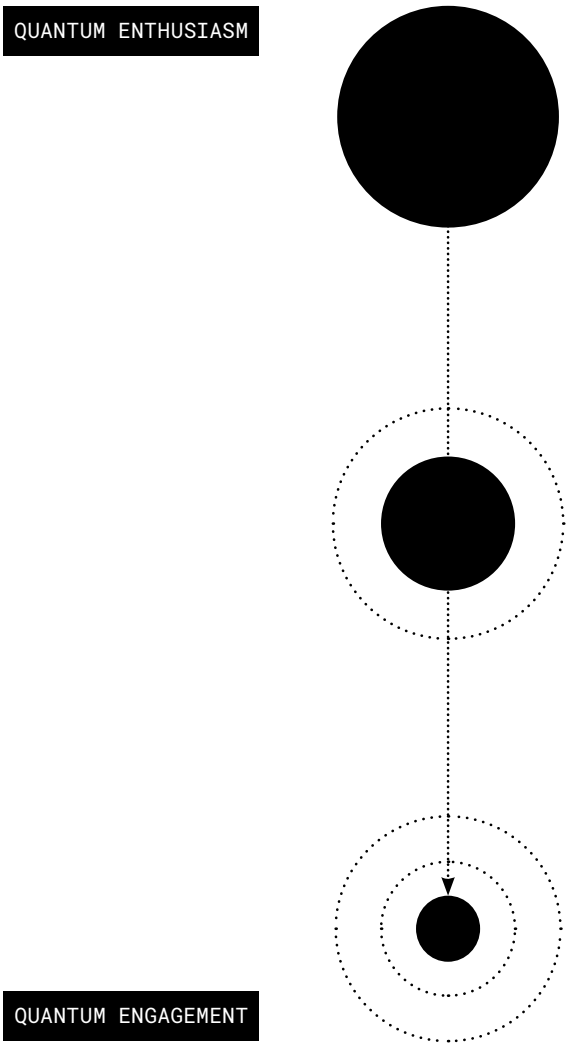
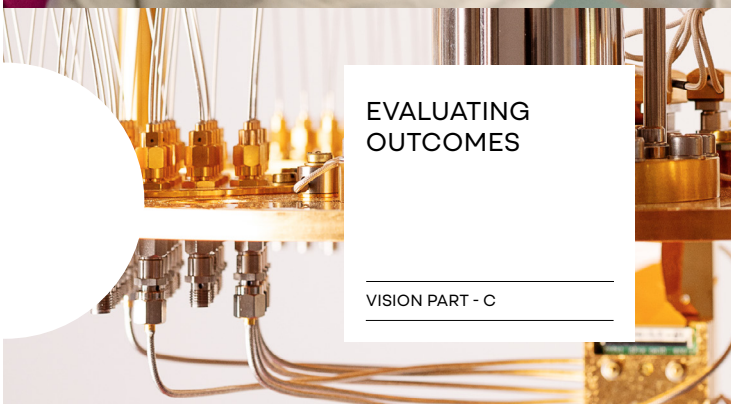
FROM QUANTUM ENTHUSIASM TO QUANTUM ENGAGEMENT

Simon Ings (LEI) , Evert van Nieuwenburg (LEI), Mayra van Houts (QDNL), Diederick Croese (CQS), Julia Cramer (LEI)

KEYWORDS: PRIVATE-PUBLIC ENGAGEMENT, EMOTIONAL-MORAL DELIBERATION, SCIENCE CAPITAL, IMPACT EVALUATION TOOL

VISION FOR SUCCESSFULLY COMMUNICATING QUANTUM SCIENCE & TECHNOLOGY





QDNL

01. Introduction

We need to overhaul how scientists and organisations communicate Quantum Science and Technology (QS&T) to the public. If we are to embed QS&T in our culture, enthusiasm from within the field is foundational, but expressions of enthusiasm are not enough. We need to shift towards evidence-based evaluation and democratic engagement.

Current science outreach is often driven by the personal hobbies and passions of researchers rather than strategic goals. Relying on enthusiasm alone often fails to create personal relevance for the audience; it can even decrease interest. Simply providing more information does not guarantee support and can actually polarise beliefs.

In this paper we argue that, instead of just lecturing the public, we need to foster genuine dialogue. The public does not need a physics lecture; they need to feel they have a voice in how the "second quantum revolution" is managed. we aim for evidence-based science communication. Activities that leave a measurable impact, and build forward on previous experiences.

So QS&T needs to foster insights from other magisteria, from anthropology and the social sciences, from philosophy and from the arts, to engage fully with the culture that sustains it. Quantifying of measurable successes is a necessary step, and primarily because it gives us the confidence and experience to envision other harder-to-measure kinds of success.

We hope to foster a move from rational arguments to emotional-moral deliberation (see Figure 01). We advocate for specific, non-traditional methods, including games, design fiction and creative workshopping, to build intuition and engagement. Public money funds quantum research, and researchers have an obligation to prove they are creating public value, not just having fun. We want to contribute to the professionalisation of the field, and we have done so by using data to measure whether outreach actually builds trust and agency.

ENTHUSIASM

Science outreach -- particularly in quantum science -- is often driven by and shaped around the specific

VISION FOR SUCCESSFULLY COMMUNICATING QS&T

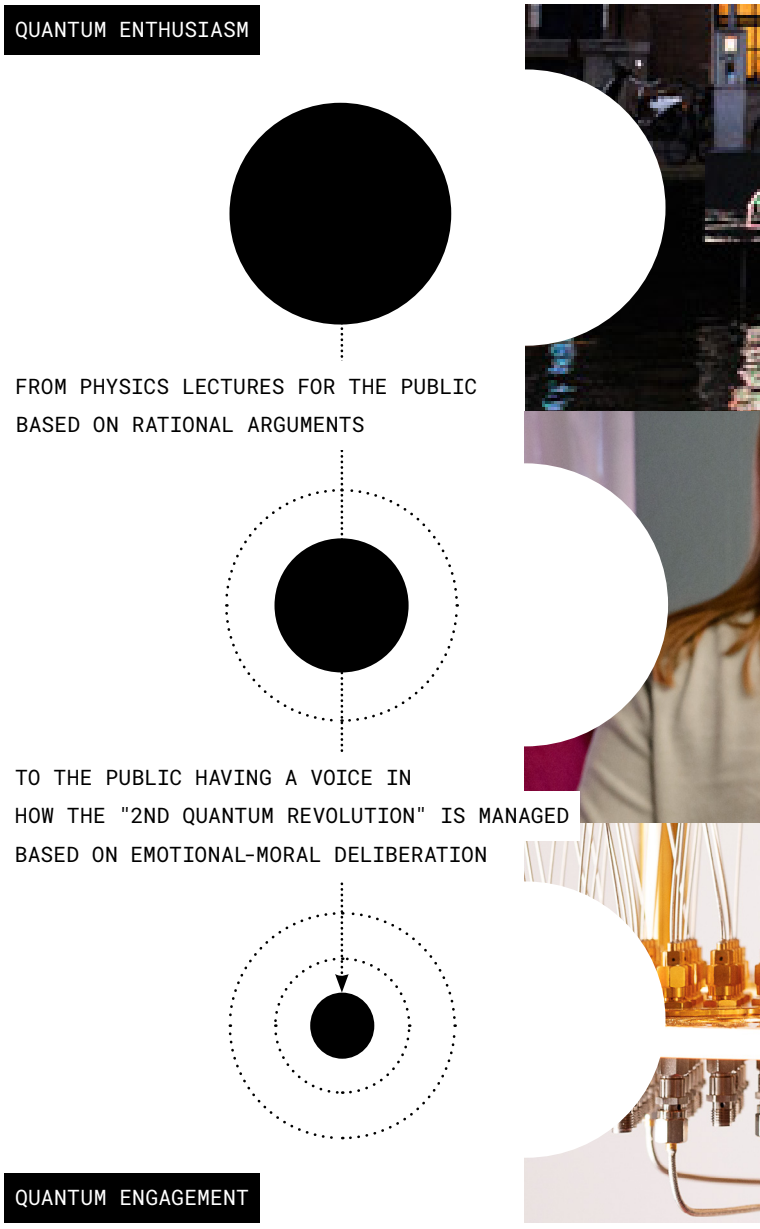


FIGURE 01: The authors envision to foster a move from rational arguments to emotional-moral deliberation.

