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Between Scylla and Charybdis: Navigating The Imagined Future Of Quantum Technologies For Healthcare

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BETWEEN SCYLLA AND CHARYBDIS: NAVIGATING THE IMAGINED FUTURE OF QUANTUM TECHNOLOGIES FOR HEALTHCARE

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Abstract

While quantum sensors have been used in healthcare for a long time, new quantum technologies, such as computing and communication, are promised to advance the field in different ways. With the technologies still emerging, questions are being raised about their impact, who will benefit, and what unintended consequences may arise. This study, therefore, explores how quantum researchers and clinical physicians perceive the future of quantum technologies in healthcare using the concept of vanguard visions. 27 semi-structured interviews uncovered four prominent perspectives, that offered cautiously optimistic visions of the technologies' feasibility. The vanguards highlight the importance of effective science communication to mitigate hype, to pinpoint use cases where quantum provides real benefits over classical systems, and to foster ecosystems that are driven by cross-disciplinary collaboration to ensure more holistic developments. Stakeholders emphasize the wish for public infrastructure and joint developments to avoid monopolies and guarantee fair access to healthcare.

Keywords: Vanguard Visions, Digital Futures, Quantum Technologies, Healthcare, Semi-Structured-Interviews

1 Introduction

In the last few years, we have seen significant progress with quantum technologies (QTs), raising questions about their societal impacts. The field usually differentiates between quantum sensing, which offers greater measurement precision, quantum communication, which ensures secure messaging, and quantum computing, which can perform calculations faster or more efficiently than classical systems, potentially benefiting sectors like transport, finance, and healthcare (Hoofnagle & Garfinkel, 2022). Promises seem especially high for healthcare: from the simulation of chemical processes to accelerate the development of new drugs to genome sequencing for improved diagnostics or personalized medicine (Allcock et al., 2022; Baiardi et al., 2023; Heidari et al., 2024; Innovate UK, 2024; Jeyaraman et al., 2024; Niraula et al., 2021). These technologies appear to be the answer to some of the biggest problems in healthcare today, such as inefficiency, reactive rather than preventive care, and the difficulty of treating complex diseases. While, e.g., quantum computing is still in the experimental stage, quantum sensors are already being used in clinics for imaging and precise diagnostics (Edelman, 2014). The promises around the technologies, in combination with continuous developments make them increasingly attractive. Investments and research projects by institutions such as Denmark's Novo Nordisk Foundation[1] or the Cleveland Clinic[2] illustrate the growing interest. The Cleveland Clinic, for example, has been working with IBM to accelerate research in healthcare and life sciences using quantum computing, high-performance computing and artificial intelligence (AI) – a $565 million

[1]https://novonordiskfonden.dk/en/projects/novo-nordisk-foundation-quantum-computing-programme/
[2]https://newsroom.clevelandclinic.org/2023/03/20/cleveland-clinic-and-ibm-unveil-first-quantum-computer-dedicated-to-healthcare-research

initiative by the state of Ohio. It is currently difficult to say to what extent these applications will actually be adopted, given that there are still a number of technological hurdles to overcome and concrete use cases are still being tested, especially true for quantum computers (Preskill, 2025). Consequently, it is impossible to predict with any certainty which solutions will be feasible in the long run, which stakeholders will benefit from them, or what the potential unintended consequences may look like. However, attempts to engage with emerging technologies face a critical tension: they risk being either too speculative to be trustworthy or too late to influence the outcome, also called the technology control dilemma or caught between Scylla and Charybdis[3], as Grunwald (2010) characterized it. On the one hand, there is the danger of being "too late" with one's assessments and waiting until quantum applications are so deeply integrated into the medical infrastructure that meaningful intervention becomes impossible. On the other hand, there is the danger of being "necessarily too speculative", i.e., undertaking an ethical and social analysis that is so far removed from the technological realities that it becomes irrelevant to the actual development processes. Early engagements with vanguard visions, however, offer a useful perspective for dealing with this tension – not by predicting the future, but by examining which visions of the future are being created, what consequences they might have, and whether certain technological pathways should be changed (Grunwald, 2024; Hilgartner, 2015).

Given these circumstances, this paper is devoted to analyzing the competing visions shaping the future of QTs for healthcare using the concept of *vanguard visions*. Intertwined with Sociotechnical Imaginaries (STIs), vanguard visions are to investigate early visions of digital futures to reflect on technology developments and society (Grunwald, 2024; Grunwald et al., 2023; Hilgartner et al., 2015; Schlagwein et al., 2025). The assessment of such visions from relevant stakeholders sheds light on the underlying assumptions, values, hopes, and fears tied to a technology. Furthermore, research has shown that collective imaginaries are highly influential, shaping research priorities, regulatory approaches, and investment decisions (Grunwald et al., 2023). These insights, therefore, serve as a foundation for discussions about ethics and responsibility and help to shape innovations that align with societal interests, particularly in an important domain like healthcare.

While the STIs surrounding QTs have drawn increasing scholarly attention (Inglesant et al., 2021; Nguyen, 2025; Possati, 2024), an analysis that specifically addresses visions in the medical field is missing. This oversight is unfortunate, given the progress made in this area. Furthermore, having in-depth conversations with domain-specific vanguards is important to ensure that the technologies best serve the needs of the sector. This paper therefore explores how QTs are envisioned in healthcare, examining the values, assumptions, and power dynamics that drive the futures envisioned by vanguards. To do so, an exploratory qualitative approach was applied, beginning with 27 semi-structured interviews. Participants included quantum researchers, who are closest to the technology's development, and physicians, who are potential early adopters. Thematic analysis was then applied to their responses to understand the visions and to answer the following overarching question: *"What vanguard visions do quantum scientists and clinical physicians construct around the adoption of QTs in healthcare, and how do these visions reflect perceived opportunities, risks and responsibilities?"*

This work is made up of two contributions. Firstly, it introduces the concept of vanguard visions to the emerging field of digital futures in information systems research. Although imaginaries and visions are widely adopted, the concept remains theoretically inconsistent, leaving it unclear how to precisely investigate these concepts in a structured way (Brause et al., 2025; Kuchler & Stigson, 2024). To address

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[3] Homer's Odyssey tells the story of Scylla and Charybdis. Odysseus must cross the Strait of Messina and decide which of the two monsters to face. Scylla is a six-headed, man-eating monster that lives on one side of the strait. Charybdis is a powerful whirlpool on the opposite side that can swallow ships and sailors. Applied to technological development, the two monsters Scylla and Charybdis metaphorically describe the difficult task of assessing digital futures, with Scylla (coming to late), or Charybdis (being too speculative). This means that on one hand, waiting until a technology is completely integrated in society leaves little opportunity for change. On the other hand, the risk of being overly speculative, providing insights that are meaningless due to their extreme distance from technological reality. Approaches that asses digital futures however can help to navigate through this dilemma, carefully balancing premature speculation and delayed reactions, much like Odysseus navigating between monsters.

this, the paper adopts a framework based on the seminal literature as an operationalizable tool to investigate emerging visions around innovations. The methods section describes the analysis process. Secondly, the results give a general overview of the possible desired and undesirable future uses of QTs in healthcare. These insights are especially useful for developers of the technology itself, and institutions interested in integrating QTs, such as hospitals, while also providing valuable insights for regulatory bodies. The remainder of the paper is structured as follows. Section 2 reviews the literature and introduces the concept of vanguard visions as the theoretical framework. Section 3 outlines the method used, followed by Section 4, which presents the findings. Section 5 discusses theoretical and practical implications for the field of information systems, followed by a conclusion and agenda for future research.

