

Quantum Ethics Literature

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1 How to use this guide

This guide is intended to serve as an entry point to topics within quantum ethics and philosophy of science¹. The guide is topical and, where possible, we have included different perspectives on each subject. Readers will find discussions of emerging technologies, introduction to ethical theories, pedagogical resources, and specific discussions of ethics in quantum technologies. The list also varies widely in accessibility - some assume readers with years of training in philosophy and physics, and others are written to a general audience. The list necessarily reflects the authors' biases and backgrounds, however, we have not limited the list to resources we agree with.

We welcome any suggestions for further references, either via email to shawn.skelton@itp.uni-hannover.de or aknorr@g.harvard.edu, or via the Discord server of the [Quantum Ethics Project](#).

2 Initiatives for responsible quantum computing

Responsible Technology Institute, University of Oxford. [Accessed 26-08-2024]. URL: <https://www.rti.ox.ac.uk/research/>

- Center of excellence with a division working on responsible quantum computing. Notable contributions include [this whitepaper on quantum technology](#)

Stanford Center for Responsible Quantum Technology. [Accessed 26-08-2024]. URL: <https://law.stanford.edu/stanford-center-for-responsible-quantum-technology/>

- Interdisciplinary project based at the Stanford Law School

Centre for Quantum and Society (Quantum Delta NL). [Accessed 03-09-2024]. URL: <https://quantumdelta.nl/centre-for-quantum-and-society>

- Do we separately mention Pieter Vermaas' ethics group at Quantum NL?

Unitary Fund. [Accessed 26-08-2024]. URL: <https://unitary.fund/>

¹Readers can find many other resources through the citations in the papers on this list, or by searching for keywords used in this document.

- Non-profit for quantum technology development, which offers grants to early-stage researchers. The organization strongly focuses on fostering open-source and equitable quantum research

Metriq - Community-driven Quantum Benchmarks. [Accessed 26-08-2024]. URL: <https://metriq.info/About>

- Online platform for researchers to share noisy intermediate scale quantum (NISQ) benchmarking results and simulations. Affiliated with the Unitary Fund

Quantum Energy Initiative. [Accessed 03-09-2024]. URL: <https://quantum-energy-initiative.org/>

- Do we want to count QEI as a responsible initiative? Or only have it in Environment section?

Open Quantum Institute - GESDA - Geneva Science and Diplomacy Anticipator. [Accessed 26-08-2024]. URL: <https://gesda.global/solutions/open-quantum-institute/>

- Focuses on equitable applications and access to quantum technology, provides reports on the projected timeline of quantum technologies

Defining responsible quantum computing — IBM Quantum Computing Blog. [Accessed 26-08-2024]. URL: <https://www.ibm.com/quantum/blog/responsible-quantum>

- The responsible innovation branch at one of the leading quantum hardware developers

QuantumEthicsProject. [Accessed 26-08-2024]. URL: <https://www.quantumethicsproject.org>

- Student organization aiming to promote equitable education in the quantum workforce and ethical applications of quantum technologies. The group gives workshops and creates tutorials on quantum ethics, cultivates community among early career researchers, and hosts a blog with essays by members

3 Quantum Ethics

Eline de Jong. “Own the Unknown: An Anticipatory Approach to Prepare Society for the Quantum Age”. In: *Digital Society* 1.2 (Aug. 2022). ISSN: 2731-4669. DOI: [10.1007/s44206-022-00020-4](https://doi.org/10.1007/s44206-022-00020-4). URL: <http://dx.doi.org/10.1007/s44206-022-00020-4>

- adopts and defends an anticipatory approach to quantum technological ethics using historical case studies. Suggests five processes - demystification, contextualization, engagement, regulation, and positioning - which can be used to prepare stakeholders and the public for the advent of quantum technology

Urs Gasser, Eline De Jong, and Mauritz Kop. “A call for responsible quantum technology”. In: *Nature Physics* 20.4 (Apr. 2024), pp. 525–527. ISSN: 1745-2481. DOI: [10.1038/s41567-024-02462-8](https://doi.org/10.1038/s41567-024-02462-8). URL: <http://dx.doi.org/10.1038/s41567-024-02462-8>

