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Communicating Quantum Technologies in an Era of Mistrust and Misinformation

Introduction

In this paper, we tell the story of a community effort to bring widespread quantum awareness to the general public through scientific outreach. The project, entitled Quantum Technologies Education for Everyone (QuTE4E), emerged from a large practising community of educators, academics, and industry representatives in the field of quantum technology with over four hundred members from forty-five countries. Coordinated by a dedicated action intended to unite disparate efforts across Europe (Quantum Technology Education – QTEdu), eleven pilot projects were established to address quantum technology education for universities, industry, high schools, and the public. QuTE4E was among the most ambitious of all the pilot projects, with the core aim being to develop guidelines for public communication of Quantum Science and Technologies, pioneering a research-based approach we call Physics Outreach Research (POR).

We believe that all citizens, regardless of background, position, and educational experience, should have the opportunity to be made aware and be inspired by Quantum Technologies (QT). Technologies such as quantum computing, simulation, sensing, and communications are already changing the world, for example, developing highly precise medical imaging (MetaboliQs, 2018) or materials that capture carbon dioxide (Wei et al., 2020). Public awareness of this field is essential for two reasons: first, because inspiration is the seed from which the future quantum workforce is recruited, and; second, because the individuals who are or will become policymakers, work at start-up companies, or hold public offices must know the implications of QT, rather than considering them distant concepts with no real application. In the present period of mistrust and misinformation around emerging technologies, aptly called the "post-truth" era ("The Challenge of the Post-Truth Era", 2018) a research-based methodology to deliver outreach for emerging technologies such as QT is essential.

To develop practical guidelines for communicating QT to the public, researchers in the pilot project first needed to answer the following questions:

- What are the main challenges that need to be overcome in order to optimise outreach efforts?
- Which ideas and content should we include in our "story"?
- What should be our narrative approach to outreach, our "storytelling"?
- What kind of tools can educators use to support this storytelling?
- How can we reach the widest audience in practice?

In assessing the challenges and content necessary for outreach, the pilot ran a Delphi Study to obtain community input, which is described in Section II of this paper. After that, a storytelling framework was developed, culturo-scientific storytelling (CSS), which is described in Section III. The CSS calls for the use of engaging tools to support the scientific-thinking process, the most effective of which are described in Section IV. In Section V, we discuss the implications of CSS for developing an awareness of Responsible Research and Innovation (RRI) in the public. Finally, in Section VI, we conclude with an overview of the increasing scope of outreach in the field of QT, and lessons learned from the pilot project on how to conduct it most effectively.

Community input: challenges and content

The first step in developing practical guidelines for outreach is to understand what they need to cover. By identifying the primary challenges for outreach, we were able to research and suggest methods to overcome them. Knowing exactly which topic areas constitute the best use of the highly limited time of educators and science communicators is also essential, and we therefore addressed all of these questions in the QuTE4E Delphi Study. The study ran between September 2021 and June 2022, and aimed to gather insights from practitioners in the field of outreach and education for QT on the most effective ways to engage with different stakeholders and the most important content to include in outreach efforts. (For the full details of the study, see Seskir et al., 2023.) Below we summarise the method, results, and key implications for QT storytelling.

The Delphi method, developed in the 1950s, is a structured process for obtaining expert opinions on a specific topic (Dalkey & Helmer, 1963). It involves a series of rounds in which experts are asked to provide their thoughts on a set of questions, with the responses from each round used to inform the next. This iterative process allows for a more comprehensive and nuanced understanding of the topic as it enables the integration of a wide range of perspectives into not only the responses, but also the questions themselves. In the QuTE4E Delphi study, a group of experts from the pilot project itself were invited to participate in the preliminary round. This was followed by two more rounds, which were open to the general public but mainly circulated within the QTEdu and associated networks. In the final round, thirty-six participants from seventeen different countries participated. Two examples of how questions evolved with expert feedback between the preliminary and final rounds are shown in Table 1.

Table 1: Example of evolution of questions between the preliminary and final rounds

Preliminary round questions	Second (final) round questions
What kind of important problems will there be for the outreach activities in quantum technologies in the following five years?	Please rate the potential problems in terms of severity for the outreach activities in quantum technologies that may be encountered or still persisting (in the next 5 years).
Which essential concepts of quantum physics should be utilised for outreach activities in quantum technologies?	Please rate the concepts/approaches provided below in terms of their usefulness to be utilised for outreach activities in quantum technologies.