2 Theoretical Background

2.1 Quantum Technologies for Healthcare

What may come as a surprise to some is that not all QTs are new to the medical domain. Quantum sensors, such as nuclear magnetic resonance, were used early on in the 50s, superconducting quantum interference devices, or SQUIDs, have been used for brain imaging since the 70s, and magnetic resonance imaging (MRI) has been used since the 1980s (Cohen, 1972; Degen et al., 2017; Edelman, 2014). In recent years, advances in fundamental research have paved the way for an increasing number of potential QT applications. The previous examples show why it is important to divide QT into three groups: quantum computing, quantum communication, and quantum sensing. Each group is developing at its own pace (Hoofnagle & Garfinkel, 2022).

Quantum computers are expected to outperform conventional systems in processing computationally intensive data once reliable, fault-tolerant systems are available. There is optimism that these computers will be the key to solutions in evidence-based medicine. Proponents of quantum computing hope for applications in drug discovery, personalized medicine, or molecular simulation, where quantum systems could advance complex modeling tasks (Allcock et al., 2022; Baiardi et al., 2023; Heidari et al., 2024; Jeyaraman et al., 2024; Niraula et al., 2021). Similarly, *quantum communication*, such as quantum key distribution (QKD) or quantum networks, is expected to work as a solution for protecting sensitive healthcare data from future cyber threats. This issue is mainly discussed in the context of a commercially viable quantum computer that, in theory, could break current encryption methods (Flöther, 2023). However, current quantum computing systems, so-called Noisy-intermediate-scale-devices, are limited in terms of error correction and scalability required for most applications, and the practical implementation of QKD, or PQC[4] methods, still faces obstacles in terms of infrastructure or adoption (Preskill, 2025; Zhang et al., 2025). Lastly, *quantum sensors* offer higher resolution and sensitivity, with newer devices being more compact and less invasive. For instance, quantum magnetometers have advanced the development of wearable brain scanners that can monitor neural activity in real time without the need for extensive cooling. These optically pumped magnetometers can monitor very weak signals and have been used for more precise imaging of the brain, heart and nervous system (Brookes et al., 2022). Similarly, nitrogen-vacancy diamond sensors can be introduced into cells, where they can help measure metabolism or disease progression (Belser et al., 2023; Gu et al., 2023). These approaches are opening the door to e.g., point-of-care diagnostics, continuous monitoring in everyday settings, and less invasive measurements.

2.2 Vanguard Visions as a lens for Digital Futures

The evaluation of the future or future studies have a long tradition in science and technology studies, technology assessment, or anthropology. These disciplines have used future visions to study their impact on social processes in the context of innovation and sociotechnical change (Jasanoff, 2015). Recently,

[4] QKD uses quantum mechanical principles to securely exchange encryption keys so that any eavesdropping attempt is detectable, while PQC uses classical algorithms designed to remain secure against future, largely scaled quantum computers.

the term *digital futures* has been used to formally introduce such research into information systems (Hovorka & Mueller, 2025; Hovorka & Peter, 2021; Schlagwein et al., 2025). Contrary to existing information systems research, which tends to lean towards a positivist stance, this approach allows for a broader epistemological perspective and speculative, multifaceted research methods. This is particularly useful for analysing the dynamics and decisions surrounding new innovations such as QTs, as it provides relevant stakeholders with forward-looking knowledge about the consequences of technology development and adoption.

Vanguard visions are an extension of the more popular concept of STIs used to investigate ideas surrounding technological futures (Hilgartner et al., 2015; Jasanoff, 2015). Spread by *sociotechnical vanguards* which are "relatively small collectives that formulate and act intentionally to realize particular sociotechnical visions of the future that have yet to be accepted by wider collectives, such as the nation." (Hilgartner, 2015, p. 34), these visions provide an early glimpse into futures that visionaries, with superior knowledge of emerging technologies, foresee in the context of sociotechnical developments. While at early stages several vanguard visions can compete with each other, some of these visions can turn into the more stabilized STIs, defined as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures" (Jasanoff, 2015, p. 4). Jasanoff states that "[o]nly when the originator's "vanguard vision"(Hilgartner 2015) comes to be communally adopted, however, does it rise to the status of an imaginary" (Jasanoff, 2015, p. 4). Some of these early visions can be tied to already existing imaginaries, as when promoters of synthetic biology drew heavily on the imaginary of the US as an innovator to make their claims more plausible to other stakeholders (Hilgartner, 2015). Therefore, the engagement with these visions and imaginaries is not only beneficial but essential, given their role in shaping societal possibilities and aspirations, regardless of whether they are ever fully realized (Grunwald, 2024; Grunwald et al., 2023).

Looking more closely at QTs, studies have investigated emerging visions surrounding these innovations. In their research, Inglesant et al. (2021) find three main visions surrounding quantum computers and conceptualized imaginaries surrounding those visions: 1) capabilities of quantum computers far beyond the most powerful classical computers, suggesting quantum computers will solve problems unsolvable for classical systems; 2) quantum computers can be useful now, or soon will be; assessing the practical implications of quantum computers in the short term; and 3) quantum supremacy. Based on these visions, the researchers conclude different imaginaries, such as heroic transformation, the quantum threat, or quantum supremacy and the arms race. Another study investigated imaginaries in science fiction, science dissemination, and journalistic outlets (Possati, 2024). The author finds similar imaginaries, such as the strangeness of quantum mechanics, superposition, the multiverse in science fiction, the arms race, quantum supremacy, and hype stories often referenced in journalism. A recent study described how these imaginaries can trigger pre-emptive export controls and knowledge regulation, resulting from visions that promote hype dynamics, securitization, and sovereignty tendencies (Nguyen, 2025). These findings show that the field is characterized by a complex web of competing visions and interests, making it necessary to continuously explore the visions in this domain to prepare for and respond to them. While these studies offer an initial overview of current QT-related visions, the question remains whether similar ones will apply to specific domains, such as healthcare.

