Nanoethics (2024) 18:2
https://doi.org/10.1007/s11569-023-00449-y

ORIGINAL RESEARCH PAPER

Quantum Technologies: a Hermeneutic Technology Assessment Approach

Luca M. Possati

Received: 5 November 2022 / Accepted: 6 December 2023

Abstract This paper develops a hermeneutic technology assessment of quantum technologies. It offers a "vision assessment" of quantum technologies that can eventually lead to socio-ethical analysis. Section 2 describes this methodological approach and in particular the concept of the hermeneutic circle applied to technology. Section 3 gives a generic overview of quantum technologies and their impacts. Sections 4 and 5 apply the hermeneutic technology assessment approach to the study of quantum technologies. Section 5 proposes distinguishing three levels in the analysis of the creation and communication of social meanings to quantum technologies: (a) fictions, (b) popularization, and (c) scientific journalism. Section 6 analyzes the results and defines some lines of action to increase social acceptance and trust in quantum technologies. The aim of this paper is to contribute to the debate on quantum technologies by enhancing the reflection on them and their potential, as well as illustrating the complexity of technological innovation and the need to shape it.

Keywords Quantum technology · Hermeneutics · Technology assessment · Innovation

L. M. Possati (✉)
Delft University of Technology, Delft, The Netherlands
e-mail: L.M.Possati@tudelft.nl

Introduction

Analyzing and understanding the social impact of technologies has become an increasingly important political and scientific problem. It is clear that technological innovation does not necessarily lead to human and social progress; on the contrary, a high level of technological innovation can lead to very negative consequences, such as global warming, with all its harmful social and political repercussions (poverty, problems in energy and food management, etc.). In short, technology is not a univocal and transparent fact but ambiguous and ambivalent [1, 2]. Evaluating the development of technologies and making decisions about its orientation have therefore become increasingly difficult and require specific methodologies, such as responsible research and innovation [3], technology assessment [4, 5], value-sensitive design, science and technology studies (STS) [6], structural ethics [7], philosophy of design [8], and applied ethics [9].

The crucial question of this paper is as follows: How can we assess the ethical and social impact of quantum technologies (QTs)? QTs can be classified as emerging technologies, still at a very early stage of development. They are not yet fully developed technologies nor widespread in society. The methodological approach of this paper is the hermeneutic technology assessment. By this, I do not mean that hermeneutic technology assessment is the only possible methodology for assessing technological

Published online: 21 March 2024

innovation, nor do I mean that technology assessment (TA) can be reduced to hermeneutic TA. TA has many different aspects and forms (engineering TA, parliamentary TA, participatory TA, constructive TA), so it is not necessarily a single methodology.

The central thesis of hermeneutic TA is that if we want to study new emerging science and technologies (NESTs), we must follow not only a consequentialist approach (i.e., reflect on the possible future consequences of those technologies) but also a hermeneutic approach (i.e., analyze the social meanings that accompany the emergence of those technologies, as well as the public debate about them). The theoretical reference model of hermeneutic TA is the hermeneutic circle. The strength of this model—and the reason why I chose it—is that it provides a good way to solve the Collingridge dilemma, as I will show.

The paper is structured in the following way. After the "Introduction" section, the "TA and Hermeneutics" section concerns the methodology featured here. This section analyzes the hermeneutic TA approach and, in particular, the concept of the hermeneutic circle and narration (i.e., narratives are considered fundamental processes in the formation of the social meaning of technologies). The "Quantum Technologies: a Short Introduction" section gives a generic overview of QTs. The "TA and QTs: Preliminary Remarks" and "Studying the Hermeneutic Circles" sections apply the hermeneutic TA methodology to the study of QTs. The "Studying the Hermeneutic Circles" section proposes distinguishing three hermeneutic circles in the creation, assignment, and communication of social meaning to QTs: (a) fictions, (b) dissemination, and (c) scientific journalism. The "Defending Inclusion and Complexity" section explores the consequences of this analysis. The goal of this section is to formulate an assessment, that is, to identify the fundamental information to shape the decision-making process.

I want to clearly state two limitations of this paper.

The first is that because hermeneutic TA is a co-design process in which social legitimacy, as well as the dimension of inclusion, is essential, this research is only the first phase of a much broader process that must also include the participation of social actors, organizations and institutions, stakeholders, policymakers, politicians, researchers, designers, and "the public of citizens" [10]. Therefore, this paper aims to prepare the ground for future broader research by staging and contextualizing.

The second limitation is that this paper does not consider a specific, defined problem (e.g., the search for a nuclear waste disposal site in Germany). The general issue concerns the ethical and social impact of QTs. However, there are several types of QTs, and their consequences can be very different. Therefore, in this paper, I want to trace the general contours of the current debate on QTs, exploring the narratives about these technologies because narratives are critically important for public perception of technology and for the relationship between technology and society [5, 11]. Therefore, the present analysis is hermeneutic and aims to offer a potentially important source of information for prospective knowledge.

TA and Hermeneutics

TA has a long history that begins in the 1960s and 1970s and culminates with the decision of the US Congress to establish the Office of Technology Assessment (OTA) in 1972. The OTA was intended to be an advisory body supporting Congress in decisions relating to the use and development of technologies. The decision to set up the OTA was also the expression of a crisis of confidence in innovation, in the discovery of the limits of development, and in the ethical and social issues posed by new technologies [12]. The TA was therefore born as the answer to a social challenge caused by the growing complexity of engineering systems, the growing opportunities, and the conflicts of values they produce. This initial vision of TA was later overridden with the development of more participatory approaches, that is, aimed at including in the discussions not only members of parliament but also citizens and businesses. Over time, TA has evolved through variations such as participative TA or constructive TA ([12], 1115–1117; [5], 47–49; [13]), which partly depart from the initial model.

There are many definitions of TA, and I do not have the space here to analyze them all. Broadly speaking, TA "is a scientific, interactive, and communicative process which aims to contribute to the formation of public and political opinion on societal aspects of science and technology" [14]. TA "has been developing since the 1960s as an approach to explore possible unintended and negative side effects of technology, to elaborate strategies for dealing with them, and to provide policy advice, to support shaping technology, and to contribute to public dialogue" ([15], 110). The fundamental trait that distinguishes TA from other approaches to the study of technology, such as the ethics of technology or STS, is the problem of the democratic controllability of technology. TA is not just a work of analysis,it implies a direct intervention in public life that aims at the defense of democracy and therefore at the balance of powers and avoiding potential risks, such as paternalism or technocracy. Grunwald [15] distinguishes three main objectives of TA: (a) policy advice, that is, advising policymakers (parliaments, ministers, authorities) in making political decisions (e.g., on funds to invest) concerning the use and development of NESTs (e.g., AI, nanotechnology, brain research, synthetic biology, human enhancement, and human–machine interaction), (b) participatory TA (i.e., creation of a broad dialogue and comparison between stakeholders, citizens, media, and organizations in technology governance); and (c) building up empirical research on the genesis of technology (i.e., the idea of shaping technology according to social expectations and values). Therefore, TA is not an external observation but part of the game; the advice must be used to achieve better technology in a better society. "Technology assessment aims at creating impact and making a difference" ([5], 4). From this point of view, TA helps make a society more democratic and supports social transformation and innovation [16, 17].