Challenges for QT outreach

In the preliminary round of the study, participants were asked open-ended questions prompting them to provide their suggestions for what they considered to be major challenges in the field of QT outreach. The experts in the first round were then shown these responses, and additional items were added by them. In the final round, the larger group of thirty-six participants were asked to rank by severity the nineteen challenges provided to them in the previous rounds. As the field is evolving rapidly, we considered two separate time frames: the present, and more than five years into the future. Results are shown below, normalised so that the highest-rated problems are assigned a value of 1.00

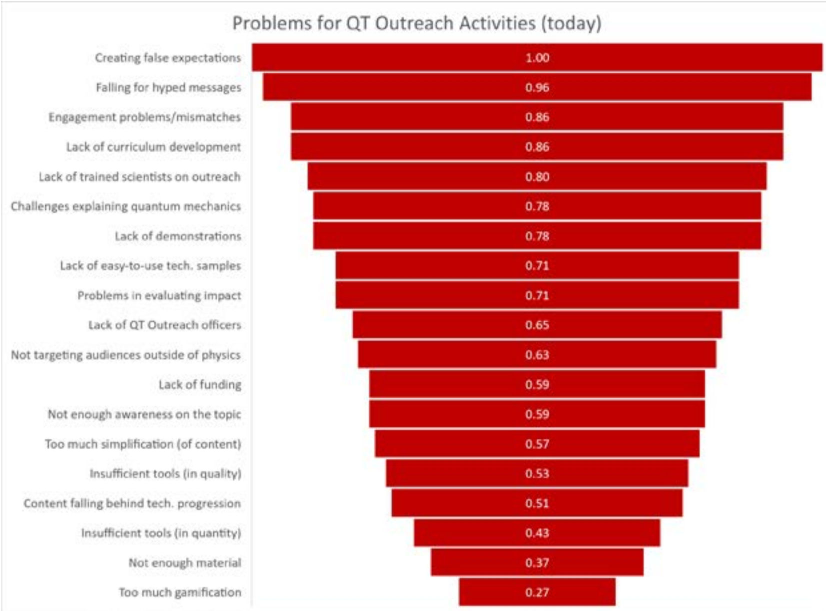

Figure 1: Challenges for QT outreach activities (present time), as ranked by participants in the final round of the QuTE4E Delphi study

Here we note several interesting findings relevant to practical storytelling. First, there is the concern about creating false expectations, which can lead to disappointment and erosion of trust. Second, there is a risk of falling for hyped messages and misinterpretation by non-expert audiences, which can hinder understanding and progress. Both of these challenges call for outreach activities that are grounded in reality and show the real-world applications of the technology. Third, there are engagement problems and mismatches between the communities working in this field and their intended audiences, which can hinder effective communication and outreach efforts. Fourth, there is a lack of curriculum development for different target audiences, which can make it difficult to effectively educate and engage these groups. Finally, there is a lack of trained scientists who are skilled in outreach activities and methods, which can limit the impact and effectiveness of outreach efforts. These problems can be addressed with more dedicated efforts in QT outreach. Indeed, these issues are not unique to the field of QT, but are present in many scientific fields. In the present age of misinformation, we must find new ways of communicating science to the public (Fähnrich et al., 2021). We believe that Physics Outreach Research (POR) and the modus operandi of the QuTE4E pilot project will significantly contribute to resolving these issues.

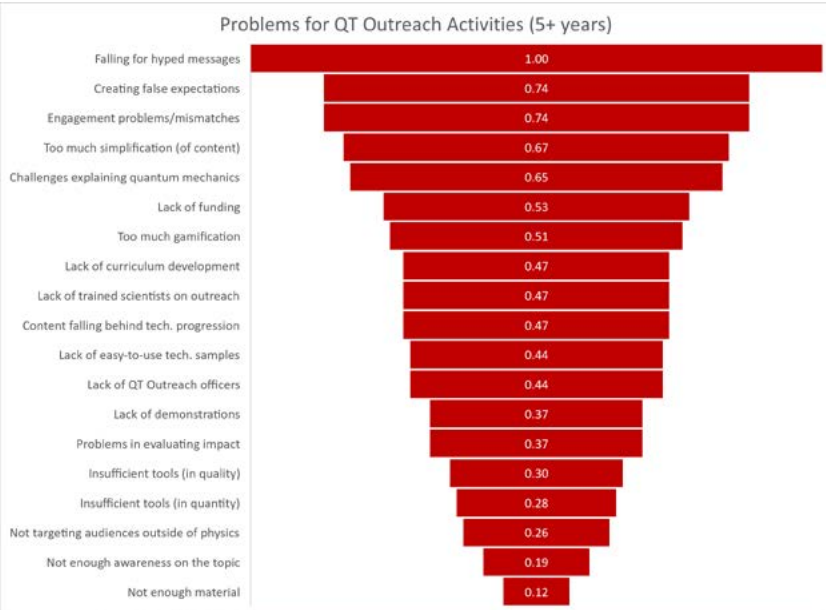

Figure 2: Challenges for QT outreach activities (five+ years into the future) ranked by participants in the final round of the QuTE4E Delphi study

Content for QT outreach

The second primary area of the study was focused on the perceived usefulness of various concepts and approaches for use in QT outreach activities, thus enabling practitioners to construct a narrative for outreach activities with specific topics in mind. As for the challenges, we first asked experts to suggest the topics they thought most important (in the first two rounds), and then asked participants to rank them by importance in the final round. The eight most important concepts as provided by EU and non-EU participants are shown below. In order to analyse their position within the narrative to be deployed, we used a conceptual tool known as the discipline-culture (DC) framework, first posited by Tseitlin and Galili (2005) to structure disciplinary knowledge. Here we describe it briefly and refer the reader to Goorney et al. (2022) for its use in structuring outreach activities.