3 Method

To answer the research question, a reflexive thematic analysis was used. This aligns with calls in information systems to investigate digital futures research by embracing interpretivist and speculative approaches that support the exploration of plural, non-deterministic futures (Schlagwein et al., 2025). Such qualitative methods are especially useful for explorative studies, since they enable rich descriptions of the phenomenon by understanding the topics and the context in which they take place in a more detailed way (Myers & Avison, 2002). The analysis proceeded in two stages. First, Atlas.ti was used to derive overarching themes from the interview responses (Braun & Clarke, 2006). Afterwards, the themes were analysed along the dimensions of STIs and vanguard visions derived from the seminal literature

(Brause et al., 2025; Hilgartner, 2015; Jasanoff, 2015; Jasanoff & Kim, 2019). The following sections will guide you through the method applied in more detail.

3.1 Sample and Data Collection

Snowball sampling was used to recruit participants. This approach ensured that data was collected from stakeholders in strategic positions who have the expertise to answer the research question. Snowball sampling provides quick access to people with the required qualities, especially in situations where reaching out to the relevant stakeholders may be challenging (Naderifar et al., 2017). A network of potential participants was first defined using existing connections. After an interview, participants were asked to suggest other potential interview candidates with the required expertise. This strategy was used since QTs are highly specialized technologies, with a small number of individuals working on them or with deep, technical knowledge about them.

Participants included both quantum researchers, as experts close to the technology, and clinical physicians, representing potential end users and early adopters. While these end users approach the technology from a clinical rather than a technical perspective, their views are critical as they will decide whether and how a technology is adopted. Because QTs are at an early stage of development, it is crucial to assess a broad range of perspectives while they can still be shaped. For the case of quantum researchers, participants were sought who actively conduct research related to quantum computing technology in healthcare. For clinical physicians, however, the recruitment criteria had to be broader because the innovation is at an early stage of technological maturity. Clinical integrations or explorations of, e.g., quantum computing have so far been limited to a few institutions. To broaden the scope of possible participants the sampling strategy was therefore extended to also include physicians with experience in similar advanced technologies such as AI, MRI, or quantum sensors. The rationale was that these physicians would be skilled in implementing new technologies and possess valuable transferable knowledge about technology adoption in clinical settings. To ensure meaningful input, it was confirmed that participants had a basic understanding of QTs. When necessary, brief additional information was provided. A total of 27 semi-structured interviews with 13 quantum researchers and 14 clinical physicians were conducted. Participants were based across multiple countries in Europe, as well as North America, including Germany, the Netherlands, Denmark, Switzerland, and the United States. They were affiliated with a range of institutions, including academic, clinical, non-profit, and research/innovation organizations. To minimize the risk of deductive disclosure in this small and specialized field, no further details on specific institutions or locations are reported. The semi-structured approach was chosen because it allows for a combination of guiding questions and the freedom for participants to provide other useful information besides the scope of the planned interview, ideal for the exploratory nature of the topic (Harrell, 2009). The interview questions, instructions, and general structure were pretested in a focus group discussion with two quantum scientists and two doctors. The final interviews were conducted online via Microsoft Teams and lasted between 60 up to 90 minutes. The interviews were held in English, recorded as well as auto-transcribed with the built-in function from Microsoft Teams. Data collection started in February 2025 and ended October 2025.

3.2 Determining Visions

A hybrid reflexive thematic analysis was applied to determine the visions (Clarke & Braun, 2017; Hovorka & Mueller, 2025; Hovorka & Peter, 2021). First, an inductive coding approach was used to identify patterns and themes in the data, an approach well-suited to the open-ended nature of vision assessment work and to cover the nuance of the data without theoretical imposition of predefined categories(Fereday & Muir-Cochrane, 2006). Second, vision dimensions were defined by screening the seminal literature for STIs and vision assessment to uncover underlying vision structures and the previously defined themes. This sequence ensures that the themes emerge from the data itself, rather than being shaped by the theoretical framework applied in the second step. The coding was conducted in Atlas.ti, with the analyses started as the data collection unfolded. The following sections explain each step.

1) The transcripts were first read several times to get familiar with the shared insights. Then, the initial coding was conducted, and codes of recurring topics were defined (Braun & Clarke, 2006). Through iterative coding processes, codes were refined and merged where appropriate, and themes were formed around related central concepts. A second round of analysis was conducted after a time interval by the same researcher to enhance analytic consistency and reflexivity. Themes were checked for appropriateness and to ensure that no further refinement was required. Table 1 shows examples of raw data extracts, initial codes, categories, and themes, as well as vision dimensions.

Raw Data Extract	**Initial Codes**	**Categories**	**Theme & Vision**	**Vision Dimension**
”With quantum in healthcare and life sciences, we haven’t found that even what problem is it really solving that we cannot do with other tools, so it hasn’t fulfilled yet step one of translation right to clinical practice in … general. That I think is more than half the challenge in most cases in medicine. But there are other challenges for example the workforce readiness.” “What I like about the quantum sensing field is that while computing is sort of 20 years away and communication as well, the sensing stuff is already happening...”	Quantum Computing for certain tasks, Hardware Improvements needed, Innovation Scepticism, Adoption Drivers/Barriers, Quantum Computing Realism, Compute, Training needs	Quantum Computing Realism, Adoption Drivers/Barriers	Quantum Computing *(Quantum computing for direct clinical integration)*	*Certainty & Future:* no demonstrated clinical advantage over existing tools; lot of challenges mentioned for integration, →low certainty and Long-term, timeframe compared to sensing *Implications:* workforce readiness and deployment challenges assign responsibility to educators and health institutions
“One of the better applications of quantum computing and that is quantum simulation. So being able to simulate chemical reactions might allow you to develop certain drugs, or particularly the if in the early stages that the drug development itself will be hard, but coming up with a way to synthesize a drug might be something you can have a quantum computer help with.”	Quantum Simulation, Quantum Computing Application, Quantum Chemistry, Drug Development, Healthcare Application	Quantum Computing Application	Quantum Computing (*Quantum computing as research accelerator*)	*Technological object and Vision:* quantum simulation as a research tool, indirect benefit to healthcare through drug R&D *Certainty*: low to mid certainty, since described as better quantum application, but conditional language used (if, might)
“I think it has to be a joint effort. I think you can’t expect any stand-alone profession to oversee all of this. I think there has to be some joint table in where people from every field of expertise come together to	Stakeholder Inclusion, Shared Responsibility, Ethical Considerations	Interdisciplinary Collaboration	Ethical Aspects/Responsibility *(Quantum computing for direct clinical integration)*	*Implications:* responsibility distributed across stakeholders rather than assigned to a single entity

make this an ethics committee, but more a committee or something where they talk about these things and say, listen, this is what is happening."				
"[The field] is really in the hands of like 5-6 companies...depending on how the market on quantum computing and access to these things develops…that can be a really big problem for equal opportunity, like small biotech startups might not have the capital to do this or might be...locked out due to export restrictions." "…but then I would rather have these things run by maybe government agencies rather than big companies."	Quantum Computing Access, Monopoly, Equal Access, Equal Market Opportunities, Public versus Private Ownership, Regulation of Access	Governance and equitable access to Quantum Computing	Quantum Computing (*Quantum computing as research accelerator*)	*Vision & Desirability:* quantum computing is only desirable if access is broadly distributed
"What I like about the quantum sensing field is that while computing is sort of 20 years away and communication as well, the sensing stuff is already happening...we're becoming better at building sensors that use quantum effects…we're going to get way better sensors, higher resolution, more precise."	Quantum Sensing, Quantum Sensing Applications, Sensing better than other QTs, Useful Sensing Application	Useful Quantum Sensing Applications	Quantum Sensing *(Quantum sensing and imaging for precise diagnostics)*	*Vision Certainty and Future:* high certainty because sensing is "already happening" unlike computing or communication which are "20 years away," *Desirability:* Framed unconditionally positive "way better sensors" framed as a clear, near-term benefit

Table 1. Overview of examples for codes, categories, themes and vision dimensions.