In this section, I would like to highlight the need for TA, underlined by Grunwald [18], to overcome the consequentialist paradigm and integrate the latter with a hermeneutic approach aimed at the identification, analysis, and understanding of social meanings attributed to NESTs.

Let us analyze Grunwald's [18] argument:

1. We cannot study the ethical and social consequences of NESTs because they simply do not exist yet, so to claim that the object of TA is the future consequences, risks, and opportunities of NESTs is wrong. We do not know these consequences; we cannot study them. We cannot have any knowledge of the future consequences based on data, facts, and evidence. Any scenario built on imagined or vaguely foreseen consequences is not knowledge but only a set of very often arbitrary and prejudicial views.
2. The object of TA cannot even be the technology itself. For TA, technology is not interesting in itself (from a technical point of view), but it becomes interesting when it spreads in society and produces socially relevant consequences. In the case of NESTs, however, there is neither technology nor the relationship between technology and society.
3. Therefore, the only object of TA may be the current communication processes on NESTs (futuristic visions, scenario analysis, prototypes, fantastic stories, debates, projects, evaluations, etc.). Grunwald ([18], 14) calls all these processes "the imaginations of future sociotechnical configurations." These (a) are processes of assigning social meaning to NESTs, (b) shape the vision and debate on these technologies, (c) determine their social acceptability, and finally, (d) influence institutions' decision-making processes. "Societal meaning is assigned to projections and visions of new technology all the time" ([18], 101), TA does not explore the future presents "but considers present futures and present imagination of the futures" ([5], 84).
4. Only in this way TA can solve the Collingridge dilemma, according to which "when change [in technological innovation and development] is easy, the need for it cannot be foreseen; when the need for change is apparent, change has become expensive, difficult, and time-consuming" (Collingridge [82], 24). The assignment of a social meaning begins in the early stages of the development of a technology; although we cannot know anything about the consequences, we can identify and understand the meanings that are attributed to that technology from the start, and therefore also try to understand its possible ethical and social impact. The consequentialist paradigm, on the other hand, remains subject to the Collingridge dilemma and its radical distinction between an earlier phase and a later phase in the development of technology.

Grunwald's [18] conclusion is that the objects of TA are all the processes of creating and assigning social meaning to NESTs. Therefore, TA must become *hermeneutic* TA. This does not mean eliminating the consequentialist paradigm. The analysis of the social meanings attributed to NESTs must be the basis for (a) understanding possible risks and opportunities and (b) orienting and shaping the public debate at institutional and non-institutional levels.

The notion of meaning could be obscure. However, Grunwald [18] has nothing ambiguous in mind. Social meaning is not a mysterious object but a communicative process, or a set of communicative processes, which can be described through a very precise model, namely the hermeneutic circle:

> According to philosopher Hans Georg Gadamer, the hermeneutic circle is an iterative process. By processing the circle, it is possible to gain a new understanding of the issue under consideration. Understanding in this sense happens in the medium of language and through conversations with others. Thus, the meaning of a specific NEST under consideration will change during processing the circle. At a specific point in time and within a particular discourse community, an agreement might be reached that represents a new understanding. However, this new meaning will again be subject to further challenges by interventions from other authors. Thus, the circle develops as a spiral of ongoing change, continuous modification, and learning ([15], 105)

The first stimulus that activates the hermeneutic circle is the link between research and development in social problems. Possible consequences or future predictions related to certain technologies are significant for society because they can cause disruptive changes. The concept of the "Great Singularity" [19] and the book *What Computers Can't Do* [20] are good examples of changes in the debate about AI. An initial stimulus arises from competing narratives, science fiction books or films, forecasts, debates, conferences, workshops, institutional or corporate reports, scientific journalism, images, and more. The role of the media is fundamental. The development of these creative and communicative processes, which materialize into artifacts (written texts, videos, images, discussions on social networks, posters, magazines, art, performances, podcasts, etc.), is not without consequences. These processes in fact produce expectations, hopes, or fears, which shape public opinion and therefore also public decisions, such as the agenda of governments and institutions, agencies' decisions about financing projects, and more. "Any societal meaning assigned to new technology is constructed, debated, and contested by various actors in ongoing communication while driving the respective hermeneutic circle" ([18], 103). Consequently, TA has to "observe the hermeneutic circles which could be relevant, not only at the occasion of a specific situation but also with its development over time. … [TA must] consist of careful observations of complex communicative processes of different kinds" (ibid.). Observing the hermeneutic circles that determine the assignment of social meanings, TA "also intervenes into the hermeneutic circle by feeding back new insights reached in its assessment process. In this sense, interventions of TA into the hermeneutic circle are part of a 'real-time' technology assessment" ([18], 104).

Quantum Technologies: a Short Introduction[1]

The term quantum technology (QT) refers to the technologies arising out of the so-called second quantum revolution [27]. The "first quantum revolution" brought technologies that are familiar to us today, such as nuclear power, semiconductors, lasers, magnetic resonance imaging, modern communication technologies, digital cameras, and other imaging devices. This first revolution resulted in nuclear weapons and energy,then, the classical computer gained a significant role. The second quantum revolution "is characterized by manipulating and controlling individual quantum systems (such as atoms, ions, electrons, photons, molecules or various quasiparticles), allowing to reach the standard quantum limit; that is, the limit to measurement accuracy at quantum scales" ([28], 2). Therefore, QT "is an emerging field of physics and engineering based on quantum–mechanical properties—especially quantum entanglement, quantum superposition and quantum tunnelling—applied to individual quantum systems, and their utilization for practical applications" ([28], 3; see also [29]).

[1] The literature on QT is continuously growing. I refer to some recent works: Osada et al. [21], Jaeger [22], Hoofnagle & Garfinkel [23], Sutor [24], Coenen et al. [25], Coenen and Grunwald [26].

One of the most important QTs is quantum information science. In classical information science, the elementary carrier of information is a bit that can be only 0 or 1. Instead, the elementary carrier of quantum information is the qubit. A qubit is a combination of two states $| 0\rangle$ and $| 1\rangle$ called "quantum superposition." This greatly increases the computing and information management capabilities. Another crucial quantum property used in quantum information science is quantum entanglement. Quantum entanglement refers to a strong correlation and synchronicity between two or more qubits, or quantum states, with no classical analog. Another crucial feature is the no-cloning theorem, which says that quantum information cannot be copied. This theorem has significant consequences for qubit error correction, as well as for quantum communication security.