DEBATE TOPICS WITHIN COMMUNICATING QS&T

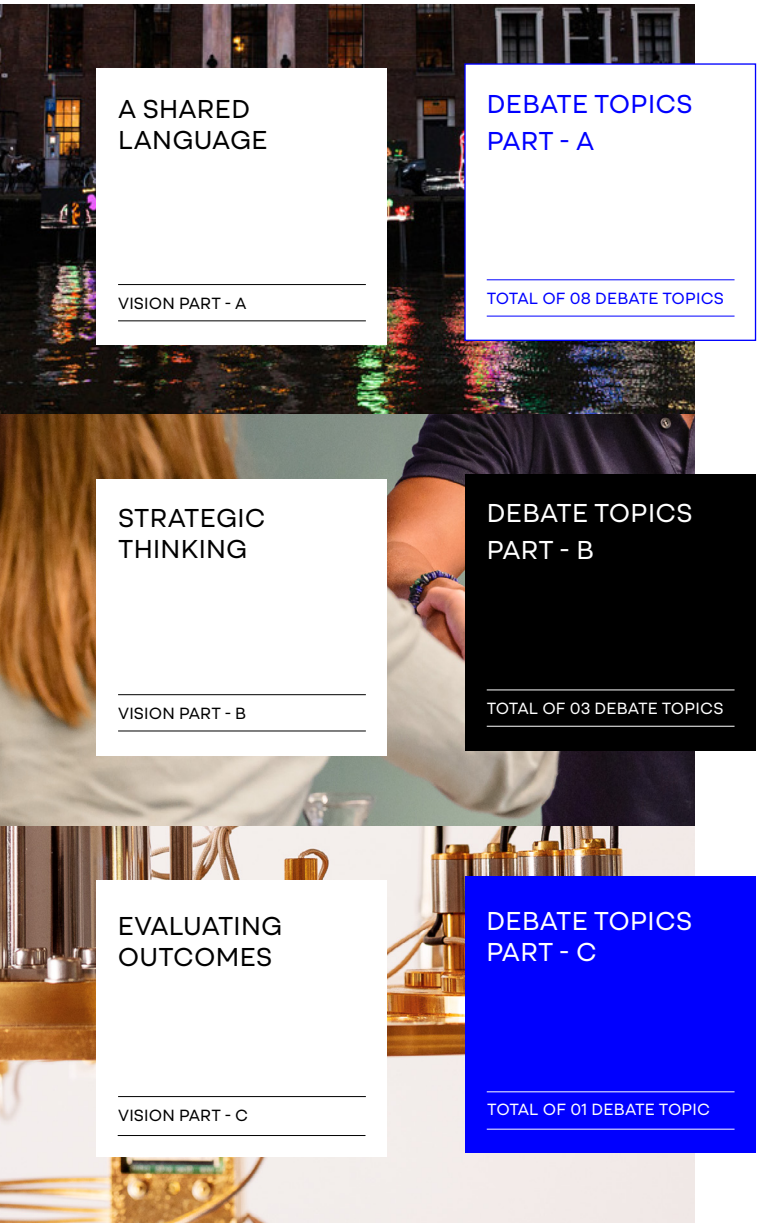


FIGURE 02: Genuine dialogue allows the public to feel a sense of ownership and voice in the technology's trajectory.

personal enthusiasms, hobbies, and passions of the communicators themselves. For example, experts in TEDx talks frequently frame their work through the lens of their own "excitement," "fun," and "fascination."

The content and style of these communications mirror the communicator's personal relationship with the subject matter. An analysis of TEDx talks on quantum science [1] found that experts use tools that reflect their personal flair. For instance, one speaker used a musician to help explain concepts through sound, effectively turning the talk into a "quantum symphony," while others designed games to engage the audience.

Personal passions also drive the choice of medium itself. Outreach through games, for example and the gamification of quantum concepts, could hardly arise without a sincere enthusiasm for gaming. Laurentiu Nita, creator of the game Quantum Odyssey, describes his work not just as a job but as a personal mission driven by his belief in the educative potential of visual puzzles. The organisers of quantum-themed hackathon QHack deliberately chose a funny, non-corporate approach that included "swag" and a goofy space-themed story, reflecting the organisers' enthusiasm for a specific (science-fiction) subculture.

In the realm of open-source quantum software, the line between professional research and hobbyism blurs, with outreach and development often sustained by personal enthusiasm rather than job requirements. Developing and maintaining open-source scientific tools is described as often being done out of pure passion, as the work is time-consuming and often unrewarded.

ENGAGEMENT

Communication must move beyond a simple "sales pitch" to foster genuine dialogue (see Figure 2), allowing the public to feel a sense of ownership and voice in the technology's trajectory. Relying solely on enthusiasm in QS&T communication often fails to translate into meaningful engagement or personal relevance for the audience.

[1] Meinsma, Aletta L., Sanne W. Kristensen, W. Gudrun Reijnierse, Ionica Smeets, and Julia Cramer. "Is Everything Quantum 'Spooky and Weird'? An Exploration of Popular Communication about Quantum Science and Technology in TEDx Talks." Quantum Science and Technology 8, no. 3 (2023): 035004.

For instance, research indicates that while students may recognise the general societal importance of the field, this awareness does not necessarily foster a personal connection or a desire to learn [2] . Studies also suggest that purely informative exhibits -- even when presented enthusiastically -- can actually decrease interest if they strip away a topic's novelty without replacing it with relatability or agency. Communication strategies must evolve beyond the "deficit model," which assumes that public scepticism arises solely from a lack of knowledge, and that providing more facts will lead to acceptance. Knowledge does not equal support: increasing scientific literacy does not guarantee positive attitudes.

[2] Moraga-Calderón, Tania S., Henk Buisman, and Julia Cramer. "The Relevance of Learning Quantum Physics from the Perspective of the Secondary School Student A Case Study." European Journal of Science and Mathematics Education 8, no. 1 (2020): 32–50.

02. Vision part - A - A shared language

Language does not merely describe physical reality; it shapes social perception, collapsing concepts into narratives. As we move away from exclusionary jargon towards a shared, inclusive language, we dismantle the perception of quantum as "too difficult" and empower diverse groups of people to participate in democratic dialogue.

Here we address technical issues around the language of QS&T. We then advocate for a communication style that admits setbacks, allows public critique, and is honest about risks. We sketch a communication model based on trust, agency, and shared inquiry (see Figure 03).