It is clear that scientific fields have their own distinct discourses and narratives. This is obvious from just the titles of textbooks, courses, and journals, (Griffiths, 2005; Copenhagen University, 2022; IOP Publishing, 2013). It is only necessary speak to a scientist in a different field to experience that what feels like an entirely different language is being spoken. Tseitlin et al. likened these disciplines to cultures with a history of development, a plurality of approaches and viewpoints, and an uncertain and evolving future – just like cultures in our society. In its approach, science may be considered a dialogue between interacting discipline-cultures, analogous to the conglomeration of cultures that make up our modern world.

In each discipline-culture there exists a *nucleus* of core concepts and key paradigms which define the discipline, a *body* of working theories and daily applications of scientists, and a *periphery* of alternative ideas and viewpoints. An example of a concept in the nucleus is that of Quantum Superposition – the idea that no object has a definite state until it is measured, and rather exists as a superposition of many possible states. The body in the DC of quantum physics hosts concepts such as the qubit, the quantum equivalent to the binary digit with which computer calculations run.

Quantum physics is known mainly for having numerous interpretations. It is possible to count no less than sixteen (Cabello, 2017), many of which engage the public's fascination, such as the Many Worlds Interpretation and Quantum Darwinism. While most of these are not in regular working use by scientists in the laboratory, they certainly contribute perspectives to the discipline-culture, and thus can be considered part of the periphery.

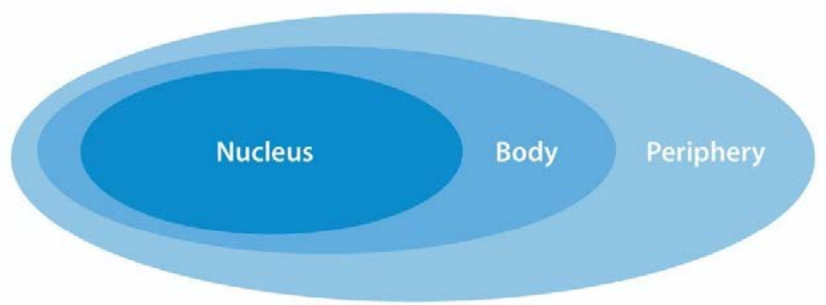

Figure 3: The discipline-culture framework as conceived and adapted by Tseitlin and Galili (2005)

Below we present the eight most important concepts for QT outreach as ranked by the participants of the Delphi study and placed in the discipline-culture framework of quantum physics. They are labelled by nucleus/body/periphery in Table 2. (See Seskir et al., 2023 for a full discussion of the implications of these results.)

Table 2: Top eight concepts/approaches to be utilised in QT outreach activities, rated in terms of their usefulness and adapted from Seskir et al., 2023

EU	Non-EU
Superposition (nucleus)	Superposition (nucleus)
Measurement (nucleus)	Measurement (nucleus)
Quantum state (nucleus)	Quantum state (nucleus)
Qubit (body)	Entanglement (nucleus)
Entanglement (nucleus)	Qubit (body)
Technological concepts (like quantum computers) (body)	Interference (body)
Interference (body)	Probability amplitude (nucleus)
Probability amplitude (nucleus)	Technological concepts (like quantum computers) (body)

The most striking result is that participants considered concepts in the nucleus of the DC (core principles of quantum physics) to be the most valuable for outreach. Those in the body of the DC (applications of core principles) were considered the next most important, and those in the periphery last. We believe this highlights an important disagreement in community opinion which must be addressed. The principles in the nucleus, while clearly valuable for inspiring the fascination of the public, are also highly prone to miscommunication and not necessarily representative of the daily experience of quantum technologists. Furthermore, we also believe there is also great value in activities in the periphery of the DC, which is supported by educational research and described in the next section. These results demonstrate the importance of clear guidelines being widely disseminated to practitioners.

Theoretical framework: Culturo-Scientific Storytelling (CSS)

Equipped with key concepts to include and problems to overcome in communicating QT, we may now consider with greater granularity how to structure outreach activities. An essential question to ask is: what outcome do we want from non-formal education? For what purpose do we communicate science? There are many benefits to doing so, such as raising awareness (Tarín-Pelló et al., 2022), preventing misinformation (La Bella et al., 2021), and inspiring future generations of scientists (Vennix et al., 2018). In this context, we are inspired by the work *Five Minds for the Future* by Howard Gardner (2008), in which he considers the *minds* required for the public to navigate and contribute to modern society. These minds must be disciplined, synthesising, creative, respectful, and ethical. We believe that public communication, with carefully crafted storytelling, may be contribute to the development of such minds.