The applications of quantum information science are numerous:

- *Quantum computing*. This refers to the utilization of quantum computers to perform computations. Although not fully developed yet today, quantum computers could solve some very highly complex problems that classical computers cannot solve. Quantum computing can be applied to simulations (discovery of new materials and drugs), cryptoanalysis (new powerful coding and decoding techniques), research and management (analysis of large amounts of data), optimization (highly complex computational problems), and machine learning and AI (faster and more effective automated learning techniques).
- *Quantum communication*. This refers to the exchange of information across networks that use optical fiber or free-space channels. In most cases, quantum communication is realized using a photon as the quantum information carrier ([28], 11). The main applications are quantum networking (transmitting quantum information across various channels), quantum key distribution (the diffusion of security systems in communications much more effective and safer than the current ones), and post-quantum cryptography (encryption techniques that should resist future quantum computer attacks).
- *Quantum sensing and metrology*. This field of QTs is the most advanced. There are several applications: quantum sensing (the development of much more powerful and accurate sensors), quantum imaging (the production of optical techniques capable of increasing image resolution), quantum clocks (much more precise time measurement systems for satellite navigation, space systems, defense, network synchronization, finance industry, etc.), and quantum radar technology (radar systems much more effective for navigation).

A single example is enough to understand the potential impacts of QTs. In 1994, Peter Shor showed that several important computational problems could, in principle, be solved significantly more efficiently using a quantum computer—if such a machine could be built [30]. He derived algorithms for factoring large integers and solving discrete logarithms rapidly—problems that the most powerful classical computer would take thousands or even millions of years to solve. This also suggested that anyone with a real-world quantum computer could break cryptographic codes, compromising the safety of encrypted communications and stored data and potentially uncovering protected secrets or private information. Our digital infrastructure, and basically anything we do online, is encrypted through cryptographic protocols based on the difficulty of solving factorization problems (i.e., the RSA algorithm). As a result, the first state or company that will develop a quantum computer powerful enough to run Shor's algorithm will have a huge strategic advantage over anyone else. The advantage here means that that state or company will be able to decrypt any messages of other states or companies violating their privacy and democratic values.

Wolbring [31] and Rosch-Grace and Straub [32] analyze social issues, especially those concerning equity, diversity, and inclusion (EDI), for specific marginalized groups in debates, policy documents, and the academic literature on QTs. The results of their survey pose a serious issue: "The quantum technologies-focused academic literature rarely if ever engages with the 'social' of quantum technologies" ([32], 24). However, their analysis also indicates opportunities for "broadening the quantum technologies discourse to the 'social' and to EDI, as well as for an increase in inter-intra-trans-disciplinary and intersectional collaborations" (Ibid.).

TA and QTs: Preliminary Remarks

The Starting Point of the Hermeneutic Circle on QTs

It is quite difficult to understand what is the initial stimulus of the hermeneutic circle for QTs. Certainly, Feynman [33] was the turning point, the beginning of the debate about quantum computing and computers (see [34]). Feynman suggested that a quantum computer could simulate physical processes that a classical computer could not. Such ideas were further developed in the work of David Deutsch. Deutsch formulated a quantum Turing machine. "Namely, what we now call the Church–Turing–Deutsch principle asserts that a universal (quantum) computing device can simulate any physical process" ([35], 2). Seskir and Biamonte [35] claim that quantum computing underwent an inflection point circa 2017 when "long promised funding materialized which prompted public and private investments around the world" (1). Techniques from machine learning influenced central aspects of the field,"on one hand, machine learning was used to emulate quantum systems. On the other hand, quantum algorithms became viewed as a new type of machine learning model (creating the new model of variational quantum computation)" ([35], 1). The next inflection point, they claim, would occur around when quantum computers will be able to solve practical problems.

I do not think that Feynman [33] can be considered the starting point of the hermeneutic circle on QTs. Not even the earliest textbooks on quantum computing, such as by Nielsen and Chuang [83], can be considered the initial stimulus. The debate about quantum mechanics and its practical applications is much older and more complex.

The real starting point of the hermeneutic circle on QTs should perhaps be identified in the debate between Einstein and Bohr in the early twentieth century. The debate was centered on the quantum nature of light and matter, particularly the different interpretations of the particle-wave duality. Einstein argued that light exists in the form of particles, while Bohr maintained that the wave nature of light cannot be ignored, and that particle-wave duality must be accepted. The discussions between the two men continued throughout the 1920s and 1930s and were fundamental to the development of quantum physics. This debate touched on some crucial questions in quantum mechanics that still influence research and the common imagination on these issues.

QTs and Other Technologies

The case of QTs cannot be compared with that of nanotechnologies or AI. The evolution of the nanotechnology debate is quite clear: hype ➔ crisis ➔ normalization. As Grunwald [36] has shown, we can distinguish at least three phases: (a) The *hype*, with the start of the hermeneutic circle after the famous lecture by Feynman [37] and the book *Engines of Creation* [38]—public and private investments increase. (b) The second phase is the *crisis*, when, in the early 2000s, a new debate focuses on the risks associated with nanotechnologies, often painted with apocalyptic tones. (c) Third is the *normalization* [39], when the tone of the debate becomes much more balanced and there is a focus on concrete problems and realistic expectations (for more about nanotechnologies, see [13], Chapter 4).

This scheme is much more complex in the case of AI. Here, we do not have such a clear trajectory (hype ➔ crisis ➔ normalization). The relationships between science fiction, popularization, philosophical reflection, scientific investigation, and technological development are in fact much more complex. Following Wooldridge [85], I propose to broadly distinguish at least five phases that correspond to as many hermeneutic circles:

1. *The golden age* (1956–1974). The classic starting point is the workshop in Dartmouth in 1956, which was followed by an era of heavy investments. Science fiction played a very important role in this phase: Famous examples of AI are Robby in *Lost in Space* (1965/68) and HAL in *2001: A Space Odyssey* (1968). *Do Androids Dream of Electric Sheep?* by P. Dick (1968) and *I Have No Mouth, and I Must Scream* by H. Ellison (1967) must also be mentioned here.
2. *The first winter of AI* between 1970 and 1980. Two reports contribute to this crisis of trust and investments: that of the phenomenologist philosopher H. Dreyfus in *Alchemy and AI* (1972) and the Lighthill Report (1972).

3. *The emergence of the symbolic paradigm* (1970–1980). This was the moment of the triumph of expert systems, for example Cyc, based on a representation of knowledge linked to logic and sets of well-defined rules. However, it was a very short phase, which ended with the crisis of the symbolic paradigm and the Brooksian revolution.
4. *The Brooksian revolution* (early 1990) corresponds to the passage from the symbolic paradigm to the behavioral paradigm, the so-called agent-based AI. It began with an article published by Rodney Brooks in [40]: "Intelligence Without Representation." This is the premise for the statistical approach to AI.
5. *The new golden age* (2000–2022). After the Brooksian revolution, an exponential increase in the success of AI takes place around the world. The Brooksian revolution was the premise of the machine learning revolution, which officially began in 2014 with the acquisition of Deep Mind by Google. This revolution fed a new AI imaginary. A few examples are Kurzweil and the idea of singularity [19], Tegmark's [41] transhumanism, and the problem of control in Russell [42]. Movies such as *Ex Machina* (2014) and *Her* (2013) are the manifestos of this new era of AI in which human beings rethink themselves and their future in relation to machines.