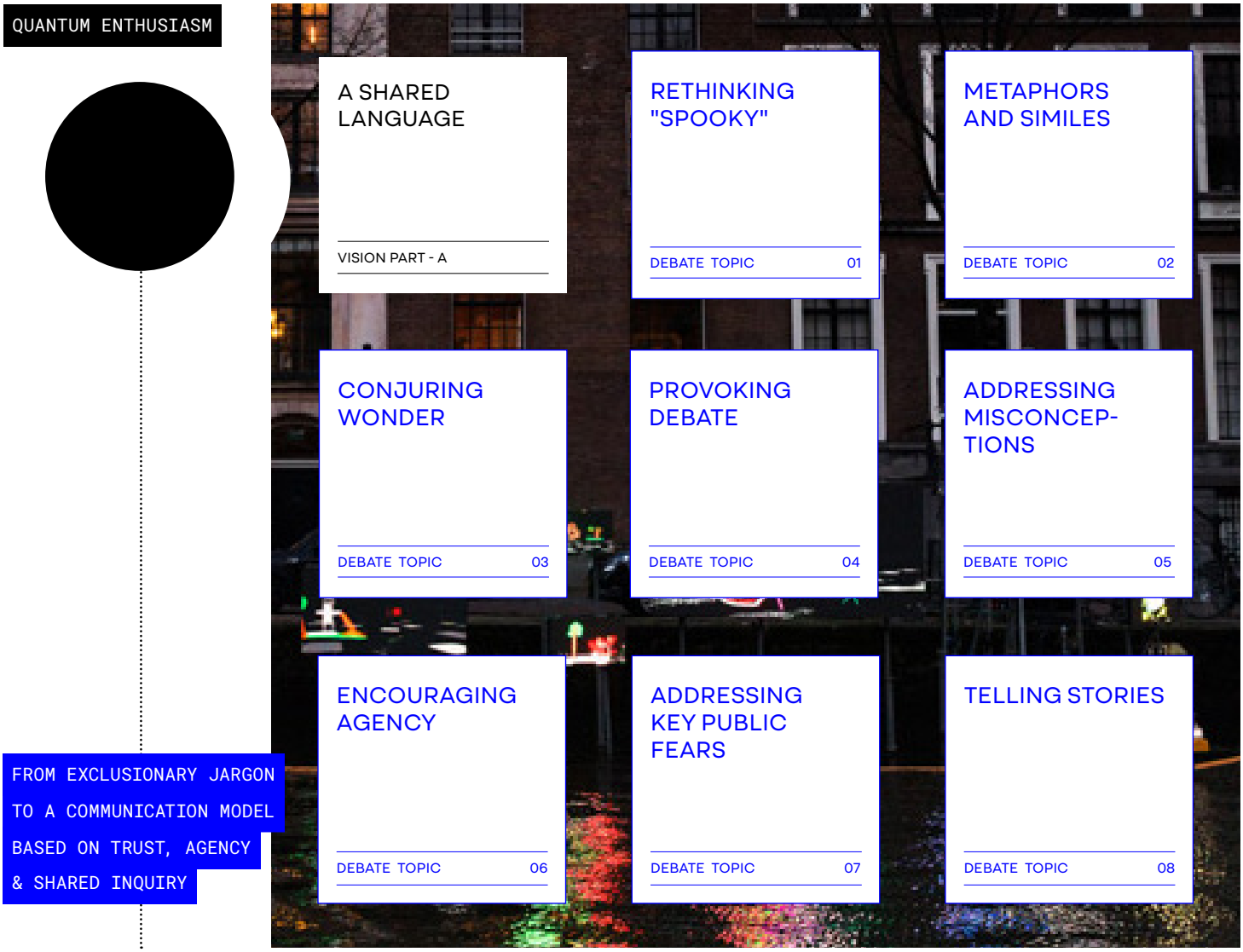


FIGURE 03: To empower diverse groups of people to participate in democratic dialogue, QS&T visions to move to a shared language.

RETHINKING "SPOOKY"

DEBATE TOPIC 01

Quantum is constantly called "spooky" or "weird" -- terminology that originated from fundamental debates surrounding quantum theory in the early 20th century. Albert Einstein famously lampooned the concept of quantum entanglement by referring to it as "spooky action at a distance" -- a phrase repeated multiple times in expert communications, though not always in the speaker's original, sardonic spirit.

Richard Feynman reckoned that "if you think you understand quantum mechanics, you don't understand quantum mechanics." Niels Bohr had it that "anyone who is not shocked by quantum theory has not understood it". These and other off-the-cuff comments from experts have, through repetition, acquired unnecessary weight, becoming at times non-explanations or, worse, reasons not to explain. There is no harm in offering newcomers a friendly warning about a novel field's difficulty or strangeness. In analyses of TEDx talks, a wide variety of adjectives used to describe the quantum world included random, fun, exciting, clunky, nonsense, impressive, romantic, and crazy [3] .

However, some worry that by framing quantum technology in this way, we make the technology feel alien and deter public engagement [4] . "Spookiness" may well be a harmless characterisation until, in an atmosphere of public anxiety and loss of agency, it causes trouble. If, for instance, quantum technology becomes majorly or exclusively associated with efforts to break personal encryption, or if quantum became the theatre for major geopolitical struggle, then its mysteriousness would not at all contribute to its acceptance.

Despite the consistent use of this framing by experts and the media, the public does not always default to describing quantum as weird or spooky. A British study found that in a public dialogue exercise around quantum science and technology, no one talked about quantum being 'spooky' or 'weird' – as some stakeholders had anticipated [5] . Tania Moraga-Calderón, a researcher affiliated with Leiden University, found that among Dutch secondary students, "weird" was not an especially coded statement, and the adjective turned out to be not as common or evident as expected [6] .

METAPHORS AND SIMILES

DEBATE TOPIC 02

We conclude that while the use of playful, minatory language may raise technical concerns, the true challenges of QS&T communication lie elsewhere. Quantum ideas are notoriously abstract, and the metaphors and similes used to express them have become staples of the lecture room and the public stage. Given the counter-intuitive nature of

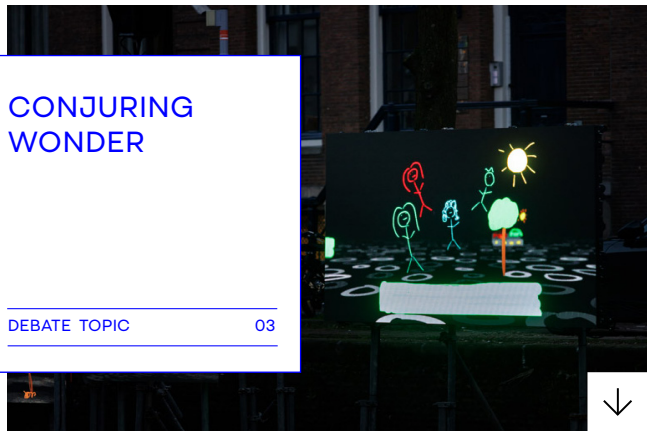
[3] Roget 2020, 24.; [4] Anka van de Merbel, Jasper Peer, Sanne J. W. Willems, and Julia Cramer, "'Quantum Technology Will Change My Life.' Citizens' Attitudes and Knowledge of Quantum Science and Technology," Journal of Physics Communications 8, no. 7 (July 2024): 075005, https://doi.org/10.1088/2399-6528/ad48d3.; [5] Aletta Lucia Meinsma, Thomas Rothe, W. Gudrun Reijnierse, Ionica Smeets, and Julia Cramer, "Quantum in the Media: A Content Analysis of Frames in Dutch Newspapers," Science Communication (2025), https://doi.org/10.1177/10755470251318300.; [6] Tania Moraga 2020, 11-12.

some quantum behaviours, many experts rely on metaphors and similes to communicate, not just the facts of their field, but also its aesthetic intrigue, and even its beauty [7]. Quantum superposition is like a coin spinning in the air (until we hit the coin on the table, it is as if the coin is both heads and tails at the same time), and like a radio that produces a jumble of sounds (until the radio receiver is hooked up to a transmitter, it is as if the radio is tuned to all possible channels at once). Quantum entanglement is like rolling a pair of dice (when one die is rolled, the outcome of the other die is predetermined, even if it is rolled on the other side of the gaming table) and like two dancers performing a perfectly synchronised dance routine (when one dancer moves, the other dancer moves in a coordinated manner, even if they are on opposite sides of the stage) [8].

Hilkamo & Granqvist (2022) find that metaphors for various quantum technologies help newcomers engage emotionally with the technology's promises and possibilities [9]. More recent work however, has revealed a growing dissatisfaction with metaphor as an approach to communication and learning. Some experts think metaphors make the subject either too complex or they convey too little, to the point where they're untruthful. Some commentators fear that metaphors simply deliver the sensation of glimpsing something difficult, and that the sense of difficulty lingers longer than the insight.

Impatience with metaphors may be an indication of the field's growing maturity. A recent large-scale experimental study found that metaphors offered no additional benefit over non-metaphorical explanations for enhancing understanding or shaping attitudes. Some experts participating in the study's preparation indicated that metaphors made quantum phenomena "unnecessarily complicated and mysterious, creating only more confusion" [10].

The risk is that we allow expressions of impatience from experts to discourage our use of metaphors and analogies in all circumstances. Through the usefulness of these rhetorical figures seems likely to diminish, the more the field matures, nonetheless people have to start somewhere, and if we judge the public negatively for gaining at least a sketchy understanding of the field, we miss the opportunity for genuine conversation.



Given the difficulty (actual or perceived) of communicating quantum science, it is sometimes tempting to sell QS&T to the public as a purely technological cornucopia.

Initial engagement can be achieved by discussing applications that will be of immediate personal benefit, particularly around medicine. But this approach may, with time, prove overly optimistic. Quantum technologies will eventually be applied to a very specific, limited set of problems, and while there have been spectacular breakthroughs, these remain "toy problems" that do not yet translate into generalised, market-ready gains or significant social impact.

In any case, studies show that the technological by-products of the second quantum revolution are not what people care most about. People are less interested in a sales pitch for the future and more

[7] See Alexei Grinbaum, "Narratives of Quantum Theory in the Age of Quantum Technologies," Ethics and Information Technology 19 (2017): 295–306, https://doi.org/10.1007/s10676-017-9424-6. [8] Meinsma, Aletta Lucia, W Gudrun Reijnierse, and Julia Cramer. Like a Coin Spinning in the Air: The Effect of (Non-)Metaphorical Explanations on Comprehension and Attitudes Towards Quantum Technology. (Pre-print) n.d. 9 Oona Hilkamo and Nina Granqvist, "Giving Sense to de novo Market Categories: Analogies and Metaphors in the Early Emergence of Quantum Computing," in Advances in Cultural Entrepreneurship, ed. Christi Lockwood and Jean-François Soublière, Research in the Sociology of Organizations, vol. 80 (Bingley: Emerald, 2022), 57–79. [10] Meinsma, Reijnierse & Cramer (in press).;

genuinely intrigued by the basic science. People have a real appetite for sceptical enquiry, and find quantum interesting because it is weird and fascinating [11] . One participant in a 2021 study by University of Leiden masters student Jesse van Welzenes specifically wanted to be kept up to date regarding setbacks in the field, since they revealed the critical thinking involved in research and development. For this participant, displays of critical thinking invoked trust more effectively than announcements of success.