In particular, Gardner's minds are inherently addressed in the everyday activities of scientists through the so-called inquiry cycle (Kuhn, 2011). Engaging in scientific thought is precisely the disciplinary thinking to which Gardner refers, and aspects of experimentation, conceptualisation, and theory-building related to such thinking develop synthesising and creative minds (Gardner, 2008). Scientists with an awareness of the need for responsible research and innovation (RRI) such as openness, inclusivity, and diversity, engage the ethical and respectful minds. Thus, promoting scientific thinking among the public through outreach may provide a great benefit in developing the skills needed to contribute to an ever-changing "society of acceleration" (Rosa, 2010). Goorney et al. (2022) collectively call these skills culturo-scientifc thinking, and believe they include elements such as disciplinary thought, creativity, and awareness of the fragility of scientific knowledge.

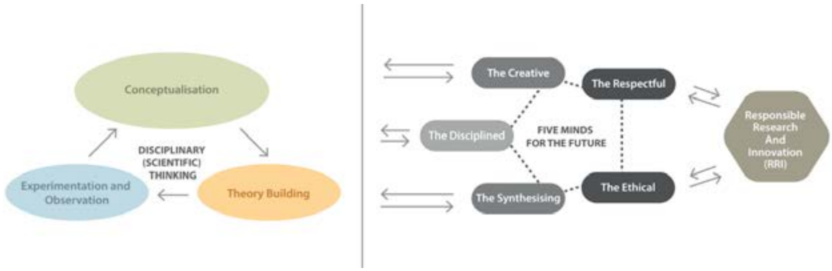

Figure 4: The approach taken by the QuTE4E pilot to develop Gardner's five minds through scientific thinking and RRI

CSS, the theoretical framework for a storytelling that best develops these skills, is summarised here (for more detail, see Goorney et al., 2022). While culturo-scientific storytelling was developed in and to promote QT, we note that it is a general framework for public communication of all areas of science and technology that are rapidly developing, such as Artificial Intelligence (He et al., 2019), cryptocurrency (Joo et al., 2019), and the Internet of Things (IoT) (Nižetić et al., 2020). We provide a summary of this method below for the use of educators.

First, we propose that activities be designed with the scientific inquiry cycle in mind. They should enable development of the disciplined, synthesising, and creating minds through application of experimentation, observation, conceptualisation, and theory building. Furthermore, we suggest that activities are designed with a sequential storytelling structure in which participants are taken on a journey through the field of QT. In order to structure this journey, we again make use of the discipline-culture framework as conceived by Tseitlin and Galili (2005).

Beginning in the periphery, where the most engaging and puzzling aspects of the field lie, is an effective hook and replicates the experience of a scientist encountering an idea that pushes the boundaries of their knowledge. Next, activities should be based around the nucleus, giving participants a paradigm through which to frame the subject. In

QT, topics in the nucleus include the notion of superposition, and the wave-particle duality nature of light (Weissman et al., 2019). Appreciating whichever of these core principles are relevant enables activities based in the body to be conducted, which consist of the applications of these ideas. For example, awareness of the superposition principle may enable explanation of quantum scenarios, such as interferometry and double-slit experiments.

Activities in the body allow participants to make predictions, test them, and build working theories in the scientific inquiry cycle. Finally, we suggest that finishing activities in the periphery is invaluable for developing culturo-scientific thinking skills. This gives participants exposure to the reality of the scientific experience – that no knowledge is ever complete, and the DC may grow and shift over time with new discoveries. These skills, including futures thinking (Levrini et al., 2021), epistemological awareness (Plakitsi & Kokkotas, 2010), and scientific thought (Chiofalo, 2022) are invaluable in the post-pandemic "society of acceleration" (Rosa, 2010) in which we currently live.

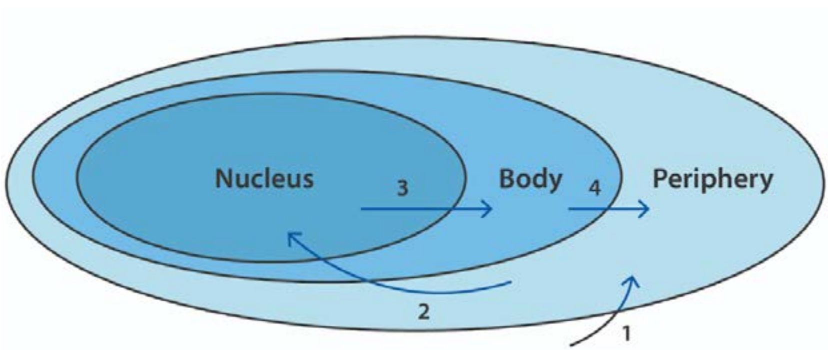

Figure 5: The culturo-scientific narrative approach explores the discipline-culture (a) in a journey reflective of the experiences of the scientist whereby each topic is addressed with scientific thinking, (b) in a journey constituted by an introduction with knowledge in the periphery (Arrow 1), later to be formalised into core principles in the nucleus (Arrow 2). Working applications can then be discussed and understood in the body (Arrow 3), before returning to the periphery to emphasise the evolving, incomplete nature of the DC (Arrow 4).