Nanotechnologies and AI are technologies that affect important sensitive aspects of human identity such as intelligence and the ability to modify the performances of the human body. Therefore, the debate on them has generated strong and complex reactions. These technologies are rooted in an ancient cultural tradition, as evidenced by Mary Shelley's story *Frankenstein* (1818).

The case of QTs is different. QTs appear today as an extension of previous technologies that could significantly enhance or accelerate. It is a problem to find whether QTs can bring something truly new, original, to the current technological landscape. From this point of view, QTs take up and extend interpretations, uses, and imaginary belonging to other technologies. The current challenge seems to be finding something that QTs do which is not yet already done (apart from doing things faster or more securely). Moreover, QTs are no less mysterious than AI (which works for reasons not completely understood). QTs seem much more immediately imagined in the sense that they are connected to an already formed culture and imagination, the ones related to quantum mechanics, i.e., the history of quantum mechanics, to its interpretations and how they have interacted with other disciplines and fields of culture (e.g., the dialogue between psychoanalyst Carl G. Jung and physicist Wolfgang Pauli, or the theology of John Polkinghorne).

Unlike other technologies, therefore, there are many imaginaries related to the quantum world, and these imaginaries have very different ethical, philosophical, spiritual, and political assumptions. The first crucial task of hermeneutic TA applied to these imaginaries is to know how to connect them and use them to understand the development of technological innovation and thus anticipate possible futures.

I propose to distinguish three aspects that are connected to three different types of interpretations of quantum mechanics. A certain kind of otherness is connected to each of these aspects—and the otherness is the most interesting philosophical category to analyze here:

- The philosophical aspect = ontological and logical otherness, search for an ontology and logic that are different from the classical ones (Quine, Whitehead)
- The psychological aspect = psychic otherness, idea of synchronicity as a collective unconscious different from the usual one (Jung, Pauli)
- The spiritual aspect = otherness in the sense of transcendence, the quantum world as a way to the divine (Capra, Polkinghorne)

In the remainder of this paper, I intend to show how these three aspects are also found in contemporary forms of imagination related to the world of quantum mechanics and QTs. I will analyze (a) science fiction dealing with quantum mechanics, (b) dissemination of quantum mechanics, and (c) scientific journalism on QTs. The purpose of section 5 is to analyze these three levels of the hermeneutic circle and identify their key elements. This is not to say that these are the only relevant aspects of the hermeneutic circle. There are certainly many others.

Studying the Hermeneutic Circles

Science Fiction

The technological applications of quantum mechanics are at the heart of the narrative of a novelist as important as Blake Crouch. In *Dark Matter* [43], the concept of quantum superposition and the many-worlds interpretation are essential to the plot—this is less clear in *Recursion* [44], though. As he said in some interviews, Crouch's interest in quantum mechanics began when he read an article on it in *Scientific American*. His fascination with the subject grew further when experimental quantum physicist Aaron D. O'Connell demonstrated that subatomic particles exist in quantum superposition. This led Crouch to ask himself, if microscopic particles occupy multiple realities, why not everyday objects, including people? What if a device could be built that allowed a person to exist in superposition? The many-worlds interpretation also plays an important role in *The Fold* by Peter Clines [45], where it is connected to two other subjects: time and space travel and teleportation—a connection already present in the famous TV series *Quantum Leap* (1989–1993), where the protagonist travels through time thanks to a quantum machine.

The importance of the connection between superposition, the many-worlds interpretation, and time travel is also confirmed by other two excellent examples: David Walton's *Superposition* [46] and Michael Crichton's *Timeline* [47]. In the latter, a company, the ITC, has invented a time machine that exploits the quantum multiverse. According to the ITC, technically, it is not possible to travel back in time. However, it is possible to travel in the multiverse (universes parallel to ours), which are apparently the same, but belong to epochs different from ours, both past and future. The same idea is at the core of *The Coming of the Quantum Cats* by Frederik Pohl [48].

Therefore, the multiverse and superposition are the most recurring themes in science fiction literature. These themes make up an imaginary that is often connected to a posthuman, or transhumanist, futuristic vision in which technology is able to redefine the human being, its identity and memory. Quantum mechanics is regarded as a worldview that radically transforms people's daily experience of things; this strangeness, translated into technology, has disruptive effects. Technologies based on quantum mechanics are considered something mysterious, which goes beyond human understanding, and therefore—precisely for this reason—can open up new scenarios for human life.

This is also illustrated in *The Quantum Thief* by Finnish novelist Hannu Rajaniemi [49]. In this novel, an alliance called the Sobornost is in conflict with a community of quantum-entangled minds who adhere to the "no-cloning" principle of quantum information theory. Most of this community, the Zoku, was devastated when Jupiter was destroyed with a weaponized gravitational singularity. The last remnants of near-baseline humanity exist on the mobile cities of Mars, where advanced cryptography and an obsessive privacy culture ensure that the Sobornost cannot upload their citizens' minds. *The Flicker Men* by Ted Kosmatka [50] presents a more specific case. Central to the novel is the famous double slit experiment and its consequences for the problem of observation and collapse of the quantum wavefunction. These themes are interpreted in an almost theological sense and connected to issues such as freedom and fate. These topics can also be found in *The Rise and Fall of DODO* by Neal Stephenson and Nicole Galland [51].

These examples of science fiction about QTs show a specific bias, that of looking for a new technology in QTs, that is, for something *completely* new in technology (i.e., something *completely* different from what we already have). In this trend, we find all the three previously distinct aspects re-interpreted in a fantastical way. These fictions are completely disconnected from the reality of QTs. The point that my analysis intends to emphasize is that this kind of fiction may lead to a general attitude toward QTs that is entirely wrong and unrealistic, with consequences that could also badly affect public decision-making.

This bias can lead to false expectations about QTs and is based on a misconception of technological development and the complexity of "innovation journey" [13]. Many applications of QTs are only theoretical or still simple laboratory experiments. We do not really know yet what the implications and developments of QTs might be. Furthermore, some types of QTs (e.g., quantum computers) will probably not eliminate existing technologies (e.g., the existing digital computers) but will serve only to enhance them. Understanding the complexity of the technological innovation process is therefore essential because "actors tend to project a linear future, defined by their intentions, and use this projection as a road map—only to be corrected by circumstances" ([13], 58). Avoiding erroneous expectations also means avoiding negative reactions and lack of confidence and trust in QTs.