2) Second, the themes were analyzed along dimensions of STIs and visions derived from the seminal literature. Up until recently, the concept of STIs has been criticized for lacking a clearly defined method to these constructs (Brause et al., 2025; Kuchler & Stigson, 2024). However, the seminal literature points to key aspects that define such future visions (Hilgartner, 2015; Jasanoff, 2015; Jasanoff & Kim, 2019), providing the foundation for deriving the dimensions of vanguard visions used to evaluate the interviews. Since vanguard visions are by definition the roots for the at some point more stabilized imaginaries, this paper argues that they share the same constitutive dimensions as STIs. Looking at the central literature surrounding vanguard visions and STIs, and a recently developed framework to investigate STIs in public communication, these dimensions are: an envisioned future role for a technological object, a desirability assessment, a spatio-temporal scope, and implications for

governance and responsibility attribution (Brause et al., 2025; Hilgartner, 2015; Jasanoff, 2015; Jasanoff & Kim, 2019). These dimensions will be briefly explained in the following paragraph:

- A *Technological Object* is related to the characteristics of the technology (e.g. large language model, autonomous vehicle) and asks the question in which societal sector the technology will be implemented (e.g. healthcare, logistics or transportation).
- The *Vision* focuses on the potential and promise a technology will have for society, on the role it will play in the specific implementation area, such as increasing health through wearables. Second, this dimension also contains statements on how certain the realisation of the vision is.
- The *Desirability* questions whether the vision is seen as (un)desirable, for whom (e.g. certain groups of society, animals, the environment), and for what reasons it may or may not be (un)desirable. The desirability assessment can either be positive, negative or stay neutral.
- The *Futures* dimension asks how far in the future the vision is presented, and what geographical scale is expressed for the vision. This dimension can be hard to assess at times, especially with highly speculative technologies.
- Lastly, the *Implications* of the vision include suggestions for what should be done and defines responsible entities that are relevant to realise this vision. These recommendations can support specific actions or suggest not to act in a certain way, a central dimension for responsibility aspects.

This second, deductive phase along these dimensions enabled to move beyond what was said to understand how participants conceptualize the visions. The framework was applied by first screening the themes according to the technological object, specifically the three main domains of QTs (quantum sensing, quantum computing, and quantum communication) and the contexts in which they are envisioned. Each object was then systematically screened for particular visions (including both the envisioned role and expressions of certainty), desirability assessments, and temporal-spatial aspects where possible. Finally, implications for action were identified. Examples on how the dimensions such as Desirability, Vision or Futures were coded can be found in Table 1. To enhance the credibility of the findings, peer debriefing was conducted with colleagues.

4 Results

The following section outlines each of the four visions. Each vision is centred around a specific application domain of QTs – quantum sensing, communication, or computing – and includes insights into the role of the technology, its anticipated impact, and the conditions under which it is seen as desirable or problematic. Notably, quantum computing prompted the most divergent views among participants and is therefore presented through two distinct visions: one envisions its role as a research accelerator, and another imagines its future integration into clinical care. These are followed by a synthesis of cross-cutting concerns that emerged across visions, such as issues of trust, access, responsibility, and the risks of technological hype. Table 2 gives an overview of the vanguard visions found.

Vision		**Futures & Certainty**	**Desirability & Affected Entities**	**Implications (Key Actions & Responsibilities)**
Technological Object	**Core Description**			
Quantum sensing & imaging for precise diagnostics	· Quantum Sensors & Imaging (e.g. NV-diamond, photonic, magnetometers) · Enable highly sensitive, localized, less or non-invasive	· Future: Short to Mid-term · Certainty: High · Space: Broad aspiration, but likely concentrated in high-income health	· Highly desirable for patients (less invasive, better care) · Clinicians benefit from precision data · Health systems gain efficiency	· Integrate sensors in workflows · Train practitioners · Ensure affordability and access · Actors: hospitals, device providers, researchers

	diagnostics (e.g. brain activity, vital monitoring, cancer detection)	institutions initially	· Concerns: risk of data overload and complexity for physicians, equal access and affordability	
Quantum communication and hybrid approaches for health data	· Secure health data handling via QKD, PQC, and quantum networks · Enabling physically provable data security · Addresses privacy, sovereignty, and long-term threats (quantum threat)	· Future: Mid to Long-term · Certainty: Medium · Space: Not shared	· Desirable for patients, hospitals, research institutions, enhances trustworthiness in data handling · Concerns: cost and integration, technological readiness, delayed adoption	· Adopt PQC, ideally hybrid approaches · Overcome technological barriers · Define regulation & ensure interoperability with existing systems · Improve science communication · Actors: government, telecoms, researchers, insurance companies, hospitals
Quantum computing as research accelerator	· Quantum computing for simulation and chemistry · Tool to enhance molecular modelling and drug design · Indirect benefit for healthcare through research and drug development	· Future: Mid to Long-term · Certainty: Medium · Space: Global aspiration; currently concentrated among a small number of high-resource actors and nations	· Desirable for pharmaceutical and tech companies, research institutions to accelerate research and enables new treatment options for patients · Concerns: Access, costs, low technological readiness, tech translation, hype, monopoly	· Continue developing quantum hardware and algorithms · Ensure equal access opportunities through regulation · Wish for publicly supported infrastructure · Ecosystem building · Actors: quantum scientists, engineers, tech companies, government
Quantum computing as a background tool for direct clinical integration	· Quantum computing (e.g., simulation, and Quantum machine learning) for better diagnostics and patient-centric treatments	· Future: Long-term · Certainty: Low–Medium · Space: Global aspiration; currently concentrated among a small	· Desirable for better and more efficient diagnostics · Patient and physician benefit through more efficient, precise diagnostics and treatments, physicians can	· Fund open R&D with collaboration across relevant actors · Focus on user-centricity · Support clinician education & explainability

	· Requires usability, transparency, and clinician trust	number of high-resource actors and nations	focus more on direct patient care · Concerns: Access, costs, low technological readiness, complexity, data handling, hype, monopoly	· Promote local ownership and workflow integration · Actors: quantum scientists, engineers, tech companies, pharma, hospitals, government

Table 2. Overview of vanguard visions.