Participatory tools for storytelling

Implementing CSS requires that the participants be treated as scientists themselves. Yet how can this be accomplished when experimental QT setups require millions of euros to create? Addressing this need, members of the QuTE4E consortium and the wider community have developed and trialled a host of tools which can make implementing CSS practical. These toolboxes include resources which support experimentation, creativity, and formalisation. (For an extensive overview of this, see Seskir et al., 2022, p. 17). Here we show some examples of the tools developed within the pilot project, as a demonstration of the possible features of QT outreach activities designed with CSS.

Providing representational competence: The Quantum Odyssey

One major challenge for engaging scientific thinking in members of the public is being able to provide them with a foundation for understanding concepts in the nucleus and the body of the DC when they have no mathematical or scientific background. Let us consider the example of quantum gates and algorithms, the working basis (in the body of the DC) of quantum computation. An experienced physicist has a certain internal perception (or representation) of how gate operations work. This could be in the form of a visualisation, such as an arrow rotating around the Bloch Sphere, or a series of mathematical operations (Goorney et. al, 2023).

Visualisation software can be a powerful means to quickly provide participants the representational competence they need to understand a concept. In the case of Computation, the software Quantum Odyssey[1] is a self-paced learning platform which utilises a unique, fully visual method of displaying quantum gates and state vectors. Developed by Quarks Interactive through cross-disciplinary dialogue between physicists, computer scientists, educationalists, and industrial end-users, the software's aim is to tackle concerns in miscommunication about what quantum computers can do and offers a rigorous yet accessible learning space where learning how to create working code for universal quantum computers can take place.

1 Available on https://www.quarksinteractive.com/

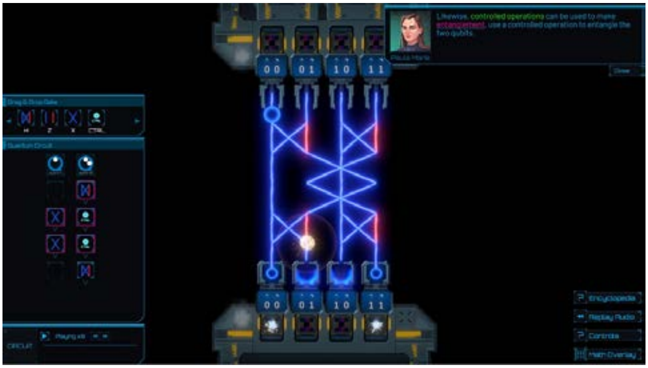

Figure 6: A snapshot from an introductory Quantum Odyssey learning puzzle. The circuit panel on the left and the Hilbert space of the circuit on the right are fully visualised. On the top right, the narration describes what is being observed. This representation of quantum gate operations is unique to Quantum Odyssey.

The software brings an original graphic version of the matrix-vector representation of the Hilbert spaces of full quantum systems. Because the translation for matrices to visual elements is exact, this representation is also exact. Indeed, advanced users can enter a "mathematics mode" and see the same operations in mathematical form. As a result, Quantum Odyssey can enable users to experience in an operational and participatory manner all of the fundamental principles behind quantum mechanics, including superposition, entanglement, and interference, and how to make use of them in constructing full proof-of-concept quantum algorithms. This means that members of the public can be guided with complete scientific accuracy through the nucleus and body of a storytelling version of quantum computation without any prior knowledge of gate operations or even fundamental principles of quantum mechanics.

Being a citizen scientist: Quantum Moves and Quantum Moves 2

Another challenge for outreach activities is providing an engaging "hook" for participants to engage with CSS. Why should they be interested in the activity? One possible solution to this is a class of tools in the field of citizen science (Roche et al., 2020), a model of conducting science in which members of the public are given the tools needed to participate in real research.

Quantum Moves (QM) and Quantum Moves 2 (QM2) are developed by ScienceAtHome based at Aarhus University (ScienceAtHome, 2012.) ScienceAtHome specialises in games and simulations in the field of citizen science (Roche et al., 2020), a model of conducting science in which members of the public are given the tools needed to participate in real research. Gamification of the tools with which the citizens interact encourages engagement and fosters participation. (Bowser et al., 2013) Thanks to the fun and intuitive nature of the games, QM and QM2 have been played over eight million times (ScienceAtHome, 2012).

In Quantum Moves, players take the role of a laser-based optical tweezer, guiding an ultra-cold atom through various challenges representing the operations of a quantum computer. The game-physics is a direct simulation of quantum mechanics, making use of the Schrodinger equation. The precise path taken through space is a class of experimental problems, known as quantum optimal control, with which physicists still grapple. Researchers using a computer algorithm to solve optimal control problems were able to demonstrate a benefit when using player-generated solutions as "seeds" over random seeding. Put simply, player solutions were able to help real researchers in a laboratory to build components of a quantum computer and conduct scientific research. Such a narrative is highly engaging for educators using the tool for outreach purposes and can provide a motivation for engaging with full CSS.