This bias of expecting a more accelerating technological innovation is deeply connected to a social phenomenon that strongly characterizes Western society at the beginning of the twenty-first century, namely "social acceleration." According to Rosa ([52], 4), "modernization is not only a multileveled process in time but also signifies first and foremost a structural (and culturally highly significant) transformation of time structures and horizons themselves. Accordingly, the direction of alteration is best captured by the concept of social acceleration." Social acceleration is, therefore, a multifaceted process that acts on a multitude of micro and macro levels of social life and is influenced by multiple cultural, economic, technological, industrial, and political factors. Rosa [52] distinguishes three forms of social acceleration: (1) technological acceleration, when there is a reduction in the amount of time it takes to achieve goal (i.e., oriented and intentional processes such as transport, or communication),(2) acceleration of the pace of life, scarcity of free time, and pressure for a more productive lifestyle; and (3) acceleration of society as a whole, when society's rate of change quickens so that there is a contraction of the amount of time it takes for social changes to occur.

Science Dissemination

Some aspects of this imaginary (the strangeness of quantum mechanics, superposition, multiverse, etc.) can also be found in the scientific popularization of quantum mechanics. These two hermeneutic circles influence each other. To demonstrate this, I want to consider some important examples of dissemination about quantum mechanics by physicists. In my opinion, these examples develop or encourage a certain image of quantum mechanics as esoteric and mystical knowledge, somehow "transcendent." These examples depict quantum mechanics and the technology based on it as something incomprehensible and far from everyday practical applications—in short, far from the normal life of human beings. The risk is that this attitude could turn into a bias, or rather the idea that these technologies have no contact with daily life, leading to the inability to see their consequences, especially the risks. This view can lead to technology determinism (i.e., a passive acceptance of technology and its consequences). The risk is that the idea of an "invisible hand" could also fuel the managers' and politicians' strategic intention to exclude alternatives and thus compromise the possibility of a truly democratic debate on these technologies (for a critique of technology determinism and social determinism, see [5], 159–167).

The first example I want to analyze is the book *Helgoland* [53] by Carlo Rovelli. Rovelli is an illustrious physicist, one of the main scholars of the problem of quantum gravity. In this fascinating book, Rovelli develops a relational interpretation of quantum mechanics in which the role of entanglement is fundamental. It is worth paying attention to the narrative style Rovelli uses, which is a narrative inspired by mysticism and esoterism. One of the central chapters of the book is in fact dedicated to the texts of Nagarjuna, who is one of the most important figures in Indian philosophy. Nagarjuna develops a metaphysical vision based on the concept of emptiness, whereby things are empty in the sense that they have no inherent reality but exist only in relation to each other. Rovelli's central goal, of course, is not to promote technological determinism but to convey the importance and extraordinary beauty of quantum mechanics.

The vision of quantum mechanics as esoteric, mystical knowledge that only a few initiates can truly understand is present in two other important books. The first is the famous *Tao of physics* [54], which explicitly links quantum mechanics with Hinduism, Buddhism, Taoism, and Chinese thought. The central theme is that of overcoming the principle of contradiction and developing a thought about the complementarity and unity of all things. This same orientation is taken up and amplified by Ricard and Thuan [55]:

> The Buddhist notion of interdependence is synonymous with emptiness, which is in turn synonymous with impermanence. The world is like a vast stream of events and dynamic currents that are all interconnected and constantly interacting. This concept of perpetual, omni-

> present change chimes with modern cosmology. Aristotle's immutable heavens and Newton's static universe are no more. Everything is moving, changing, and impermanent, from the tiniest atom to the entire universe, including the galaxies, stars, and mankind. (278)

Linking this kind of imaginary to the development of QTs can lead again to a form of technological determinism feeding false expectations and thus a failure to recognize the real possibilities that QTs provide. This lack of recognition can have serious ethical impacts, such as forms of Lysenkoism, i.e., a systematic distortion of scientific and technological reality in the name of political or economic interests.

Scientific Journalism

In studying the debate on QTs in scientific journalism, I analyzed about 200 articles published online, in English, and in the last 3 years (2019–2022). I analyzed these texts through NVivo software (release 1.6.2). Two search engines (Google and Bing) and three databases (Scopus, Google Scholar, IEEE Xplore) were used for this survey. The keys were very generic: "quantum technology," "quantum computers," "quantum sensing," "quantum communication," "quantum internet." I selected only those articles that take quantum technologies and their applications as the main subject (this means that I excluded all articles that consider quantum technologies in a derivative or secondary way).

The first result is that there are three prevailing themes in the current debate: quantum supremacy, quantum computing, and cryptoanalysis. Quantum supremacy refers to the advantage of quantum computers over classical ones (i.e., the ability of quantum computers to solve problems that classical computers are unable to solve) [56–58]. The first developer of a powerful, fault-tolerant quantum computer will have a long list of potential applications to choose from. Quantum computers could be used to transform the defense and space sectors, for example. Who will win the "quantum computing race"? Which company will demonstrate quantum supremacy first and how? What exactly does quantum supremacy consist of? How many qubits are needed for quantum supremacy? These are the questions at the center of most of the articles on this topic [59–63]. The metaphor of the "race" is dominant. For example, Al-Rodhan [64] talks about "the race for AI," linking it to quantum supremacy and the consequences of the latter in the geopolitical field, especially in the context of the confrontation between China and the USA. Yirka [65] analyzes the claims of two Chinese teams that say they have achieved quantum supremacy.

The insistence on the metaphors of "race," "hunt," and "competition" (especially the competition between the USA and China) risks forgetting a crucial aspect: that technological development is never isolated (i.e., QTs develop in connection with other technologies, such as AI or nanotechnologies) and that this effort is multilateral, in the sense that countries collaborate with each other. Any quantum race is intimately tied to developments in AI and cybersecurity. Nevertheless, it should not be forgotten that the Biden administration has recently approved a new set of restrictions on QTs as a strategic asset. Thus, the dominant political line seems to be to restrict competition and isolate direct competitors.

In the articles that I have analyzed, there is a clear prevalence of quantum computing compared to other possible applications of QTs. One hundred forty-one articles out of 200 are dedicated to the possible developments of quantum computing. A recurring metaphor (present in 75 articles) is that of the "new frontier" [66] connected to the idea that quantum computers can be applied to any type of problem and can surpass classical computers in any type of application—a false idea because in reality quantum computers are applicable only to a small group of highly complex computational problems,moreover, the practical and commercial utility of these devices has yet to be demonstrated. From this point of view, we can identify a hype that concerns specifically quantum computing. This hype has two opposite values: on the one hand, "hype can be considered harmless and even beneficial, often driven by researchers themselves seeking the attention of funders" [67], on the other, media coverage "dangerously misrepresents science in the public eye" (Ibid.). It is thus useful "to position hype on a spectrum, from uncertain but scientifically well-founded predictions about the future, to highly speculative claims based largely on conjecture, to the practically or scientifically absurd" (Ibid.). In 70 articles that I have analyzed, the level of hype on quantum computing was moderate (i.e., optimistic but aware of the limits and real applications of this technology). In 36, the level of hype was very high and unrealistic, going so far as to talk about quantum computing as the technology that will solve the problem of cancer or plagues, or even wars (see for example Greene [84]). In 34 articles, the level of hype was low, without futuristic pretensions: the number of optimistic statements was less than that of pessimistic statements.