Quantum sensing and imaging for precise diagnostics. Devices such as photonic sensors or diamond-based sensors (among others) are envisioned to improve diagnostics and monitoring of patients due to more sensitive and precise measurements. According to the statements, compared to the already existing devices, they provide benefits by enhancing resolution in, e.g., imaging, more specificity, or sensitivity in measurements, potentially leading to better and, at times, faster monitoring in smaller spaces with less invasive methods for the patient: *"You have…a nitrogen vacancy center…when you want to map out your brain activity, you measure electric fields, sometimes also magnetic fields. And if you would be able to measure these things with a higher resolution, maybe even localize the position in the brain better, then you can think of a whole range of applications…in diagnostics."* – Scientist 4.
Certainty is high and grounded in continuity: quantum sensors were mentioned as the most feasible and mature application of QTs in the near term, based on the fact that first-generation quantum sensors are already being used. Furthermore, emphasis was placed on the technological readiness of these sensors, with particular comparisons drawn to QTs such as computing: *"What I like about the quantum sensing field is that while computing is sort of 20 years away and communication as well, the sensing stuff is already happening...we're becoming better at building sensors that use quantum effects…we're going to get way better sensors, higher resolution, more precise."* – Scientist 10, making it the most feasible QT compared to the others. These advancements are described as desirable for the patients in terms of better and less invasive treatment and the physicians who would be provided with more precise insights for diagnostics: *"...more information is better. The better way you can inform the patient what's going to happen...will help the physician enormously."* – Physician 13.

Spinning this further, the experts see benefits in this future for the healthcare system and society in general, since treatment outcomes can be improved by earlier or more precise diagnosis, potentially earlier interventions or prevention, resulting in a healthier society and also lower healthcare costs, if the technology is adopted broadly. Some experts shared that this might be undesirable for physicians due to the burden of additional data, the risk of getting lost in details, or the complexity in interpreting these results. Additionally, concerns were raised regarding the affordability of such technologies: *"...you might get a lot better healthcare if you use new quantum sensors, new quantum algorithms, new stuff. But this might be very expensive to do, and we already see this a bit, right? An MRI machine is actually quite expensive to have in your hospital…quantum technology is going to be very pricey; the manufacturing costs are going to be very high. The development costs have been very high and need to be recouped, so I can see that you're going to get a divide between people that can afford these new technologies."* – Scientist 10.

The shared implications were to focus on integration and access, with a strong emphasis on training practitioners, pointing towards hospitals, research institutions, and medical device companies as the responsible institutions.

Quantum communication and hybrid approaches for secure health data centers around the vision of ultra-secure communication and "…*transferring patients' data in a secure way*..." – Scientist 12, describing the technology as a solution for broader concerns about digital sovereignty and privacy. Quantum Networks, Quantum Cryptography using QKD or PQC could help cover the need for more reliable and transparent data protection. This issue is becoming more and more relevant in times of cloud computing, the platform economy and the potential quantum threat through a commercially useful quantum computer, likely breaking currently used encryption. Further experts point out that quantum communication theoretically offers novel approaches that are not achievable with classical approaches, potentially a combination of multi-party computation and unclonable quantum encryption with certified deletion.[5] These approaches are seen as an answer to problems related to the use of sensitive health data and data protection in the healthcare context, since access to, use of, or exchange of this data is currently subject to strict regulations or limited. With these approaches, the security of sensitive data could be placed on physical rather than legal foundations, potentially increasing a patient's trust. The certainty of this vision is moderate, and experts are ambivalent. While the technological mechanisms are described in detail, their practical translation varies depending on the chosen approach. The implementation of PQC algorithms is possible today. Although it might be sufficient for now, the experts acknowledge "*…that you cannot foresee there might be in the future a different type of algorithm that runs on a quantum computer. So this is you cannot exclude this 100% [safe], while if you do QKD you could mathematically prove that it's secure whatever the development in algorithms."* – Scientist 4.

They therefore point towards Quantum Networks and QKD in the long term as safer approaches: *"... quantum encryption and cryptography [helps] with privacy issues, especially in healthcare. When you have distributed datasets of patient data across many hospitals…and you want to run an algorithm on all that data, you run into privacy violations. Quantum encryption…could help make the data much more secure and may allow you to transmit patient data from one center to another or treat a patient with distributed data…between multiple centers of excellence."* – Scientist 11. The researchers point out that the system, although promising, *"…still has to operate in our reality.",* saying that the infrastructure has to be built and scaled "*And as long as you cannot go to something which is called device independent QKD, where you are completely independent from any real world assumptions, any, realistic problems, you will always have a way to hack the message because at the end of the day you have a computer there and you have a human that operates this computer."* – Scientist 4.

Nevertheless, the vision was described as highly desirable for patients and hospitals with sensitive data (e.g., genetic data, psychiatric diseases), or competing research institutions needing to collaborate without sharing sensitive aspects of data. However, it may be undesirable for e.g., institutions that face integration complexity or higher infrastructure costs. Responsibility was assigned across multiple actors: governments for regulation and the definition of standards, institutions such as insurance companies or hospitals for adoption, and most importantly, researchers for hardware improvements and fundamental research as well as good science communication. It was shared that "*…my biggest, like scariness is that we won't be prepared [for the quantum threat] because we don't know how to talk about it."* – Scientist 12, therefore delaying adoption and risking being too late, putting healthcare data at risk.

Quantum computing as a research accelerator. The participants share that quantum computing and simulation will be beneficial for molecular modeling, genomic simulation, drug discovery, or accelerating medical research in general since these systems can model molecular and chemical processes more precisely or faster than classical systems: *"But if you look at smaller scales, like, if we you want to design new drugs, then we have to simulate molecules in the end, like, and that's where quantum mechanics is…really is good at."* – Physician 1. Quantum computing is seen as a tool for research, mainly used in the laboratory, pharmaceutical companies or in more general computational contexts, indirectly supporting healthcare, where "*quantum applications to accelerate drug discovery will have huge impacts on healthcare and life sciences without really requiring the engagement of a clinician at any point."* – Physician 12.