Navigating uncertain futures: The Quantum Decide Game

A final tool we would like to highlight is one that proved very popular among educators in the pilot project for its ability to engage individuals in the periphery of the DC, which is an essential component of CSS and invaluable in developing Gardner's minds. QT is generally perceived as complex, difficult, and remote, and many do not grasp the potential benefits it will bring to society. The Quantum Decide Game (QDG), developed by the Spanish photonics institute ICFO (ICFO, 2021), aims to introduce member of the public to the field of QT and its implications through a participative activity that makes use of cards as discussion artefacts. An example of one such card is below in Figure 7:

Figure 7: An example of one of the thinking cards used by participants of the Quantum Decide Game in order to foster discussion about the possible implications of Quantum Technologies

During QDG, the participants split into small groups (four to six people) that play the role of committees responsible for designing policies in research and innovation. Throughout the activity, they read, select, and discuss quantum concepts and technology, and explore cutting-edge scientific projects. The material provided underlines the importance of science and research in their lives with accessible examples. At the end of QDG, each committee reaches a strategic decision about the future of QT and shares it with the rest of the participants. The content of the cards varies from core concepts (nucleus), information about applications (body), and open discussions about issues with no clear solution (periphery), thus making it a powerful tool for implementing the CSS. Several examples of such discussions are provided in the next section. In addition, it promotes useful abilities for all citizens such as critical thinking and communication skills, and increased awareness about the current and future impact of QT on society at large.

Organising QDG for the public is simple and practical because it requires few resources. The cards that the participants use to gather information are freely available on ICFO outreach website (ICFO, 2021) in paper and digital format, and are translated into four different languages (Catalan, Spanish, English, and Italian). This makes QDG versatile and flexible, allowing it to fit into many different contexts and countries. ICFO and other institutions around Europe have used QDG to introduce quantum physics to high school students, secondary school teachers, and the general public. The simple setup makes it possible to organise it online and in person, and in many different settings (e.g. schools, museums, libraries, bars).

Feedback from participants emphasises the game's enjoyable and participatory nature, and that it allowed them to discover new concepts in an informal and engaging environment. In the Decide Game, people are not passive receivers of concepts as they are in classical outreach seminars, but are active characters that can choose information that is more relevant to them and interact with other participants to reach a consensus about what should be the future of QT.

Discussion: storytelling for the ethical and respectful

The tools described in Section IV are an effective means to engage individuals in the scientific thinking process, and thus develop the synthesising, creative, and disciplined minds of which Gardner conceived. We now discuss the implications of the CSS for reaching and developing the ethical and respectful minds through the promotion of Responsible Research and Innovation (RRI) (see Fig 4).

In February 2022, an RRI team at the University of Pisa ran a workshop for PhD students in both scientific and non-scientific disciplines as a transversal competence building activity (University of Pisa, 2022). Forty PhD students from a range of departments participated and were divided into twelve groups named after inspirational Quantum Physicists such as Marie Curie and Erwin Schroedinger. After an introduction to some of the historical development and core concepts of quantum mechanics through short accessible animations (QPlaylearn[2]), a keynote speech was delivered to tell the story about what quantum technologies are and where they are leading us. In this way, the discussion proceeded in the framework of CSS, from the periphery to the nucleus and the body of the discipline-culture.

The primary activity for the groups was based around QDG, which was specialised to address the following questions: (i) what should be the priorities of QST scientific policies in order for them to be consistent with the RRI dimensions? and; (ii) how should the above priorities be ranked? The use of guided scientific inquiry (Furtak, 2006), where-

2 Available on https://qplaylearn.com/education

by selected examples of possible implementations of the RRI dimensions in QT contexts were previously highlighted in the keynote, was a means of engaging the scientific thinking process of the participants (as highlighted in CSS, see Figure 4), even of those without any prior knowledge of the topic area. Participants were then provided with the Decision slide (see Figure 8) containing a basic set of priorities to be supported and/or changed at will. They then defined their choice of priorities, ranked them according to the RRI dimensions, and recorded the decision in a shared document according to a provided template. Finally, in the remaining half hour the different groups briefly reported their work in a plenary session. The final minutes were devoted to a discussion and question-and-answer session. The issues brought up here returned the participants to the periphery of the field, engaging with ideas and perspectives that are beyond what most scientists consider daily applications of QT.