The third theme I delved into concerns the so-called quantum threat [68], that is, the risk that quantum cryptography represents for all current communication systems, as I mentioned in the previous section. A sufficiently powerful quantum computer would be able to decrypt any type of existing communication, and this could have serious implications for governments, institutions, businesses, and even citizens. In this case, the articles examined focus on the current state of the algorithms (e.g., [69], the measures that banks are taking to prevent the threat (e.g., [70], the legislation to be defined to prevent the threats of quantum cryptography (e.g., [71], the state of post-quantum cryptography systems [72, 73], and the time remaining before facing the threat [74].

In the set of articles analyzed, expressions such as "revolution," "doomsday," and "earthquake" (i.e., expressions or metaphors that tend to create considerable expectations or excessive fears) occur very little and in a very limited number of articles. Also, the term "hype" appears very little in the articles analyzed. As shown by two recent articles published in the *Financial Times* [75, 76], the debate on the "hype" or "bubble" of QTs is still open and complex.

This does not mean that there is no hype about QTs—as I have shown, there is specific hype surrounding quantum computing. In academic research, the hype is more circumscribed to small circles. Roberson [77] examines the emergence of the notion of "quantum technologies" and the expectations shaping this field through an analysis of research grants funded by a national research funder, the Australian Research Council, between 2002 and 2020. It shows how "quantum technology" and "quantum computing" have come to dominate claims and expectations surrounding research in quantum science. These expectations do more than inform the scientific goals of the field. They also provide "an overarching, uniting rhetoric for individual projects and people and shape the uses imagined for quantum technologies" ([77], 1). This analysis shows how claims for this emerging technology draw on "breakthrough" metaphors to engage researchers and marshal investment and concludes by highlighting the need for increased clarity regarding expectations for QTs.

At the conclusion of this analysis, I make two groups of considerations.

The real risk is that this kind of imaginary and rhetoric may fuel the development of QTs as a power in the hands of a few groups of people that manage them esoterically, exclusively, imposing their rules on everyone else. This kind of imaginary can be used for political purposes (i.e., for supporting the politics of restrictions). Two scenarios are foreseeable in the mid-term: (a) the victory of a single player, most likely the USA, or China, able to reach a level of QTs development first such that it assumes an unchallenged monopoly position; (b) a duopoly based on competition between two countries, most likely the USA and China. In both scenarios, the risk of a quantum divide that would exclude and endanger less developed countries, especially those in the Global South, is very high.

What is needed is an intervention that is based on the following: (a) a more systematic view of QTs, able to understand the realistic opportunities and possible connections with other technologies and thus their integration into our already existing social and engineering systems; (b) a greater involvement of stakeholders, policymakers, and citizens in the evaluation and development process in order to enhance all perspectives. A recent report of the World Economic Forum (2022) has indicated nine key topics for governance: (1) transformative capabilities, (2) access to hardware infrastructure, (3) open innovation, (4) creating awareness, (5) workforce development and capacity building, (6) cybersecurity, (7) privacy, (8) standardization, and (9) sustainability. The recommendations about these topics pay particular attention to a set of seven core values that resemble many of the basic principles in computer, data, and AI science, i.e., (1) common good, (2) accountability, (3) inclusiveness, (4) equitability, (5) nonmaleficence, (6) accessibility, and (7) transparency. Now, it is evident that a crucial condition for the promotion of these values and governance principles is social awareness about QTs. Any kind of social awareness is based on the three fields we have analyzed: fiction, dissemination, and science journalism. Understanding the biases and trends in these fields is crucial to improve social awareness about these technologies.

Defending Inclusion and Complexity

Why do we need the reference to quantum mechanics to understand the novelty of QTs? Is this reference necessary? Would it not be enough to illustrate the applications of QTs to understand their novelty and potential? Does not connecting QTs to quantum mechanics illustrated as a strange and counterintuitive theory, to some extent mysterious, compromise the possibilities of understanding and accepting these technologies? An evaluation process should lead to the definition of a chain of if/then, that is, of alternatives connected to different possible scenarios. These alternatives should be defined on the basis of the knowledge used in the hermeneutic TA process. The purpose of this paper is not to build this chain of if/then about QTs but to define the context, "setting the stage" (i.e., to provide knowledge of the context in which the construction of the scenarios and the evaluations must take place).

From a regulatory point of view, TA is characterized by its *commitment to democracy*. This means that TA is not normative neutral. Instead, it is committed to the defense of democratic values such as justice, inclusion, the division of powers, and human rights. "Among the roots of TA was and still is the concern that scientific and technological advance does not per se support democracy" ([5], 97). The defense of inclusion also means avoiding any form of technological determinism that could lead to seeing technology as a superior power, impossible to orient and limit. This danger strictly concerns the hermeneutic circle, hence, the social meaning attributed to technology. We have seen, in fact, that this danger is present in the image that is given of quantum mechanics and QTs in popularization and science fiction. However, even the polarization of scientific journalism's interest on two issues (quantum supremacy and cryptography) can hinder the understanding and social acceptance of QTs (e.g., neglecting the positive effects these technologies can have to focus solely on the geopolitical confrontation between the USA and China). The main consequence of a lack of understanding and acceptance of technology is a lack of trust.

Another important problem is that QTs are invisible technologies in the sense that people cannot directly observe how they work. QTs are "noumenal technology" [78]. They therefore present a phenomenological paradox: "Technology is a human creation that involves human knowledge and serves human needs,this firmly roots it in phenomena, and it appears absurd to speak of technology that exists beyond human perception and experience among the things-in-themselves" ([78], 3). The noumenal world is "nature uncomprehended, unexperienced, and uncontrolled; it is nature in the sense of uncultivated, uncanny otherness" ([78], 3).

From this perspective, the role of TA must be to produce and/or encourage different narratives that are able to convey the complexity of QTs without reducing their understanding and therefore bring these technologies from the realm of noumena to that of phenomena, integrating them in the human experience. This also means showing the relationship between QTs and our current engineering systems and then showing how QTs will transform such systems by integrating into them and producing greater social cohesion (e.g., by developing safer, more effective, and more widespread communication systems, providing the possibility of improving administrative and decision-making processes, and yielding the possibility to discover new materials and drugs). Such narratives do not necessarily have to be based on the strangeness, or on the esoteric, of quantum mechanics. They must also be sensitive to the social context they address to include every social group, especially minorities. In this, philosophers of physics "can help in speeding up this change in framing quantum theory and thus in enabling all stakeholders to join the social debate on quantum technologies" ([79], 243).

A good popularization is an essential basis for generating trust and therefore responsible use of new technologies. As Grinbaum [86] claims, "quantum mechanics is typically accompanied by an aura of absolute novelty and total strangeness. For a popular account, it is crucial to dispel this aura" (302). This means that the technological complexities of QTs should not stop the debate on the ethical and social implications of QTs.

An objector might respond to this by pointing out that this is a false problem: few people really understand the complexity of AI, but this has not prevented the debate about this technology from developing.