- Proposes an analytic framework² for developing responsible quantum technologies. The authors suggest responsible innovation efforts in quantum technologies target one of three goals - safeguarding, engaging, or advancing (SEA) society. Furthermore, they suggest that responsible quantum technology must have three layers of analysis - technical considerations, ethical considerations, and social/legal/political considerations

Luca M. Possati. “Ethics of Quantum Computing: an Outline”. In: *Philosophy & Technology* 36.3 (July 2023). ISSN: 2210-5441. DOI: [10.1007/s13347-023-00651-6](https://doi.org/10.1007/s13347-023-00651-6). URL: <http://dx.doi.org/10.1007/s13347-023-00651-6>

- Discusses the novelty and scope of ethical questions in quantum technologies. A survey of existing papers on ethics in quantum technology is presented, as well as an overview of ethical issues related to privacy and data management

Philip Inglesant et al. “Asleep at the wheel? Responsible Innovation in quantum computing”. In: *Technology Analysis & Strategic Management* 33.11 (Oct. 2021), pp. 1364–1376. ISSN: 1465-3990. DOI: [10.1080/09537325.2021.1988557](https://doi.org/10.1080/09537325.2021.1988557). URL: <http://dx.doi.org/10.1080/09537325.2021.1988557>

- A survey of contemporary themes and debates within quantum responsible innovation (RI). It contains a discussion of RI for three possible pathways for quantum computing: specialized near-term applications, solutions to otherwise intractable problems, and ‘quantum supremacy’. It contains many sources for expert opinions on the trajectory of quantum computing

4 Quantum Applications

Steven Umbrello. “Quantum Technologies in Industry 4.0: Navigating the Ethical Frontier with Value-Sensitive Design”. In: *Procedia Computer Science* 232 (2024), pp. 1654–1662

- Industry 4.0 refers to the integration of technologies into manufacturing and delivery processes. This paper concisely surveys quantum applications to such industries and proposes using value-sensitive design to mitigate three kinds of risks: technical, ethical, social, economic, and environmental. This consists of embedding empirical, conceptual, and technical investigations of application ethics within the design phase of new technologies

²Analytic framework is a loosely defined term used throughout social sciences and humanities. An analytic framework contains a specifically defined set of definitions, relations between definitions, and often specific strategies for studying objects within the framework. They are used to examine complex social/political dynamics with a shared set of terms.

Carolyn Ten Holter, Philip Inglesant, and Marina Jirotko. “Reading the road: challenges and opportunities on the path to responsible innovation in quantum computing”. In: *Technology Analysis & Strategic Management* 35.7 (Oct. 2021), pp. 844–856. ISSN: 1465-3990. DOI: [10.1080/09537325.2021.1988070](https://doi.org/10.1080/09537325.2021.1988070). URL: <http://dx.doi.org/10.1080/09537325.2021.1988070>

- Discusses current ways in which responsible innovation is being applied to quantum technologies in the United Kingdom. Public dialogue, workshops, case studies, and individual interviews were conducted to determine RI action and attitudes in the UK quantum ecosystem. The paper closes with recommendations for implementing RI in the UK quantum ecosystem

Chris Jay Hoofnagle and Simson L Garfinkel. *Law and policy for the quantum age*. en. Cambridge, England: Cambridge University Press, Jan. 2022

- Recent book on policy and legal implications of quantum technologies. The book focuses heavily on quantum sensors and communication

5 Environment and Quantum

David Rejeski. “An Environmentalist’s Guide to Quantum Computing — Network DEE — networkdee.org”. In: (2022). [Accessed 26-08-2024]. URL: <https://www.networkdee.org/publications/an-environmentalist%E2%80%99s-guide-to-quantum-computing>

- A discussion of quantum technology, considering the potential for a hype cycle, potential applications within environmental research and technologies, and the potential energy consumption costs of quantum devices

6 Partnership and Funding Ethics

“Responsible Innovation Defence Briefing Note — NQIT — nqit.ox.ac.uk”. In: (). [Accessed 26-08-2024]. URL: <https://nqit.ox.ac.uk/content/responsible-innovation-defence-briefing-note.html>