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[5] Multi-party computation allows institutions to jointly compute over distributed datasets without any raw data leaving its origin (possible with classical approaches); unclonable encryption ensures a ciphertext can only be decrypted once by one party; and certified deletion produces a verifiable cryptographic proof that data has been irreversibly destroyed. Both require quantum memory not yet available. For more information read the following: https://dl.acm.org/doi/pdf/10.1145/3576897

Experts painted a realistic picture with a mix of optimism and skepticism regarding the certainty, describing that *"It's not gonna magically make everything faster, just in the specific case, we could take a shortcut."* – Scientist 10. Physician 12 explained in a concrete example that "the *best that we have shown in the quantum chemistry space is that there are certain, clinically relevant questions where quantum is equivalent to what we get with machine learning."* showing first successes in research settings. Experts also share that the field is facing challenges related to data, access, and costs, comparing some of the developments to problems with AI: "*If you want to integrate quantum computing, you must downsize the data generally and the access to the systems…is, often not so simple it's costly…challenges, quite closely linked also to the adoption of AI technologies."* – Scientist 11.
Certainty is also linked to transparent communication from researchers as well as the private sector to avoid hype cycles or a quantum winter: *"... funding will dry up as soon as the promises will not come to fruition...it's also not a good long-term strategy...[but] if you're just the only one not getting on the hype train, that just means you're not getting the money and everybody else is."* – Scientist 11. The desirability is seen as high for pharmaceutical companies and research institutions, accelerating research discovery and potentially giving answers to problems that are currently unsolvable. Healthcare would indirectly benefit from lower costs and potentially new treatment options for patients. Besides that, participants also mentioned undesirable aspects such as the cost of hardware, or potential monopolization by big tech, raising questions of fairness, equal access, and the independence of science: *"[The field] is really in the hands of like 5-6 companies...depending on how the market on quantum computing and access to these things develops…that can be a really big problem for equal opportunity, like small biotech startups might not have the capital to do this or might be...locked out due to export restrictions."* – Scientist 10.

The experts, however, shared counter, more desirable visions, clearly defining actions and responsibilities, asking for open-source mandates, public ownership models, collaboration, and shared infrastructures that should be explored to prevent history from repeating itself: *"…but then I would rather have these things run by maybe government agencies rather than big companies."* – Scientist 3. Physician 12 went further and suggested to *"…create a structure that rewards an ecosystem rather than an organizational entity, so allocate funding towards programs that reflect what you want that ecosystem to look. So for quantum, for example, if all you have is funding opportunities to support making the quantum computers less error prone, for example, that focus on one of the hardware challenges, that's nice, but that's not gonna help really with creating that ecosystem. But funding mechanisms that support ecosystem development, where there is a hardware provider, there is a software developer, there is an NGO, there is a community representation, there is local government representation, and you need to have all those pieces for you to qualify for this grant funding mechanism in a way that is forcing the development of these ecosystems, right? And so far I haven't seen that…across the globe."* Many of the ethical reflections and implications associated with this vision – regarding governance, access, monopolization, also relate to the more speculative clinical vision that follows and will be explained in the following.

Quantum computing as a background tool in clinical integration. Across interviews, another vision was shared, seeing quantum computing as a background tool within the clinical context. Here, it would power quantum-enhanced AI and machine learning to support diagnostics, e.g., by enabling biomarker discovery that supports physicians in their decision-making. Physician 1 was claiming that *"…having more computational power…in my field, it would be more detailed simulations, for example. And there to have a more personalized medicine approach that I see a huge benefit in quantum computing."* This would enable more personalised treatment and help overcome the challenge across multiple diseases to "*predict accurately the patients who will deteriorate quickly versus those who will have a milder course to their disease [or] how a patient will respond to a particular therapy course."* The technology here would mainly help overcome barriers of classical, e.g., machine learning systems: *"Either the model is not good enough, accurate enough in its prediction, or it is too computationally intensive. Those are the ones that we are taking and looking at them from a lens of how, what can [a] quantum computer [do].*

Can it help us with simplifying the number of features that are needed for those models to run? Can it help us develop better models with smaller datasets?" – Physician 12.

The certainty of the vision is low, as experts share that "*we haven't found that even what problem is it really solving that we cannot do with other tools…so it hasn't fulfilled yet step one of translation right to clinical practice."* – Physician 12. The desirability is high in principle, with the overarching vision being better patient-centric care and precision treatments. However, hospitals are already struggling with the computing requirements of AI models; QC could amplify these pressures. Additionally, participants worried about workflow burdens, loss of transparency, and centralization of computational resources in the hands of a few large technology providers, with a Physician noting that global reach, while desirable, is *"realistically…probably focused on the developed world for quite some time."* – Physician 5.

In terms of futures, this is the most distant and uncertain of the visions discussed. Clinical integration depends on a long sequence of breakthroughs, each of which is itself unresolved. The geographic scope of benefit, if realised, is likely to follow existing patterns of technological inequality, with early concentration in well-resourced health systems. Participants recommended several actions and implications. Building trust in the systems, mainly through education, was mentioned as the essential factor for clinical adoption, with experts highlighting the need for "middle-men" or translators who can bridge knowledge gaps between quantum technology developers, healthcare practitioners, and in the end also patients. *"I think education is like the term here that pops in my head that, yeah, we know what it is, what it can, what it can't, and that we also understand it and can explain it to our patient, what, what we are using it for. And I think, yeah, that can only be achieved by like, training people on the matter."* – Physician 03.

Further, clinician-centered design was stressed repeatedly and pointed out as a lesson learned from low AI adoption in healthcare. Tools, therefore, must integrate smoothly into existing workflows without adding steps for end users, and outputs must be sufficiently explainable for clinicians to interrogate and challenge. Additionally, one participant argued that for real precision medicine and patient-centric drug development, healthcare institutions must have local QC infrastructure in the long term – both for ethical reasons (keeping treatment tied to the patient's context) and for logistical speed: *"I mean, that's something you want to do here in the hospital. You want to develop the drugs for the specific patient in this location and use it right away…you don't want a big pharmaceutical company in a way which has to keep shareholders happy."* – Physician 13, challenging how drugs are currently being developed and distributed through big pharma players. These statements for the visions surrounding quantum computing for healthcare clearly imply and responsibilities that promote public, state-driven, and open quantum infrastructures, driven by collaboration for healthcare. Without such measures, participants warned, we risk entering a future where autonomy of the health sector, same as scientific work, is constrained by commercial logic. Consequences that would not only have an impact on the market but could also affect patients at the individual level.

5 Discussion and Implications

This study investigated early-stage, expert-driven vanguard visions surrounding QTs in healthcare. This is particularly relevant with emerging technologies, where institutionalized visions have not yet formed into sociotechnical imaginaries, leaving room for changes surrounding their sociotechnical integrations. The findings reveal several nuanced expert visions, thereby opposing techno-positivist claims about "revolutionary" capabilities of QTs. Rather than joining the pure enthusiasm for the transformative promises of these applications often found in public discourse, they expressed upbeat but tempered views marked by clear statements about opportunities and challenges: quantum sensing was identified as the most suitable near-term application, whilst quantum computing was seen as promising for drug discovery, genomics, and precision medicine, with initial use cases emerging in which quantum computing is showing its usefulness. However, further technological development and the search for proof-of-concept studies are still required, which, according to the experts, also means that direct and widespread clinical integration remains a long way off. Security and cryptographic applications for safer data in healthcare were rated as medium in terms of readiness for deployment, at least for PQC and

QKD. The statements align with current literature in terms of technological readiness of QTs (Flöther, 2023; Gupta et al., 2025; Hoofnagle & Garfinkel, 2022). Central to information systems research, the vanguard visions move beyond technology-centric evaluations and toward a focus on their role within complex digital infrastructures, describing (un)desirable pathways and the challenges and responsibilities along the innovation chain. Additionally, the shared visions enabled discussions that are more open as to where the technologies might be useful and which visions should be pursued, thus leaving room for responsibility and ethical discussions.

