methods

In 2018, we started to develop an approach to design a teaching module for secondary school students to value the cultural scope of the Second Quantum Revolution [4,5]. The approach and the module have been iteratively refined following a Design-Based Approach [6], which implies a back-and-forth dynamics between educational hypotheses and empirical results. The module was refined through five rounds of implementation in extra-curricular courses with secondary school students (for a total of almost 130 students) and two rounds with pre- and in-service teachers. We employed a comparative methodology to address the questions posed in the introduction, by systematically analysing the First and Second Quantum Revolutions across conceptual, epistemological, and experimental dimensions. Initially, our focus lay in delineating the similarities and differences between the two revolutions. Building upon the seminal contributions of Aspect [7], we considered each revolution centers on distinct concepts: complementarity and entanglement. These concepts, initially conceived through mental experiments, also became experimental challenges, exemplified by landmark experiments such as the double-slit experiment and Aspect's experiment of Bell's inequalities violation. Subsequently, the comparative methodology was applied to scrutinize the fundamental principles underlying classical and quantum computing architectures, notably binary and quantum logic. Finally, elaborating on the ideas of Deutsch, Landauer, and Preskill about the physical nature of information [8], the comparative methodology was applied to compare foundational experiments and circuits by reconceptualizing the three main phases of the experiment - state preparation, state manipulation/evolution and measurement- in terms of computation - input information, processing information, and output information [4,5].

Conclusion

Through the comparative methodology described before we carried out a bunch of design principles to unpack the Second Quantum Revolution [4,5] and developed a teaching module that was iteratively refined following a Design-Based Approach [6]. In the contribution, we will discuss the design principles, the final version of the teaching module, and the main results of the upcoming implementation with pre-and in-service teachers.

References

[1] O. Mishina, J. Sherson, L. V. Kroon, C. Brand, R. Müller, W. van Joolingen, ... & F. Wilhelm-Mauch. Strategic agenda summary: education for QT, (2019).

[2] A. De Touzalin, C. Marcus, F. Heijman, I. Cirac, R. Murray, & T. Calarco. Quantum manifesto: A new era of technology. *European Commission*, (2016) 1-20.

[3] N. Gisin, *Quantum chance: Nonlocality, teleportation and other quantum marvels*. Springer, 2014.

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

[5] S. Satanassi, Investigating the learning potential of the Second Quantum Revolution: development of an approach for secondary school students, 2023.

[6] P. Cobb, J. Confrey, A. DiSessa, R. Lehrer, L. Schauble, L. (2003). Design experiments in educational research. *Educational researcher* **32**(1) (2023) 9-13.

[7] Aspect, A. (2008). Introduction: John Bell and the second quantum revolution. *Speakable and Unspeakable in Quantum Mechanics: Collected Papers on Quantum Philosophy (Cambridge University Press, Cambridge, 2004) pp. xvii–xl*.

[8] R. Landauer, The physical nature of information. *Physics letters A* **217**(4-5) (1996) 188-193