Cultural Storytellings in Quantum Science and Technology Education

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Abstract. The field of Quantum Science and Technologies (QST) has the potential to generate significant changes in every citizen's lives, and so a carefully designed approach to its formal and informal education activities is essential. In this contribution, we reflect on the functions of outreach in developing the modern scientific mind, discuss its essential importance in the modern society of rapid technological development, and propose a novel framework, *Culturo-scientific storytelling*. In a manner consistent with Responsible Research Innovation, we propose tools to implement this narrative within the pilot project Quantum Technologies Education for Everyone (QUTE4E).

Introduction

The rapidly evolving field of Quantum Technologies (QT) requires the understanding of Quantum Science (QS) through a renovated mindset, posing important challenges to outreach experts to find engaging, rigorous, and effective narratives. QST offers a thriving opportunity to design an outreach framework able to support citizens of any age and cultural background to develop a modern scientific mind, and be able to navigate the "society of acceleration" [1,2]. These considerations have motivated the design of the Quantum Technologies Education for Everyone (QUTE4E) pilot project [3], part of the QTEdu Coordination and Support Action under the European Quantum Flagship Program. QUTE4E is centered on the idea of accessible quantum science to every citizen through shaping outreach as an accessible non-formal education framework, alongside existing formal activities. We present the general theoretical framework of culturo-scientific storytelling (CSS) [4], discuss its links to Responsible Research Innovation, and analyse the available interactive tools [5] that can be exploited to implement the CSS idea into practical outreach context.

The theoretical framework of Culturo-scientific storytelling and research questions

As discussed in Ref. [4] disciplinary structure exists in the fundamental sciences which is firmly respected to this day [6]. Tseitlin et al. [6] highlighted that the rigid, disciplinary description does not incorporate their temporal evolution. To this end, they introduced a *discipline-culture* (DC) *framework* in which scientific knowledge is organized into a nucleus of core principles, a

body of working applications, and a periphery of alternative views and accounts. It is also understood that scientists process and develop knowledge in a narrative cycle, which proceeds from observation, to creative understanding, formalization, and refinement [7]. To do so demands creative, formal and experimental literacies and the awareness that scientific knowledge is an ongoing dialogue of interacting discipline-cultures. However, what of the modern scientist? What skills are needed to contribute to the rapidly emerging fields such as QTs, those with an enormous impending impact on society? QTs indeed offer an opportunity in which a narrative can be presented that may enable students to develop skills of *future-scaffolding*, including recognition of causality, scenario-thinking, and multi-perspective problem-solving [8]. The emphasis on education for "everyone" naturally calls for another question, of how to design generalizable guidelines which educators can exploit and the essential concepts of physics on which they rely, in a captivating and language-accessible manner.

Methods and findings

Guidelines would be evanescent without a theorization which they can ground into, and abstract without a reasoned toolbox at hand. To answer the above questions, we have thus first conceived the theoretical framework of *Culturo-scientific thinking* , representing the ability to embrace scientific thinking with an appreciation of the past, present, and future of the field and society. We found that an engaging narrative, *culture-scientific storytelling (CSS)* can be conceived by drawing in participants with unexplainable knowledge from the periphery of the field. In interpreting a paradigm by which this can be understood, curiosity is engaged and participants are able to access the working applications of the field. Finally, with the dual entry and exit through the periphery, where knowledge cannot be fully explained, participants are directly exposed to the reality of being a scientist: there is always more to learn. CSS echoes the conclusions of Levrini et al. [9] that skills, not just disciplinary knowledge, should be the goals of science education and must be considered in activity design and educational policies. CSS is also deeply connected to the RRI dimensions. Here, we report on a specific QST characterization of the RRI dimensions, by means of a participatory process involving PhD students of the University of Pisa [10]. We now address the suitability of available tools. As compared to formal education, outreach activities have a distinct advantage in not being limited to any formal curriculum, so that a focus on activities which are deeply engaging, such as gamified and creative experiences, can overcome some of the challenges educators are faced with in teaching quantum concepts with traditional means of instruction. To implement the CSS should not necessarily require the production of new tools, as many exist already which can support it. Indeed we classify [5] the existing interactive tools and quantum game creation events supporting the CSS approach, that are being validated in outreach activities of the QUTE4E pilot.

Conclusions

The QUTE4E pilot project is a fertile opportunity to reflect on the importance of designing suitable outreach frameworks for rapidly evolving scientific fields of research, such as QST. We found that an engaging storytelling, with high educational content, can be conceived by combining the concepts of discipline-culture and the cycle of scientific thinking. Our theorization fosters sustainable, practical implementations, as it uses existing interactive tools to support creative, formal, and experimental literacies, besides properly addressing the development of new ones. With this theoretical and practical toolbox, we have sown a fertile ground for a transformative and RRI-coherent QST storytelling, which is now in testing through selected outreach activities of the pilot.

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