Comparing the results to previous studies, the visions identified here were more cautious than those that have previously dominated the quantum discourse. The participants' visions primarily reflected scenarios in which QTs offer specific advantages over existing classical methods, rather than supporting visions of heroic transformation. Similarly, while the quantum threat was referenced in discussions of both quantum computing and communication, the visions shared around quantum communication were not exclusively driven by calls to prepare for the post-quantum era (Inglesant et al., 2021; Possati, 2024). The participants highlighted the new opportunities this technology offers for overcoming the current limitations in the handling of health data and assessed the technology on the basis of its potential for the field rather than solely from a fear-driven perspective, of course, under the condition that these still largely theoretical descriptions prove to be possible in practice. Furthermore, the vanguards openly criticized previously identified visions associated with hype and arms race dynamics (Nguyen, 2025; Possati, 2024). This shows that these vanguard visions for the healthcare sector are driven by a motivation that is clearly different from visions or imaginaries found in the broader quantum discourse. Along with the visions, the experts shared a clear set of values such as equitable access, open and shared infrastructures, user-centric design, and developments shaped through collaboration rather than competitiveness. The participants openly criticised scenarios in which QTs, and quantum computing in particular, are controlled by the private sector, a view that reflects recommendations expressed in the seminal literature on responsible quantum technology (Seskir et al., 2023; Ten Holter et al., 2022). The participants raise concerns that if a future in which quantum computing would be deployed in a way that replicates monopolistic patterns they compared to AI, this would create entry barriers for, e.g., smaller healthcare institutions with limited resources. Instead, the desired future was one in which quantum healthcare applications are developed through multi-stakeholder ecosystems, governed by public institutions, and designed around the needs of clinicians and patients. This opens a fundamental normative question: whether QTs will develop as a shared resource open for beneficial healthcare use, or as a proprietary tool driven by commercial imperatives.

Alongside the critical reflection of future visions, the participants shared responsibilities they see. Researchers identified their role in communicating science, clarifying technological potentials, and mitigating hype. In parallel, physicians stated that they are ultimately responsible for decisions made when treating patients. This second point also highlights the view shared by doctors that trust in decision-support systems is a key factor for the adoption of such technologies, along other aspects such as ease of use, workflow integration and more. This is an important takeaway for those developing quantum computing applications, especially given that quantum was seen as being even more difficult to understand and less transparent than AI. Beyond these individual roles, participants consistently identified the government as the main responsible entity for mitigating risks through guardrails and a central actor that should be involved at all costs. Across the visions, several practical implications emerged. To realise this potential, the focus must shift from technological progress as an end in itself to the overarching goal of improving healthcare services. Participants argued that funding mechanisms should create structural incentives for collaboration and the development of broad ecosystems rather than for competition, as without such structural incentives, this reorientation remains dependent on the goodwill of individual stakeholders. A multi-stakeholder approach, bringing together researchers, clinicians, technology companies and patient representatives, was seen as essential to align development with actual healthcare needs from the outset and to address regulatory uncertainties prior to widespread adoption. For healthcare institutions, building quantum expertise was identified as a key requirement, particularly for quantum sensing in diagnostics and the future integration of computing applications. Quantum technology developers, for their part, were urged to prioritise explainability, transparency and equitable access and to involve end-users at an early stage, learning from experiences with the uneven integration of AI in healthcare.

From a theoretical standpoint, the findings contribute to the scarce literature on digital futures in information systems research (Hovorka & Mueller, 2025; Schlagwein et al., 2025). The approach used not only shows how vanguard visions can be systematically used to evaluate futures surrounding emerging technologies such as quantum. It also shows how visions can be used to navigate between "Scylla and Charybdis" with systematic reflections of socio-technical system integration (Hilgartner, 2015; Jasanoff, 2015). Considering the emerging literature around quantum, the results show that domain-specific discussions surrounding QTs are increasingly important to investigate the needs of stakeholders in certain application areas in more detail: different QTs (sensing, communication, computing) are tied to different visions, levels of certainty, and stakeholder concerns. By identifying concerns such as data overload, the importance of physician agency, hype, monopolization by big tech, and the absence of governance, this study also contributes to responsible innovation literature in information systems, providing insights for regulatory frameworks or potentially design decisions for quantum-enhanced tools.

6 Limitations and Future Research

Although this study provides valuable insights into the imagined futures around QTs, there are limitations to consider. First, the sample size is limited to the national contexts of Western Europe and North America, as well as in terms of the number of participants. This was a necessary consequence of the highly specialized nature of the field, where only a relatively small number of experts have the required knowledge. How quantum healthcare futures are envisioned in other national contexts remains an open question, and comparative imaginaries research suggests such differences can be significant (Au, 2022; Berling et al., 2022). In the future, research should include other stakeholders, such as policymakers and patients. This would enable us to compare the different groups and their underlying perspectives. Furthermore, longitudinal research or triangulation using supplementary data, such as white papers or strategic documents, could help determine which visions ultimately become collectively held sociotechnical imaginaries. Lastly, a single researcher conducted the analysis, which may introduce bias. Although measures such as peer checks and repeated coding were taken to ensure analytical accuracy, future research should consider multiple coders to strengthen the validity of the findings.

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References

Allcock, J., Vangone, A., Meyder, A., Adaszewski, S., Strahm, M., Hsieh, C.-Y., & Zhang, S. (2022). The prospects of Monte Carlo antibody loop modelling on a fault-tolerant quantum computer. *Frontiers in Drug Discovery*, *2*, 908870.

Au, L. (2022). Imagining the public: anticipatory discourses in China's push for precision medicine. *BioSocieties*, *17*(1), 53-77.

Baiardi, A., Christandl, M., & Reiher, M. (2023). Quantum computing for molecular biology. *ChemBioChem*, *24*(13), e202300120.

Belser, S., Hart, J., Gu, Q., Shanahan, L., & Knowles, H. S. (2023). Opportunities for diamond quantum metrology in biological systems. *Applied Physics Letters*, *123*(2).

Berling, T. V., Surwillo, I., & Sørensen, S. (2022). Norwegian and Ukrainian energy futures: exploring the role of national identity in sociotechnical imaginaries of energy security. *Journal of International Relations and Development*, *25*(1), 1-30.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77-101.