That study was not large enough for us to draw any strong conclusions, but we noted a close analogy with space science, where people engage with astronomy, not because it occasionally gives us a new gadget, but because of the questions it asks about the universe. Enthusiasts of space science embrace the way ideas are revised and replaced in light of new evidence, and they typically treat setbacks as opportunities. Encouraged by this, we believe we should focus on the wonder and the mystery of the QS&T field, turning the public into active, critical thinkers instead of just a passive audience.

If we give a "balanced" view of a new technology, by listing all the promises and perils it brings in its wake, we offer a "view from space" that will more than likely leave people disengaged and confused about the technology's everyday relevance [12].

We have found it more effective to use strong emotions to get a conversation started.

Those that know a little about quantum technology most likely have read articles about quantum computing, and these articles will almost certainly have mentioned that quantum computers could one day break all the encryption that protects our banks and private data. Talking about specific, tangible threats like this, and what is being done to address them, is a legitimate and effective way to draw people's attention to the wider field of QS&T.

The public do not need reassurance; they need agency over their technology. The vexed history of the civil nuclear industry shows all too clearly how silence around a new technology is more than enough to make people afraid of it. In the 1950s and 1960s, when minor nuclear incidents occurred and were downplayed or kept quiet, the eventual discovery of these "secrets" made the technology seem inherently untrustworthy. By focusing on real-world issues like cybersecurity, we can give people a clear starting point for their engagement with the QS&T field.

Three big misconceptions about QS&T dominate the public narrative:

Misconception 1. The second quantum revolution is all about computation.

Quantum communication, quantum sensing, and quantum simulation are all well-advanced in comparison to quantum computing -- and yet the public is hardly aware of these technologies.

[11] For examples, see Moraga 2020 and van Welzenes 2021 [12] https://arxiv.org/abs/2404.14104

Misconception 2. We'll all have a quantum iPhone one day.

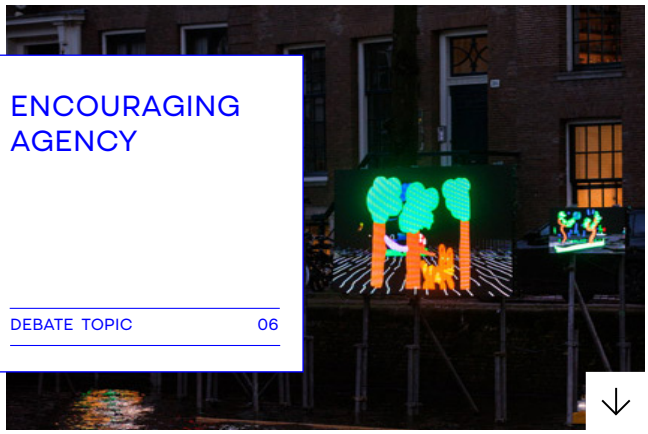
The infrastructure underpinning QS&T -- and quantum computing in particular -- is anything but unobtrusive. Citizens are largely unaware of the complex and massive infrastructure that will be required to enable the full flowering of the second quantum revolution.

Misconception 3. Quantum computation is a superpower that will be able to do everything.

In truth, quantum computing is expected to solve only a very limited set of specific tasks, and will in no way replace classical computation.

There's nothing uniquely scary or suspicious about quantum technology, but we must still consider how it will be received by a culture that has learned to mistrust science and expertise more generally.

Dawning awareness of the amount of infrastructure involved in quantum computing leads some to compare QS&T development to nuclear science, raising the spectre of quantum technology's "dual use" potential [13].



The roll-out of 5G broadband and official responses to the COVID-19 pandemic both triggered an efflorescence of conspiracy theories, illustrating how fetishised fears arise in communities who feel they have no agency over a technology [14].

Once we can make practical use of a technology, however, we tend to give it a free pass. In 2019, 5G made a visible change in the environment: its network of towers advertised its ubiquity: "Wherever you are in the world, our rays will touch you." Paranoia surrounding the roll-out reached epidemic proportions -- but largely evaporated the moment people found they could use the improved signal to watch films and television on their commute into work.

Perverse and fraudulent explanations germinate in ignorance. But it's the sense of absent agency that provides them with the medium in which to grow and spread [15].

Public engagement with QS&T has to be about more than education. Effective engagement must give the public tangible and effective agency over the field.

All technological innovation is met by some degree of pervasive anxiety based, not on intrinsic technical risks, but on a perceived lack of agency or comprehension, combined with a pre-existing societal mistrust of science.

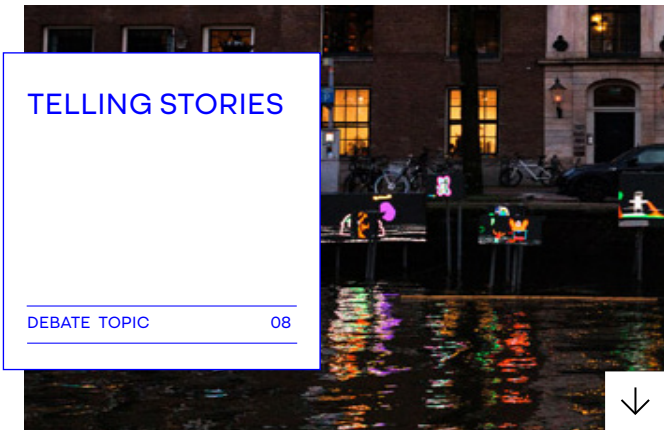
Fears highlighted in recent fieldwork include the fear that quantum technologies "will be used to control people." The concern that Xi / Putin want to monitor their citizens or even us is not completely absurd,

[13] See Jesse van Welzenes, "The Public View and Understanding of Quantum Mechanics and Technology: Setting the Stage" (master's thesis, Leiden University, 2021).; [14] Trijsje Franssen et al., "Creatively Deliberating on Quantum: Art-Based Creative Forms of Public Engagement to Emotional-Moral Deliberation on the Societal Impact of Quantum Technology" (OSF Preprints, March 27, 2025). [15] Gavin Francis, Adventures in Human Being: A Grand Tour from the Cranium to the Calcaneum (London: Profile Books, 2015), 184.

although the means to that end is irrelevant to them, so can be quantum or non-quantum. The fears might exist, but we should indicate this is only the case for public key encryption that has not migrated to existing solutions. Otherwise this statement might cause fear itself. Here are two more fears concerning the second quantum revolution:

- Quantum applications will break all current and future encryption efforts.
- The scale and cost of quantum infrastructure will widen the global tech gap to the profound disadvantage of poorer nation.

To build trust, CQS is developing modest, evidenced approaches to public messaging, focused on a 10- to 15-year horizon, within which both the opportunities and the risks afforded by quantum science and technology stand out clearly. Rather than stage tit-for-tat battles between positive and negative visions of the quantum far-future, CQS seeks to satisfy the public's real appetite for sceptical enquiry, and makes the most of the intrinsic intrigue of the basic science.



We believe public education should move beyond outdated "deficit models", where experts lecture to a captive public. We don't want to put technologists in loco parentis, saying, as to a child, "I hear what you're saying but I'm still strapping you into the child seat." On the contrary, public education should be a genuine dialogue, capable of influencing field's development.

Visions of the quantum future originating in the technological community describe what will happen should a particular development go as expected. They are issued as statements of expert opinion, and the public receive them as such. They are non-fictional, in the sense that they attempt (however speciously) to predict the actual future. Stories are different. They play with possibilities. They conjure up best-case and worst-case scenarios on the fly, in light of new information.

In fiction, we find a practical method to bring a sense of agency to public discourse. Because fiction is not asserted as absolute truth, it cannot be consumed passively. Rather, it is a creative act, where the audience helps co-create the meaning. Employed in a QS&T context, fiction allows for a more honest exploration of best-case and worst-case scenarios.

The application of science fiction to design was first formalised in the mid-2000s by Bruce Sterling, who coined "design fiction" to use narrative props as prototypes for future technologies. This approach evolved into a strategic methodology in the 2010s through initiatives like Intel's Science Fiction Prototyping and Neal Stephenson's Project Hieroglyph, which paired writers with engineers to inspire optimistic R&D.

Today the practice extends to systemic planning; authors like Kim Stanley Robinson model climate-resilient urban design, while specialised consultancies contract writers to help corporations and governments stress-test their strategies against complex future scenarios.

Design fictions don't pretend to any kind of ground truth. They are not asserted, and consequently they are not received or consumed in any passive sense. On the contrary, comprehending the meaning and value of a fiction is a creative act. Fiction is co-created by the author and the audience, as music is co-created by the composer and the musician.