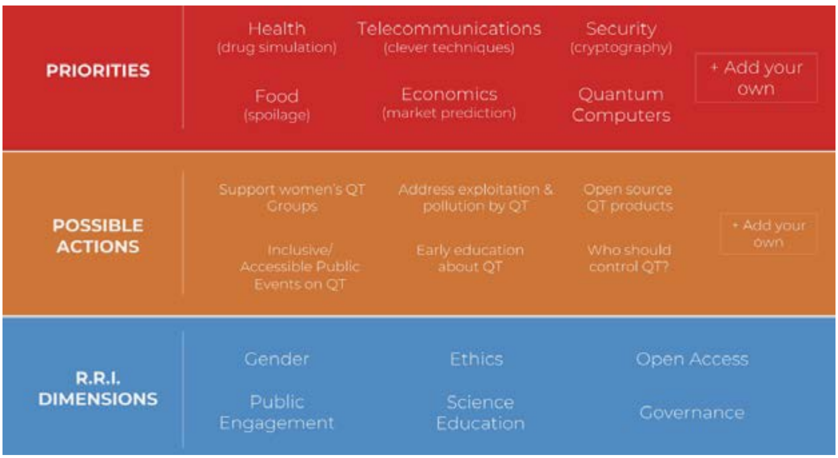

Figure 8: Guidance provided to participants of the RRI workshop based on QDG at the University of Pisa (2022)

In keeping with the spirit of RRI, training activities led to further collaborative design of a tool for developing RRI awareness and Gardner's respectful and ethical minds. The methodology used in these activities, which took place in the same PhD student workshop the following year, is inspired by "staff-student co-creation" in which learners and teachers together generate educational content for future learners. Because learners are engaged in the process of developing educational material with staff, "learning by doing", this method has been shown to yield benefits in engagement, awareness, and enhancement of learning (Cook-Sather, 2014), Through the duration of the didactic path described above, participant groups were prompted to highlight key stories and info cards that raise important questions they might use to educate the public about the principles of RRI. Several examples of resulting discussions are shown below, and the key cards from QDG which prompted them are available in the Appendix (Figures A1–A5):

i) Is scientific funding into the "mysteries" of quantum mechanics a wise investment for society? Is it worth investing significant resources into potential applications that might benefit society only in the long-term? (Figure A1)

ii) We are already using some of the unusual properties of quantum mechanics as the founding principles of widespread common technologies, i.e. lasers, solar panels, etc. (Figure A2).

iii) We can use quantum mechanics to generate new technologies that will impact society in many different fields. It should therefore be considered a responsible investment for governments worldwide (Figure A3).

iv) Many principles of quantum physics contradict common sense. Is this a limitation of the validity of this theory? Should the public trust such a "weird" theory (Figure A4)?

v) Because most members of the public are not educated to "speak the language" of quantum physics, news outlets often generate misinformation. If this misinformation makes its way to policymakers and investors, it can do serious damage to the adoption of QT in society, which may cause us to miss out on many of the future benefits of QT, for example in healthcare and environmental safeguarding (Figure A5).

Typically, one of the difficulties of making the public aware of issues related to RRI is the lack of contextuality. Dimensions such as "open access" and "ethics" can seem distant and disconnected from everyday life without a field in which to ground them, and can thus be difficult to convey in both formal and informal contexts (Margherita & Bernd, 2018).

The QDG allows these issues to be contextualised by QT and carefully explained through story, thinking, and information cards, encouraging participants to develop the respectful and ethical minds in the process.

Conclusion

A key ongoing theme in the findings from the QuTE4E Pilot is the value of an engaging narrative in outreach efforts in order to develop the skills people need to navigate the uncertain futures brought on by the advent of modern technologies. Participatory, hands-on tools are a key to implementing CSS, and the recent work of the scientific community in this area is now extensive. The majority of concepts we consider important to communicate to the public (shown in Table 2) are accessible through the demonstration of games and interactive tools (Seskir et al., 2022). Over the duration of the pilot project, these tools and CSS were implemented in many small-scale events intended to expose the general public to the wonders of QT, such as hackathons (Quantum AI Foundation, 2022) and game jams (Internet Festival, 2021). As governments become more aware of the negative implications of public misunderstandings of new technology, QT outreach is increasingly becoming a major part of international strategies for developing the field. Overhype (Sartori & Theodorou, 2022), misinformation (La Bella et al., 2021), and widespread misunderstanding (Dignam, 2020) are several recent examples from the field of AI, which is currently undergoing a public explosion of interest.

Europe Day, held in the headquarters of the European Commission in Brussels, was a particularly large initiative (European Union, 2022). QuTE4E ran the booth representing the research and development efforts of QT in Europe, the Quantum Flagship[3]. An estimated fifteen thousand members of the general public passed through the venue where Quantum Moves 2 and Quantum Odyssey were set up and used in a participatory manner to engage members of the public directly into the periphery of the DC, and offer a discussion around the implications of the technologies they demonstrate.

In Italy, the project Italian Quantum Weeks[4] was the first national effort of its scale, intended to raise awareness of QT and help members of the

3 Available on https://qt.eu/
4 Available on http://www.quantumweeks.it

public make sense of the quantum news they may have encountered on the web, in newspapers, or elsewhere. IQWs has now run over two consecutive years, and involved more than one-hundred and thirty researchers, technicians, communicators, and teachers from over forty research institutes across seventeen Italian cities.