This objection, however, seems wrong to me. There is a difference between AI and QTs. The real problem lies in the fact that while the complexity of AI is a computational complexity, i.e., an *epistemic* complexity, the complexity of QTs is related to the laws of quantum mechanics, i.e., it is an *ontological* complexity. This means that while in the case of AI we do not understand how it works but we *could* understand it (if we had more time, more capabilities, more resources, etc.), in the case of QTs we cannot understand it on principle (i.e., it is ontologically complex because of the inherent characteristics of quantum phenomena). The goal of hermeneutic TA applied to QTs should be to prevent the use of the ontological complexity of QTs to manipulate the public debate on QTs. The message should be that in-depth technical knowledge of quantum mechanics is not necessary to understand QTs and thus their applications. A layperson must be reassured that "even if quantum technologies are indeed strange, even paradoxical, they are less otherworldly than one may have feared. They are not divine or demonic, for they have parallels in human culture and in the history of ideas. Bringing them into everyday life would then become more routine and acceptable" (302).

One of the central aspects on which the popularization of quantum mechanics could focus—as Grinbaum himself suggests—is to convey the theory's sense of beauty. "Like other physicists, quantum theorists develop an intuitive aesthetic heuristic by working with the mathematical formalism of quantum theory. Mathematical reasoning leads to the emergence of a feeling of formal elegance, which subsequently serves as a thinking aid" (Grinbaum [86], 303).

As Ricoeur [80] suggests, narrative is the basis of ethics, in the sense that ethics always presupposes a narrative, personal, or social identity. If ethics is above all the desire for "the good life with and for others in just institutions" ([80], 171), this desire can only take on meaning starting from the narrative as a temporalization of human experience and therefore as a conferment of unity and meaning to this experience. In a nutshell, the narrative has ethical implications. For this, it is essential to understand how to narrate new emerging technologies to facilitate their social acceptance and awareness of the risks and opportunities involved. From this point of view, in the case of QTs, combining the beauty of theory with a more inclusive narrative that is attentive to the social context of the audience could be the basis for a better ethical approach to these technologies. It could also be a way to steer the development of these technologies in the right direction. As Grunwald [5] claims, "while technology can indeed be modified after it has been developed and produced only by spending great effort, its meaning can still be changed, e.g., by developing new targets and purposes for existing technology and innovation, or by putting it into another context" (193). As an "honest broker" and "mapmaker" [5, 81], the TA practitioner must first try to contribute to the hermeneutic circle, direct it, and thus strengthen the democratic dialogue on technologies. Hermeneutic TA is not external to the process it describes, analyzes, and guides.

References

1. Mitcham C (1994) Thinking through technology. University of Chicago Press
2. Nordmann A (2007) If and then: A critique of speculative nanoethics. NanoEthics 1(1):31–46
3. Van den Hoven J, Vermaas P, Van de Poel I (2015) Handbook of ethics, values, and technological Design. Springer, Dordrecht
4. Grunwald A (1999) Technology assessment or ethics of technology? Reflections on technology development between social sciences and philosophy. Ethical perspectives 6:170–182
5. Grunwald A (2019) Technology assessment in practice and theory. Routledge, London
6. Latour B (2005) Reassembling the social. Oxford University Press
7. Brey P (2014) From moral agents to moral factors: The structural ethics approach. In: Kroes P, Verbeek P (eds) The moral status of technical artifacts. Springer, Berlin, pp 124–142
8. Vial S, Vermaas P (2018) Advancements in the philosophy of design. Springer, Berlin

9. Chadwick R (ed) (2014) Encyclopedia of applied ethics. Elsevier, Amsterdam
10. Habermas J (1970) Toward a rational society. Heinemann, London
11. Grinbaum A, Groves C (2013) What is responsible about responsible innovation? Understanding the ethical issues. In: Owen R, Bessant J, Heintz M (eds) Responsible innovation. Wiley, London, pp 119–142
12. Grunwald A (2009) Technology assessment: Concepts and methods. In: Mejiers A (ed) Philosophy of technology and engineering sciences. Elzevier, Amsterdam, pp 1103–1146
13. Rip A (2018) Futures of science and technology in society. Springer, Wiesbaden
14. Decker M, Ladikas M (eds) (2004) Bridges between science, society, and policy: Technology assessment, methods, and impacts. Springer, Berlin
15. Grunwald A (2017) Assigning meaning to NEST by technology futures. Journal of Responsible Innovation 4(2):100–117
16. Owen R, Bessant J, Heintz M (2013) Responsible innovation: Managing the responsible emergence of science and innovation in society. Wiley, Chichester
17. Rip A, Misa T, Schot J (eds) (1995) Managing technology in society: The approach of constructive technology assessment. Pinter, London
18. Grunwald A (2020) The objects of technology assessment. Hermeneutic extension of consequentialist reasoning. Journal of Responsible Innovation 7/1:96–112
19. Kurzweil R (2005) The Singularity is near: When humans transcend biology. Penguin, New York
20. Dreyfus HL (1972) What computers can't do. Harper & Row, New York
21. Osada A, Yamazaki R, Noguchi A (2022) Introduction to quantum technologies. Springer, Dordrecht
22. Jaeger L (2019) The second quantum revolution. Springer, Dordrecht
23. Hoofnagle C, S., Garfinkel. (2022) Law and policy for the quantum age. Cambridge University Press, Cambridge, MA
24. Sutor R (2019) Dancing with qubits. Packt Publishing, Birmingham
25. Coenen C, Grinbaum A, Grunwald A, P., Vermaas. (2022) Quantum technologies and society: Towards a different spin. NanoEthics 16:1–6
26. Coenen C, Grunwald A (2017) Responsible research and innovation (RRI) in quantum technology. Ethics of Information Technology 19:277–294
27. Dowling J, Milburn G (2003) Quantum technology: The second quantum revolution. The Royal Society Publishing https://doi.org/10.1098/rsta.2003.1227
28. Krelina M (2021) Quantum technology for military applications. EPJ Quantum Technology 8:24. https://doi.org/10.1140/epjqt/s40507-021-00113-y
29. Ayoade O, Rivas P, Orduz J (2022) Artificial intelligence computing at the quantum level. Data 28:7. https://doi.org/10.3390/data7030028
30. Shor PW (1994) Algorithms for quantum computation: Discrete logarithms and factoring. Proceedings 35th Annual Symposium on Foundations of Computer Science, Santa Fe, 124–134
31. Wolbring G (2022) Auditing the social of quantum technologies. A scoping Review. Societies 12:41
32. Rosch-Grace D, Straub J (2022) Analysis if the likelihood of quantum computing proliferation. Technol Soc 68:101880. https://doi.org/10.1016/j.techsoc.2022.101880
33. Feynman RP (1982) Simulating physics with computers. Int J Theor Phys 21(6–7):467–488
34. Shor PW (2022) The early days of quantum computation. https://arxiv.org/abs/2208.09964
35. Seskir Z, Biamonte J (2022) Milestones in research activity in quantum computing. arXiv:2207.02857v1 [physics.hist-ph] 6 Jul 2022
36. Grunwald A (2012) Responsible nano(bio)technology: Ethics and philosophy. Pan Stanford Publishing, Singapore
37. Feynman RP (1959) Talk given on 29 Dec. 1959 at the Annual Meeting of the American Physical Society. California Institute of Technology, Pasadena
38. Drexler KE (1986) Engines of creation. Oxford University Press, Oxford
39. Grunwald A, Hocke-Bergler P (2010) The risk debate on nanoparticles: Contribution to a normalization of the science/society relationship? In: Kaiser M, Kurath M, Maasen S, Rehmann-Sutter C (eds) Governing future technologies. Springer, Dordrecht, pp 157–177
40. Brooks R (1991) Intelligence without representation. Artif Intell 47(1–3):139–159
41. Tegmark M (2017) Life 3.0. Being human in the age of artificial intelligence. Penguin, New York
42. Russell J (2019) Human compatible. Penguin, New York
43. Crouch B (2016) Dark matter. Crown, New York
44. Crouch B (2019) Recursion. Pan Macmillan, London
45. Clines P (2015) The fold. Crown, New York
46. Walton D (2015) Superposition. Pyr, New York
47. Crichton M (1999) Timeline. Knopf, New York
48. Pohl F (1986) The coming of the quantum cats. Bantam Books, New York
49. Rajaniemi H (2010) The quantum thief. Tor, New York
50. Kosmatka T (2019) The flicker men. Henry Holt, New York
51. Stephenson N, Galland N (2017) The rise and fall of DODO. Morrow, New York
52. Rosa H (2013) Social acceleration: A theory of modernity. Columbia University Press, New York
53. Rovelli C (2021) Helgoland. Riverhead, New York
54. Capra F (1975) The Tao of physics. Shambhala, Boulder
55. Ricard M, Thuan T (2001) The quantum and the lotus. Crown, New York
56. Arute F, Arya K, Babbush R et al (2019) Quantum supremacy using a programmable superconducting processor. Nature 574:505–510. https://doi.org/10.1038/s41586-019-1666-5
57. Brooks M (2019) Beyond quantum supremacy: the hunt for useful quantum computers. Nature (3 October) https://www.nature.com/news
58. Giles M (2019) Here's what quantum supremacy does – and doesn't – mean for computing. MIT Technology Review, Cambridge (MA) (September 24)
59. Rincon P (2019) Google claims 'quantum supremacy' for computer. BBC News https://www.bbc.com/news/