And once we look past the bizarre futuristic context

of design fiction, we find that fundamental questions are being asked about the impact of technology on human flourishing.

SUMMARY

Terms like "spooky" or "weird" from early 20th-century debates have become "non-explanations" that can clutter, but rarely deter, public engagement.

Playfully framing quantum as "alien" or "impossible to understand" may fuel public anxiety if the technology becomes associated with sensitive areas like geopolitical struggles or breaking encryption.

The public does not naturally default to thinking that QS&T is "spooky" or "weird" unless prompted by experts; many find the basic science fascinating rather than frightening.

Metaphors and similes help newcomers engage emotionally and provide a starting point for understanding. As the field matures, however, both experts and the public are beginning to show impatience with these figures. Their usefulness diminishes as a participant's knowledge grows.

Effective communication must move away from experts lecturing to a "captive" public. People need a sense of agency, i.e. the power to influence the technology's development.

Admitting setbacks and being honest about technical risks builds more trust than a sales pitch of guaranteed success. Silence and absent agency - not the technology itself - are what cause conspiracy theories to grow.

Unlike expert "visions" that attempt to predict a non-fictional future, stories and "design fictions" allow the public to to explore best-case and worst-case scenarios.

03. Vision part - B - Strategic thinking

Since substantial public money is spent on QS&T, researchers have an obligation to engage society, and evaluation helps demonstrate the return on this investment in terms of public value rather than just expert enjoyment.

Current data shows that while citizens are positive about quantum technology, a majority feel they personally cannot influence its trajectory [16]. Evaluating public sentiment early in the development phase -- rather than waiting until applications are fixed -- allows for the identification of ethical, legal, and social implications while the technology is still shapeable.

We need to evaluate our communications activities to ensure that they are fostering genuine dialogue. We need to assess whether the public feels their values and concerns are being heard regarding the direction, scale, and speed of innovation. To maximise impact, we must think strategically, tailoring content to specific audiences and rigorously evaluating whether we are building the necessary trust and agency for responsible innovation (see Figure 04).

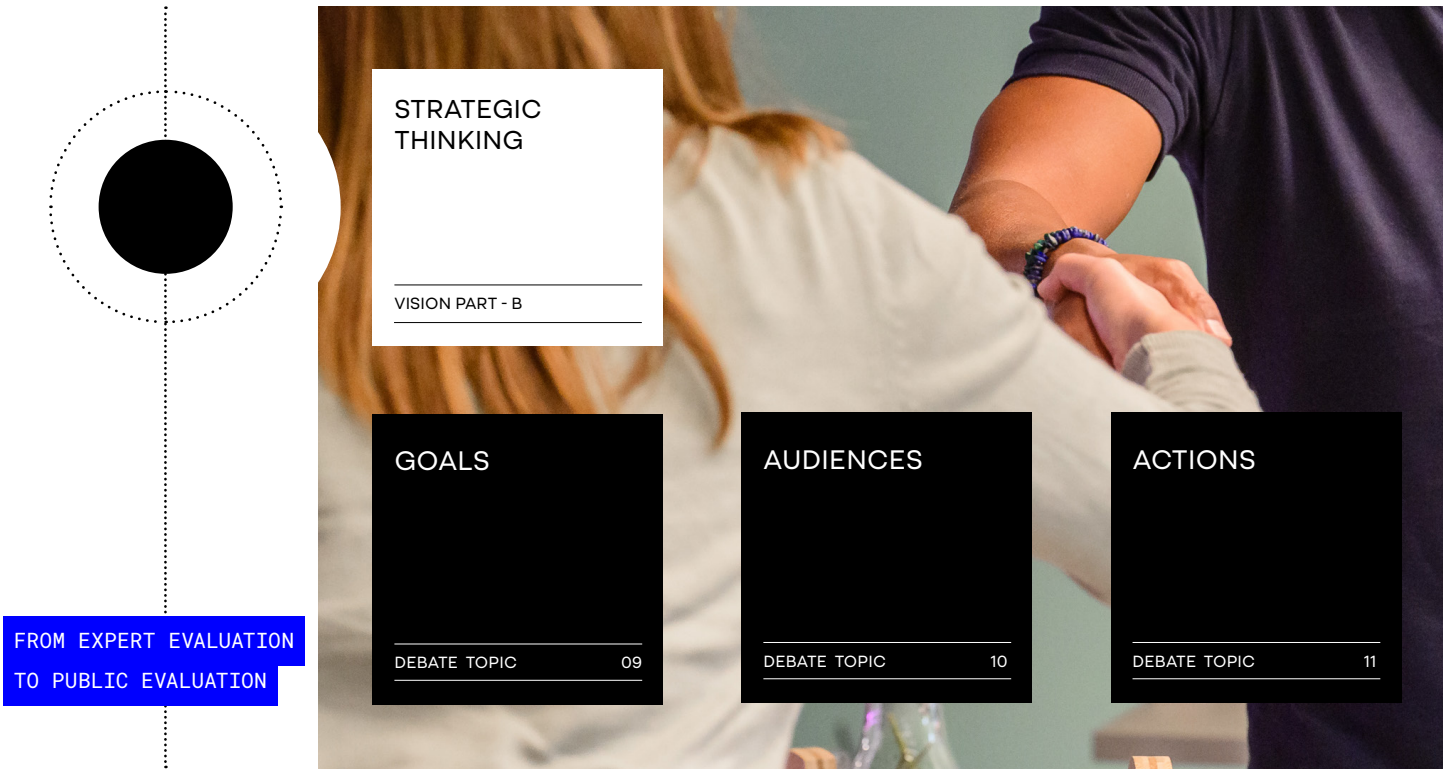
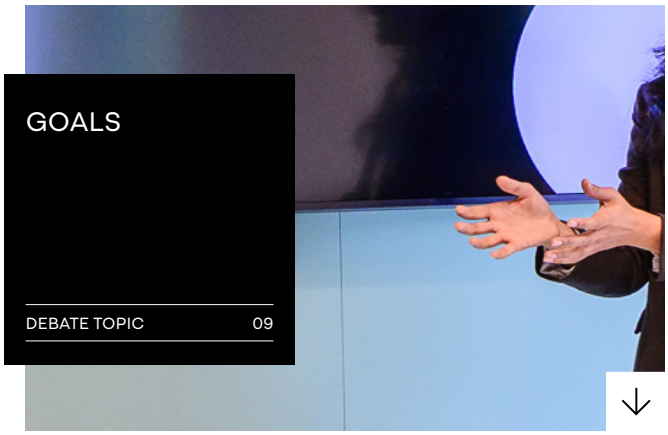


FIGURE 04: To maximise impact, QS&T visions to think strategically, tailoring content to specific audiences and rigorously evaluating whether we are building the necessary trust and agency for responsible innovation.

[16] The Leiden "Quantumverstrengeld" study demonstrated this point in stark terms, revealing that 60 per cent of citizens in the Vreewijk neighborhood of Rotterdam felt they could not influence its development.



Effective communication needs a specific, well-articulated goal. The following discussion of possible goals is far from exhaustive.

We may choose, for example, to foster intuitive understanding to bridge the gap between expert and lay knowledge. This approach challenges the misconception that quantum physics is too difficult for non-experts to grasp.

By explicitly linking the technology to tangible outcomes, such as improved healthcare, climate modelling, and data security, we can empower citizens to participate in the governance of science, ensuring innovation aligns with societal values rather than solely commercial or state interests.

More narrowly, we may want to counter specific instances of mystification and over-promising, providing in their stead realistic timelines and transparent acknowledgment of current technological limitations.

Since tools serve both civilian good and military or criminal harm, we may want to encourage a mature discussion about the dual use of quantum technologies, addressing both the opportunities (e.g., drug discovery, sustainability) and the risks (e.g., encryption vulnerabilities, inequality) to ensure a balanced perspective.

One major practical goal will be to attract talent beyond the physics community, appealing to engineers, software developers, legal experts, and business leaders to build the necessary infrastructure for a robust quantum ecosystem.

Or we may simply want to locate the QS&T field as an integral part of culture, and foster an appreciation for the intrinsic value of inquiry. By enhancing "science capital" -- a person's science-related knowledge, attitudes, and social contacts -- we can encourage lifelong engagement and support for fundamental research.

Moving from passive, "push" models of information delivery to an active models of engagement allows the field not only to define who it is speaking to, but to clearly measure the impact of its conversations.

Our audience can be categorised into five distinct groups. Each group has different engagement goals, ranging from democratic empowerment to commercial implementation.