And finally, UNESCO is currently in the planning stages for the dedication of 2025 as the International Year of Quantum Science and Technology. This prospect is representative of the degree to which QT development will impact society, and yet it is currently significantly underknown and misunderstood by members of the public. With increasing attention drawn to QT on an international scale, it is crucial that the opportunity to communicate the field is not wasted, and that every outreach scenario is conducted as effectively as possible. The risks of drawing attention to QT, without careful thought to how to do so, are substantial (Sartori & Theodorou, 2022; La Bella et al., 2021; Dignam, 2020). QT may avoid such issues by developing large scale outreach efforts, but only if they are accompanied by research-based guidelines. We highlight that the development of such guidelines, which we call Physics Outreach Research (POR), is crucial in the current "society of acceleration" (Rosa, 2010) where technological advancements are driving rapid sociocultural reform. Such a perspective must also be adopted in other emerging fields such as cybersecurity, and particularly Artificial Intelligence. These fields may benefit from a community-based approach as the QuTE4E pilot project has used in QT.

The result of this community has been CSS (Goorney et al., 2022), and the many tools available for implementing it (Seskir et. al, 2022). In this paper, we have offered several examples of their application, and how they may develop in members of the public the disciplined, synthesising, creative, respectful, and ethical minds they need to navigate the uncertain future of a society rapidly changed by technology.

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Appendix

Quantum Decide Game discussion cards used in RRI workshop:

David Díaz

I am a **historian** and a university lecturer.
I think many people put a lot of pressure on scientists to quickly turn their research into applications that benefit society. I think we should not demand results so soon. **We should be patient and continue to foster research.**
For example, while the theoretical principles on which lasers are based were known back in 1917, it was not until the 1960s that we had the first prototype. It took many more years for it to become an essential technological tool.

Figure A1: Is scientific funding to explore the "mysteries" of quantum mechanics a wise investment for society? Is it worthy to invest significant resources for the possibilities of application that might benefit society, but only in the long term?

Simón Salgado

ENERGY AND ENVIRONMENT

I'm a partner in a small furniture family business. A few years ago, I had **solar panels** installed on the roof of the building that we use as factory and warehouse. It was a big investment, but now I save a lot of money when it comes to paying my company's electricity bills. Plus, a choice like this is beneficial to the planet, too!

STORY CARD 11

Figure A2: We are already using the bizarre properties of quantum mechanics as the founding principles of widespread common technologies, i.e. lasers, solar panels, etc.

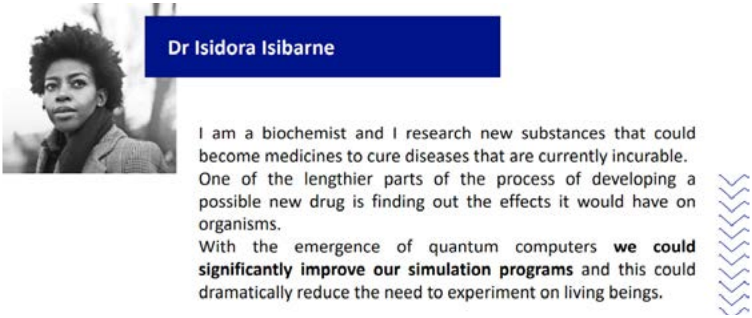

Figure A3: We can use quantum mechanics to generate new technologies that will impact society in many different fields. It should therefore be considered a responsible investment for governments worldwide.

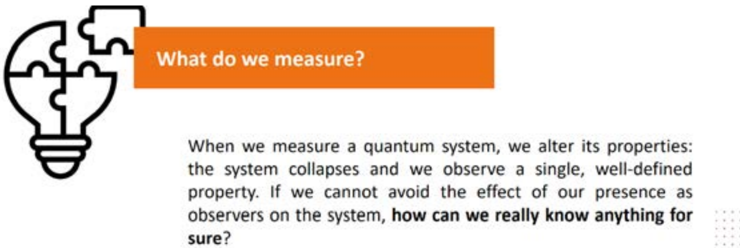

Figure A4: Many principles of quantum physics contradict common sense: is this a limitation to the validity of this theory? Should the public trust such a "weird" theory?

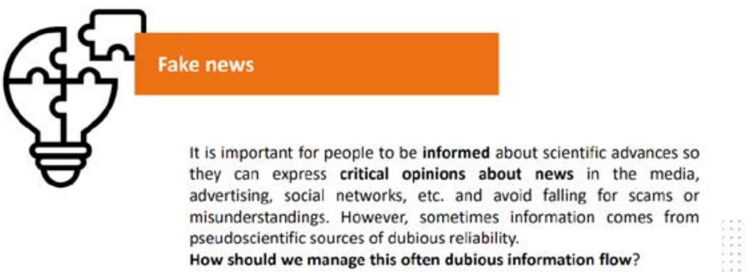

Figure A5: Because most citizens of the public are not educated to "speak the language" of Quantum Physics, news outlets can be prone to generating misinformation. If this makes its way to policymakers and investors, it may do serious damage to adoption of QT in society, which may cause us to miss out on many of the future benefits of QT, such as in healthcare and environmental safeguarding.