Brause, S. R., Schäfer, M. S., Katzenbach, C., Mao, Y., Richter, V., & Zeng, J. (2025). Sociotechnical imaginaries and public communication: Analytical framework and empirical illustration using the case of artificial intelligence. *Convergence*, 13548565251338192.

Brookes, M. J., Leggett, J., Rea, M., Hill, R. M., Holmes, N., Boto, E., & Bowtell, R. (2022). Magnetoencephalography with optically pumped magnetometers (OPM-MEG): the next generation of functional neuroimaging. *Trends in Neurosciences*, *45*(8), 621-634.

Clarke, V., & Braun, V. (2017). Thematic analysis. *The journal of positive psychology*, *12*(3), 297-298.

Cohen, D. (1972). Magnetoencephalography: detection of the brain's electrical activity with a superconducting magnetometer. *Science*, *175*(4022), 664-666.

Degen, C. L., Reinhard, F., & Cappellaro, P. (2017). Quantum sensing. *Reviews of modern physics*, *89*(3), 035002.

Edelman, R. R. (2014). The history of MR imaging as seen through the pages of radiology. *Radiology*, *273*(2S), S181-S200.

Fereday, J., & Muir-Cochrane, E. (2006). Demonstrating rigor using thematic analysis: A hybrid approach of inductive and deductive coding and theme development. *International journal of qualitative methods*, *5*(1), 80-92.

Flöther, F. F. (2023). The state of quantum computing applications in health and medicine. *Research Directions: Quantum Technologies*, *1*, e10.

Grunwald, A. (2010). From speculative nanoethics to explorative philosophy of nanotechnology. *NanoEthics*, *4*, 91-101.

Grunwald, A. (2024). *Handbook of Technology Assessment*. Edward Elgar Publishing.

Grunwald, A., Nordmann, A., & Sand, M. (2023). *Hermeneutics, History, and Technology: The Call of the Future*. Taylor & Francis.

Gu, Q., Shanahan, L., Hart, J. W., Belser, S., Shofer, N., Atature, M., & Knowles, H. S. (2023). Simultaneous nanorheometry and nanothermometry using intracellular diamond quantum sensors. *ACS nano*, *17*(20), 20034-20042.

Gupta, R. S., Wood, C. E., Engstrom, T., Pole, J. D., & Shrapnel, S. (2025). A systematic review of quantum machine learning for digital health. *npj Digital Medicine*, *8*(1), 237.

Harrell, M. (2009). Data Collection Methods: Semi-Structured Interviews and Focus Groups. *RAND Corporation*.

Heidari, N., Olgiati, S., Meloni, D., Slevin, M., Noorani, A., Pirovano, F., & Azamfirei, L. (2024). A Quantum-Enhanced Precision Medicine Application to Support Data-Driven Clinical Decisions for the Personalized Treatment of Advanced Knee Osteoarthritis: The Development and Preliminary Validation of precisionKNEE_QNN. *Cureus*, *16*(1), e52093. https://doi.org/10.7759/cureus.52093

Hilgartner, S. (2015). Capturing the imaginary: Vanguards, visions and the synthetic biology revolution. In *Science and democracy* (pp. 33-55). Routledge.

Hilgartner, S., Miller, C., & Hagendijk, R. (2015). *Science and democracy: Making knowledge and making power in the biosciences and beyond*. Routledge.

Hoofnagle, C. J., & Garfinkel, S. L. (2022). *Law and policy for the quantum age*. Cambridge University Press.

Hovorka, D. S., & Mueller, B. (2025). Speculative foresight: A foray beyond digital transformation. *Information Systems Journal*, *35*(1), 140-162.

Hovorka, D. S., & Peter, S. (2021). Speculatively engaging future (s): Four theses. *MIS quarterly*, *45*(1), 461-466.

Inglesant, P., Ten Holter, C., Jirotka, M., & Williams, R. (2021). Asleep at the wheel? Responsible Innovation in quantum computing. *Technology Analysis & Strategic Management*, *33*(11), 1364-1376.

Innovate UK. (2024). *Quantum for Life: How UK Life Sciences and Healthcare Can Benefit from Quantum Technologies*. https://iuk-business-connect.org.uk/wp-content/uploads/2024/10/Innovate-UK-Quantum-for-Life.pdf

Jasanoff, S. (2015). Future imperfect: Science, technology, and the imaginations of modernity. *Dreamscapes of modernity: Sociotechnical imaginaries and the fabrication of power*, 1-33.

Jasanoff, S., & Kim, S.-H. (2019). *Dreamscapes of modernity: Sociotechnical imaginaries and the fabrication of power*. University of Chicago Press.

Jeyaraman, N., Jeyaraman, M., Yadav, S., Ramasubramanian, S., & Balaji, S. (2024). Revolutionizing healthcare: the emerging role of quantum computing in enhancing medical technology and treatment. *Cureus*, *16*(8).

Kuchler, M., & Stigson, G. M. (2024). Unravelling the ‘collective’in sociotechnical imaginaries: A literature review. *Energy Research & Social Science*, *110*, 103422.

Myers, M. D., & Avison, D. (2002). *Qualitative research in information systems: a reader*. Sage.

Naderifar, M., Goli, H., & Ghaljaie, F. (2017). Snowball sampling: A purposeful method of sampling in qualitative research. *Strides in development of medical education*, *14*(3).

Nguyen, A. (2025). Export controls as innovation marketing?: Sociotechnical imaginaries in the ringfencing of quantum technologies. *Law, Technology and Humans*, *7*(1), 68-83.

Niraula, D., Jamaluddin, J., Matuszak, M. M., Haken, R. K. T., & Naqa, I. E. (2021). Quantum deep reinforcement learning for clinical decision support in oncology: application to adaptive radiotherapy. *Scientific reports*, *11*(1), 23545.

Possati, L. M. (2024). Quantum Technologies: a Hermeneutic Technology Assessment Approach. *NanoEthics*, *18*(1), 2.

Preskill, J. (2025). Beyond nisq: The megaquop machine. In: ACM New York, NY.

Schlagwein, D., Currie, W., Leimeister, J. M., & Willcocks, L. (2025). Digital futures: Definition (what), importance (why) and methods (how). In (Vol. 40, pp. 2-8): SAGE Publications Sage UK: London, England.

Seskir, Z. C., Umbrello, S., Coenen, C., & Vermaas, P. E. (2023). Democratization of quantum technologies. *Quantum Science and Technology*, *8*(2), 024005.

Ten Holter, C., Inglesant, P., Srivastava, R., & Jirotka, M. (2022). Bridging the quantum divides: a chance to repair classic (al) mistakes? *Quantum Science and Technology*, *7*(4), 044006.

Zhang, H., Zhu, H., He, R., Zhang, Y., Ding, C., Hanzo, L., & Gao, W. (2025). Towards global quantum key distribution. *Nature Reviews Electrical Engineering*, 1-13.