Citizens generally hold positive attitudes towards quantum but feel they have no personal influence over it,. They often view quantum as "vague" or "spooky", though research suggests this sentiment is no barrier to learning. Our aim should be to build trust, manage expectations, and allow citizens to have a voice in how the technology shapes society. Favoured venues for communication are largely

informal and include festivals, escape rooms and art installations.

Students and young people generally often value the individual relevance of learning (curiosity, skill development) over abstract expressions of the field's social importance. To overcome the perception that quantum is "too difficult" or "not for me", science communicators seek to instil quantum literacy (see Figure 05). Spreading an understanding of quantum reasoning and logic at an early stage builds human capital for the field and ensures a future workforce. The best modes of address include gamified learning (e.g., Quantum Odyssey, Quantum Tic-Tac-Toe), and online courses. For instance, the QWorld network and its Q Cousins program have successfully organised more than 30 events in 18 cities and 13 different countries, handing out more than 600 diplomas for workshops that typically span two or three days. Real-world supplements to the high school curriculum include the Quantum Rules! school visit programme. Launched in Leiden in 2018, this structured educational intervention involves presentations and hands-on experiments. Surveys show it has had a positive effect on students' perception of the importance of quantum physics and technology [17].

Industry and business are focused on specific use cases such as drug discovery, financial optimisation, and logistics. This audience does not necessarily need to understand the underlying physics, but rather what the technology can actually do. Catalyst programs, innovation hubs and roadmaps best convey the field's market potential and economic impact.

Policymakers and government are mediators of the technology and require a realistic understanding of timelines to manage expectations and geopolitical risks. White papers, legal and societal soundboards, and strategic foresight scenarios provide the necessary knowledge to make informed decisions regarding ethics, legal frameworks, and security risks. The quantum workforce and hobbyists form a bridge audience between academia and industry, often engaging through open-source communities (see Figure 06).

Software developers and enthusiasts, for all that they lack a PhD in physics, are essential for building the software stack and tools. By encouraging non-academics to contribute to the ecosystem, we effectively democratise the field's development. Engagement method include hackathons (e.g., QHack), open-source software projects (e.g., Qiskit, QuTiP), and community discord servers. To leverage & apply new tech as a business advantage / differentiator / not too late to apply compared to competitors versus avoiding negative business impact.

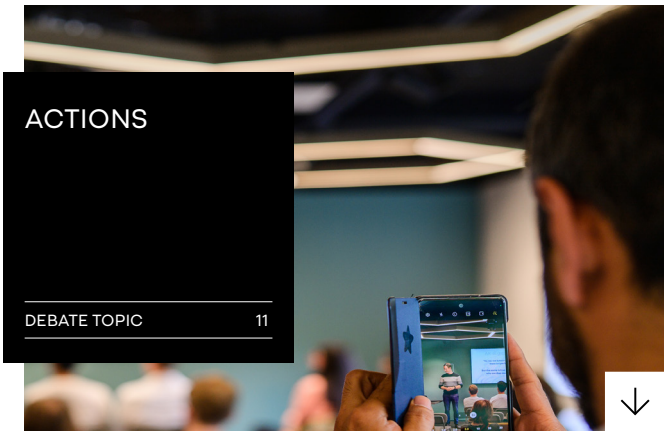
AUDIENCE: YOUNG PEOPLE

FIGURE 05: To overcome the perception that quantum is "too difficult" or "not for me", science communicators seek to instil quantum literacy.

AUDIENCE: QUANTUM ACADEMIA, QUANTUM INDUSTRY & BUSINESS, POLICYMAKERS AND GOVERNMENTS

FIGURE 06: The Quantum for Good day 2025 was organised to share forces between quantum academia, quantum industry & business, policymakers and government.

[17] Moraga-Calderón, Tania S., Henk Buisman, and Julia Cramer. "The Relevance of Learning Quantum Physics from the Perspective of the Secondary School Student: A Case Study." European Journal of Science and Mathematics Education 8, no. 1 (2020): 32-50.



The Centre for Quantum and Society (CQS), part of QDNL, employs a "creative action line" to engage the public the potential impact of quantum technology applications. This initiative moves away from the traditional deficit model (lecturing to fill a knowledge gap) toward "experience over explanation", using art, gamification, and theatre. We describe examples of the different types of CQS actions below.

Exhibits

Engagement cannot be increased simply by providing more and more information, and this may be why general pop-up exhibits are often perceived as rather boring. To measure the utility of such exercises, researchers studied the responses of 812 visitors to a quantum exhibit at the Lowlands Music Festival in Biddinghuizen, Netherlands. Quantum: The Pop-Up Exhibit was originally designed by the Institute for Quantum Computing in Canada. The exhibit aimed to communicate the impact and opportunities of quantum science and technology (Figure 07).

Thirteen panels of text, images, two videos and four interactive elements covered fundamental concepts such as superposition and wave-particle duality, alongside technologies like quantum computers, sensors, and networks. Using a pre- and post-survey design, researchers measured changes in four variables: attitude, concern, interest, and subjective knowledge regarding quantum science and technologies.

The impact assessment yielded mixed results, highlighting the complexity of public engagement in informal settings. The exhibit had little immediate impact on how visitors felt about the field, though visitors felt slightly more concern regarding quantum technologies -- a positive result, since the exhibit was designed to communicate the risks of quantum technology, as well as its benefits. The exhibit clearly increased visitors' confidence in their understanding of quantum concepts. However, participants reported a significant decrease in interest in learning more about quantum technologies after visiting the exhibit.

High initial interest in the exhibit may have been driven by the mystique or perceived novelty of quantum technology. By explaining the concepts successfully, the exhibit would necessarily dampen people's motivation to learn more. A negative result may simply reflect a visitors' feeling of satisfaction.

Ultimately, the analysis suggests that while exhibits are effective for knowledge transfer, future outreach should focus more on relatability and maintaining novelty to sustain public interest. The public responds with interest to exhibits that from a basis in scientific fact, explore potential technology applications and their impact on society. CQS is conducting research and gathering findings on the effectiveness of the following actions: games, experiments, theatrical events and creative workshops.

ACTIONS: EXHIBITS

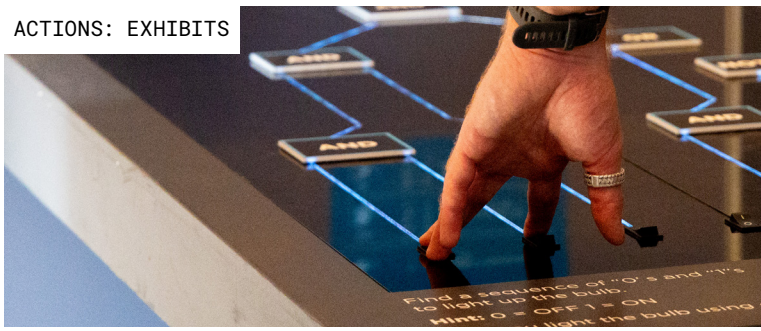


FIGURE 07: The Pop-Up Exhibit by the Institute for Quantum Computing at Lowlands aims to communicate the impact and opportunities of quantum science and technology.

Games

Gamified formats provide specific rule sets that remove barriers to conversation, allowing laypeople to interact with experts without needing a physics lecture first.

Quantum Tic-Tac-Toe adapts the traditional 3x3 grid to simulate three core quantum mechanics: superposition, measurement and entanglement, see Figure 08. (The format currently lacks a simple mechanic for interference.)

Quantum Escape Rooms provide hands-on agency, an embodidied learning experience, and leave participants feeling qualified to discuss the technology (see Figure 09).

Card and board games, in which players build portfolios of quantum innovations, offer hopeful glimpses of possible futures, free of industry hype and overpromising (see Figure 10).

One reason quantum is so hard to grasp is that we don't experience it in our daily lives, the way a child learns about gravity by throwing balls or toppling off the couch. Games can synthesise that intuitive experience by manipulating the player's sense of agency. The philosopher and gamer C. Thi Nguyen explains:

> ... when we play games, we take on an alternate form of agency. We take on new goals and accept different sets of abilities. We give ourselves over to different -- and focused -- ways of inhabiting our own agency. Goals, ability, and environment: these are the means by which game designers practice their art. And we experience the game designer's art by flexing our own agency to fit [18] .