60. Sparkes M (2022) Quantum supremacy has been achieved by a more complex computer. New Scientist https://www.newscientist.com/article/2290832-quantum-supremacy-has-been-achieved-by-a-more-complex-quantum-computer/
61. Garisto D (2021) China is pulling ahead in global quantum race, new studies suggest. Scientific American, New York (July 15)
62. Green T (2022) Google wants to win the quantum computing race by being the tortoise, not the hare. TNW, New York (March 24)
63. Raj A (2022) IBM unveils new roadmap for quantum computing supremacy. Techwire, New York (May 12)
64. Al-Rodhan N (2022) The race for AI, quantum supremacy. Modern Diplomacy, New York (August 18)
65. Yirka B (2021) Two Chinese teams claim to have reached primacy with quantum computers. Phys.org https://phys.org/news/2021-10-chinese-teams-primacy-quantum.html
66. Randieri C (2023) Quantum computing: the next frontier or a hype-filled bubble. Forbes Technology Council (Feb. 27) https://www.forbes.com/sites/forbestechcouncil/2023/02/27/quantum-computing-the-next-frontier-or-a-hype-filled-bubble/?sh=6df584726d03
67. Meyer J, Pollock S, Wilcox B, Passante G (2023) How media hype affects our physics teaching: the case study of quantum computing. Phys Teach 61(339):342
68. Mone G (2020) The quantum threat. Commun ACM 63(7):12–14
69. Kommadi B (2022) The current and future state of quantum algorithms. Forbes (August 3) https://www.forbes.com/sites/forbestechcouncil/2022/08/03/the-current-and-future-state-of-quantum-algorithms/
70. Clancy L (2022) Banks may spend 'billions' to stop quantum hacking threat. Risk.net (July 27) https://www.risk.net/risk-management/7952386/banks-may-spend-billions-to-stop-quantum-hacking-threat
71. Kelley A (2022) More quantum-focused legislation aims to implement stronger cryptography standards. Nextgov (July 21) https://www.nextgov.com/cybersecurity/2022/07/more-quantum-focused-legislation-aims-implement-stronger-cryptography-standards/374787/
72. Lapienyte J (2022) Post-quantum encryption algorithms underrigorous scrutiny: expect more hacks. Cybernews (August 8) https://cybernews.com/editorial/post-quantum-encryption-algorithms-under-rigorous-scrutiny-expect-more-hacks/
73. Spiegelman K (2022) Now is the time to plan for post-quantum cryptography. DarkReading https://www.darkreading.com/dr-tech/now-is-the-time-to-plan-for-post-quantum-cryptography
74. Underwood K (2022) The quantum cryptography conundrum. AFCEA International (April 27) https://www.afcea.org/signal-media/quantum-cryptography-conundrum
75. Benjamin S (2022) Separating quantum hype from quantum reality. Financial Times, London (September 2)
76. Gourianov N (2022) The quantum bubble. Financial times, London (August 25)
77. Roberson TM (2021) On the social shaping of quantum technologies: An analysis of emerging expectations through grant proposals from 2002–2020. Minerva 59:379–397
78. Nordmann A (2006) Noumenal technology: Reflections on the incredible tininess of nano. In: Schummer J, Baird D (eds) Nanotechnology challenges: Implications for philosophy, ethics and society. World Scientific Publishing, Singapore, pp 49–72
79. Vermaas PE (2017) The societal impact of the emerging quantum technologies: a renewed urgency to make quantum theory understandable. Ethics Inf Technol 19:241–246
80. Ricoeur P (1992) Oneself as another. University of Chicago Press
81. Pielke R (2010) Expert advice and the vast sea of knowledge. In: Bogner A, Kastenhofer K, Torgersen H (eds) Inter-und Transdisziplinaritat in Wandel. Baden-Banden, Nomos
82. Collingridge D (1980) The social control of technology. St. Martin's Press, New York
83. Nielsen M, Chuang I. (2000) Quantum computation and quantum information. Cambridge University Press, Cambridge
84. Green T (2021) Quantum computers will win the next world war. TNW https://thenextweb.com/news/quantum-computers-will-win-next-world-war-3-three-artificial-intelligence-ai
85. Wooldridge M (2020) The road to conscious machines. The story of AI. Pelican, an imprint of Penguin Books
86. Grinbaum A (2017) Narratives of quantum theory in the age of quantum technologies. Ethics Inf Technol 19:295–306