Playing a game helps us understand something by engaging with a task. We are perfectly qualified

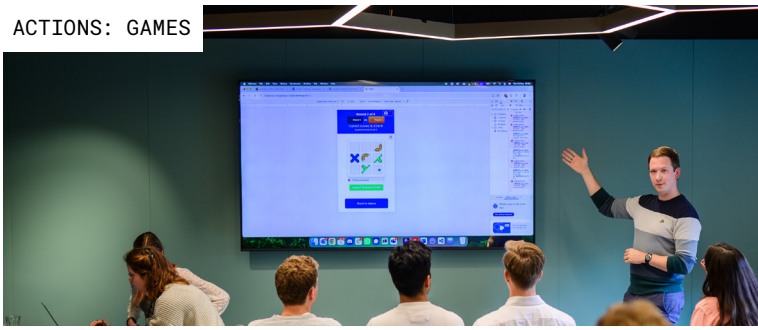


FIGURE 08: The game Quantum Tic-Tac-Toe allows laypeople to interact with experts without needing a physics lecture first.

FIGURE 09: The Quantum Escape Rooms provide hands-on agency, and leave participants feeling qualified to discuss the technology.

FIGURE 10: In the Quantum Applications Card Game players build portfolios of quantum innovations, critical materials and policy instruments.

[18] C. Thi Nguyen, Games: Agency as Art (New York, NY: Oxford University Press, 2020)

to talk about what we experienced in the game, even if we don't feel smart enough to discuss the complicated science that might underpin it. This creates a level ground across which people and experts have a real conversation.

Experiments

From our current vantage point, it seems unlikely that QS&T will ever prove as rich a source of "citizen-science" interventions as biology and astronomy. Still, the success and proven usefulness of such projects as 2007's Galaxy Zoo (which classified over 50 million galaxies in a year) and 2008's Foldit (which solved decades-long molecular puzzles in days) is tantalising. The field's limited capacity need not act as a brake on its aspiration.

Most likely, innovations in gamification will appear in the technological sector. Online hackathons like QHack successfully engage large developer communities (around 3,000 people in 800 teams), and by reducing the barrier to entry -- by providing pre-written code and requiring smaller solutions -- QHack's organisers massively increased the number of teams actively engaged and writing code [19].

Theatrical Events

Theatrical shows use performance, narrative, and visual metaphors to address societal impacts and visualise the world of the very smallest.

In November 2025 at the Amsterdam Light Festival, a theatre show for children featuring Quizzel (a personified photon) used the festival's medium of light (specifically lasers and colour splitting) to demonstrate the duality of light and the concept of particles occupying two states simultaneously, see Figure 11. Its young audience proved adept at handling counterintuitive concepts like wave-particle duality, and in imagining the future 50 years hence.

During the 2025 celebration at the Grote Kerk (Big Church), Enschede, household items like sugar water and olive oil were employed to demystify quantum science. Quantum for Everyone, a highly interactive

ACTIONS: THEATRICAL EVENTS

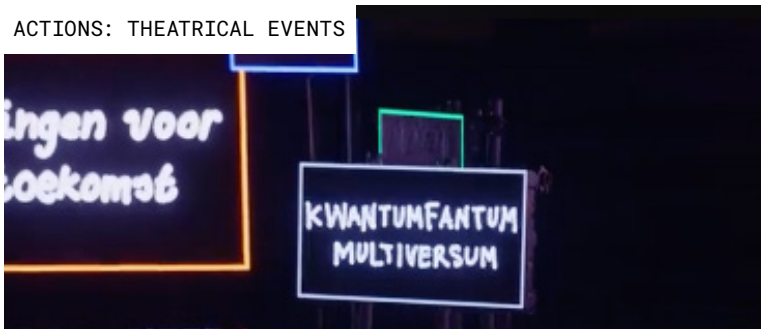


FIGURE 11: The Amsterdam Light Festival Amsterdam gave space to handle counterintuitive concepts for a young audience.

ACTIONS: THEATRICAL EVENTS

FIGURE 12: The Gala van Quantum en Samenleving was designed to view quantum technology "from the outside".

ACTIONS: THEATRICAL EVENTS

FIGURE 13: World Quantum Day was organised to promote the public understanding of quantum science and technology.

[19] Catalina Albornoz, "QHack: The One-of-a-Kind Quantum Hackathon" (paper presented at Quantum Science Days 2023, QWorld, May 29–31, 2023)

show, had the audience voting via lights and collective gestures to simulate particle connection.

On 14 March 2024, a theatre evening, the Gala van Quantum en Samenleving (Gala of Quantum and Society) was held at TivoliVredenburg in Utrecht, Netherlands, see Figure 12. Designed to view quantum technology "from the outside", the evening addressed moral and societal questions, through a script that explicitly used emotional adjectives like "bizarre," "spooky," and "magical."

World Quantum Day (first celebrated on 14 April 2022) is an annual, bottom-up initiative launched by scientists from over 65 countries to promote the public understanding of quantum science and technology, see Figure 13.

Creative workshops

We have found that creative workshops effectively shift focus from purely rational argumentation to emotional-moral deliberation, see Figure 14, creating a space where emotions are treated as valid sources of moral insight rather than obstacles to rationality.

In one pilot workshop, participants were asked to select emojis to represent their gut feeling regarding future technological scenarios. This playful method allowed participants to express complex feelings. For example, an expression of "fear" regarding surveillance allowed researchers to identify underlying moral values such as privacy and autonomy, which might not have surfaced in a purely technical debate.

Creative workshops function by emotionalising the technological debate. They use art and physical creation -- embodiment, materiality, and affect -- to help citizens articulate and deliberate on Quantum 2.0's intangible societal implication.

People need very little information about a new technology before they are able to articulate the emotional and ethical dimensions of that technology. This should not surprise, since people are emotional and ethical beings. Discussions in which emotions could play a role elicited articulate contributions about safety, privacy, health, sustainability and the kind of values a future technology might shape and serve. Since they bring to light important underlying values and fundamental questions about the impacts of new technology, good deliberation should incorporate space for emotional, creative – even disorderly – modes of communication [20] .

Creative workshops use prototyping or tinkering with simple materials (paper, foam, clay) to help participants make sense of abstract concepts. Through play, participants concretise their vague ideas about the future. The act of physical creation can alter the moral trajectory of the discussion. In one instance, a group discussing quantum computing started with a highly optimistic verbal discussion. However, once they began the hands-on activity of building a physical model (a "brain chip"), their focus shifted toward the terrifying potential of the technology, bringing values of personal identity and human nature to the fore.

Workshops dismantle the traditional hierarchy between expert and layperson. To prevent a formal or hierarchical atmosphere, introductory presentations on complex topics (like quantum physics) may be given by non-experts (e.g., philosophers) rather than physicists, while citizens are asked to envision their own future scenarios (e.g., "What will your life be like in 30 years?"), allowing the discussion to be driven by their own lived experiences and values.

ACTIONS: CREATIVE WORKSHOPS

FIGURE 14: Creative workshops effectively shift focus from purely rational argumentation to emotional-moral deliberation.

[20] Trijsje Franssen et al., "Creatively Deliberating on Quantum: Art-Based Creative Forms of Public Engagement to Emotional-Moral Deliberation on the Societal Impact of Quantum Technology" (OSF Preprints, March 27, 2025), https://osf.io/2kgqy.

04. Vision part - C - Evaluating outcomes

Outreach can have complex and sometimes counterintuitive effects. To successfully evaluate a piece of scientific communication, we have to look beyond comprehension to explore specific shifts in attitude, concern, interest, and engagement.
We are seeking out and testing evaluation methods that reflect the richness and complexity of the responses being studied, see Figure 15.

An increase in "concern", for example, may not necessarily reflect a failure of communication. A simultaneous increase in positive attitude and concern may indicate that an intervention successfully communicated both risks and benefits, a requirement for building trust. Evaluation is critical to detect when outreach fails to meet expected goals, as when, for example, an exhibit at the Lowlands music festival actually resulted in a moderate decrease in interest in the topic. Evaluation is also required to distinguish between perceived comprehension (feeling that one understands) and actual comprehension.

For example, while metaphors can increase actual understanding of phenomena like quantum superposition, they can simultaneously lower a reader's perceived comprehension of a text. Conversely, metaphors can sometimes create an illusion of comprehension where people believe they understand more than they do.

Specific media and rhetorical tools are being evaluated to determine their utility with different audiences and in different contexts. For example. evaluations of games like Quantum Odyssey or Quantum Tic-Tac-Toe suggest they are effective because they allow users to build intuition through experience and play, bypassing the intimidation of formal physics explanations.

Creative formats like art installations and videos, employed primarily to stimulate emotional-moral deliberation, need sensitive evaluation, since their outcomes can be hard to establish in metric form. Nonetheless, evaluation is necessary to verify their impact. One pilot study found that while an artistic video was intended to stimulate reflection, some participants criticised it for vagueness and a lack of information, suggesting that creative engagement must still provide a baseline of context.

In an effort to kickstart a broad conversation around evaluation methods in the QS&T field, The Centre for Quantum and Society has develops a standardised impact evaluation tool designed to assess public engagement activities.

FIGURE 15: QS&T is seeking out and testing evaluation methods to reflect the richness and complexity of the responses being studied

Our approach explains patterns in science participation based on a person's attitudes, knowledge, media consumption, and social contacts. The questionnaires were developed in collaboration with the Impactlab, a Dutch initiative that develops tools to measure the impact of science communication activities.

Recognising that emotional experience predicts long-term impact, the tool asks participants to rate their feelings immediately after the activity using descriptors like "bored vs. excited," "unhappy vs. happy," and "hopeless vs. hopeful". Participants are then encouraged to assess how the activity changed them. Statements include:

> "I want to participate in quantum-related activities more often."
>
> "I know more about quantum."
>
> "I foresee more problems due to the implementation of quantum."
>
> "I think it is important that quantum is included in politics and policy."

Organisers can append specific modules to measure different dimensions of engagement. As well as modules to measure objective knowledge, modules are available to test a participant's subjective knowledge, i.e. their confidence in their knowledge, and to measure along three axes -- personal, social and organisational -- the perceived relevance of the communication.

THE LIMITS OF EVALUATION

As we encourage attempts quantify the effectiveness of QS&T communication, we acknowledge that what is easily counted is not necessarily what is most important.

Outside structured events, we see positive outcomes from more dispersed, bottom-up efforts at community building.

The inaugural World Quantum Day, first celebrated on April 14, 2022, staged more than 200 events in over 44 countries, and in the second year the number of events more than doubled. Since then World Quantum Day campaigns have continued to enjoy significant success, measured in mass mobilisation and institutional support.

Nonetheless, the achievements of World Quantum Day (WQD) campaigns are hard to quantify. How, after all, is one to measure the sheer variety of events held under the WQD umbrella, never mind assess the specific value of a small festival in Leiden that in 2025 featured a vat of quantum soup -- "that is, an interpretation of what quantum would look like if it could be a soup"?

Some kinds of things are systematically harder to measure because they are more variable, more personal, or more delicate. C Thi Nguyen imagines an evening with friends to make this point vividly:

> The problem isn't that cheese and dinner parties are intangible. It's the precise opposite. The problem with them, from the perspective of the modern world, is that they're hard to abstract [21] .

[21] C. Thi Nguyen, The Score: How to Stop Playing Someone Else's Game (London: Allen Lane, (in press))

04. Conclusion

The transition of Quantum Science and Technology (QS&T) from theoretical physics to practical application is not merely a technical challenge; it is a societal one, see figure 16. As we navigate the "second quantum revolution," the communicator ceases to be a mere broadcaster of enthusiasm and becomes a facilitator of democratic agency. We must ask ourselves the critical questions: What are we communicating, and, more importantly, why? Are we communicating to fuel a hype cycle, or are

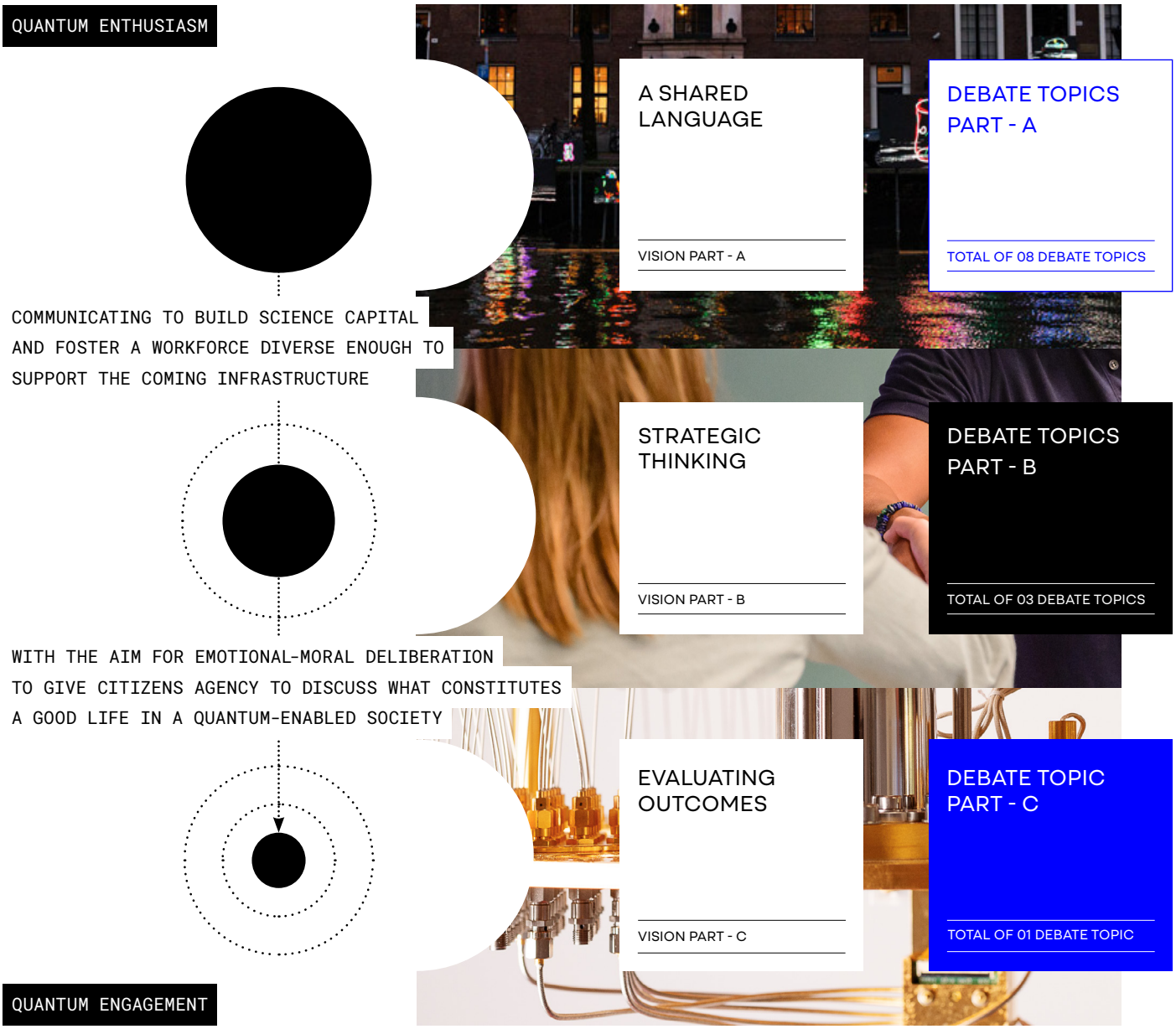


FIGURE 16: The vision for successfully communicating Quantum Science & Technology (QS&T).

we communicating to build science capital and foster a workforce diverse enough to support the coming infrastructure?

We must aim for emotional-moral deliberation, giving citizens the agency to discuss not just how the technology works, but what constitutes a good life in a quantum-enabled society. If we believe this technology has the power to disrupt encryption, alter geopolitics, and revolutionise medicine, we have a moral obligation to engage the public while the technology is still shapeable.

Good intentions are not a substitute for data. Enthusiasm alone is insufficient and can sometimes backfire. To ensure that our engagement strategies -- whether they be gamification, art installations, or educational curriculums -- are actually fostering understanding and trust rather than confusion or apathy, we must rigorously evaluate our efforts. We must measure not only objective knowledge retention but also changes in attitude, concern, and the perceived ability of citizens to influence the future.

There is much to do, and many other forms of assessment exist explore and consider for use in the the QS&T environment. These range from cheap and easy interventions -- voting jars, graffiti walls and "happy or not" kiosks, for instance, offer low-friction participatory feedback -- to complex IT-enabled feedback infrastructures. Observational and ethnographic assessments of events may include measuring how long attendees stay in specific areas, mapping crowd dynamics, and analyzing photos and videos to gauge emotional responses. With the right permissions in place, even interviews and long-form written feedback can be further processed through large language models for sentiment analysis.

We want to foster as many approaches to feedback as possible, always keeping in mind that what is important may not be measurable, and that measurement cannot in every instance substitute for expertise and taste. The incommensurability of different approaches need not disqualify any of them, and their correct field application will largely be a matter of trial, error and practice.

We believe such efforts are well worth the cost. By adopting shared metrics, by developing and distributing other methods of assessment, and by transparently assessing our successes and failures, we can build a responsible quantum ecosystem that safeguards society, engages diverse stakeholders, and advances technology for the common good.

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To get in touch, please reach out to Diederick Croese or Julia Cramer at cqs@qdnl.nl or visit the website of Quantum for Good.