- Workshop summary of an Oxford Martin School event in 2016. The workshop discussed potential applications of quantum technology related to UK national defense and security. The summary includes an overview of applications, especially sensors and imaging, and responsible innovation discussions at the workshop

Tara Roberson, Joan Leach, and Sujatha Raman. “Talking about public good for the second quantum revolution: analysing quantum technology narratives in the context of national strategies”. In: *Quantum Science and Technology* 6.2 (Jan. 2021), p. 025001. ISSN: 2058-9565. DOI: [10.1088/2058-9565/abc5ab](https://doi.org/10.1088/2058-9565/abc5ab). URL: <http://dx.doi.org/10.1088/2058-9565/abc5ab>

- An analysis of the rhetoric used in the United Kingdom, Canada, and the United States of America to describe their respective quantum strategies, paired with interviews with elites who gave insights into the strategy developments of each country. Public rhetoric is also contrasted against physicists’ accounts of their own motivations. These rhetorical strategies are discussed in the context of several understandings of “public good.”

Tina Dekker and Florian Martin-Bariteau. “Regulating Uncertain States: A Risk-Based Policy Agenda for Quantum Technologies”. In: *SSRN Electronic Journal* (2022). ISSN: 1556-5068. DOI: [10.2139/ssrn.4203758](https://doi.org/10.2139/ssrn.4203758). URL: <http://dx.doi.org/10.2139/ssrn.4203758>

- Risk-based analysis of emerging quantum technology in a Canadian context. Potential applications are discussed, and three social risks are highlighted. Risks relating to privacy and data, access and use, and market competition are all discussed, along with suggestions for pre-existing regulatory pathways in Canada

Zeki C Seskir et al. “Democratization of quantum technologies”. In: *Quantum Science and Technology* 8.2 (Feb. 2023), p. 024005. ISSN: 2058-9565. DOI: [10.1088/2058-9565/acb6ae](https://doi.org/10.1088/2058-9565/acb6ae). URL: <http://dx.doi.org/10.1088/2058-9565/acb6ae>

- Discusses current strategies toward democratizing quantum technology across academia, government, and industry. These strategies are discussed within three definitions of democracy - deliberative, participatory, and representative democracies. Recommendations to further the democratization of quantum technologies are given

Emma McKay. “Keep the fight unfair”: *Military rhetoric in quantum technology*. 2022. arXiv: [2203.01415](https://arxiv.org/abs/2203.01415) [physics.soc-ph]. URL: <https://arxiv.org/abs/2203.01415>

- Analysis of United States of America military rhetoric at a quantum conference. Several themes are identified within the proposed applications of quantum technologies, especially those related to quantum sensors. These themes are then discussed within anti-imperialist theory

7 Hype Mitigation and Scientific Opinion Pieces

Christopher Coenen et al. “Quantum Technologies and Society: Towards a Different Spin”. In: (Nov. 2021). DOI: [10.1007/s11569-021-00409-4](https://doi.org/10.1007/s11569-021-00409-4). arXiv: [2111.12442](https://arxiv.org/abs/2111.12442) [physics.soc-ph]

- Researcher manifesto with calls to help quantum technology avoid or mitigate some challenges of emerging technologies

David P. DiVincenzo. “Scientists and citizens: getting to quantum technologies”. In: *Ethics and Information Technology* 19.4 (Aug. 2017), pp. 247–251. ISSN: 1572-8439. DOI: [10.1007/s10676-017-9435-3](https://doi.org/10.1007/s10676-017-9435-3). URL: <http://dx.doi.org/10.1007/s10676-017-9435-3>

- An extremely readable account of the history and physics motivations of quantum computing, as well as the author’s perception of how the field may evolve along with future applications. Also, an impassioned defense of funding theoretical physics in anticipation of resultant technological breakthroughs

Scott Aaronson. *Shtetl-optimized*. [Accessed 26-08-2024]. URL: <https://scottaaronson.blog/>

- A personal blog with many articles on recent and historic hyped complexity and quantum advantage claims. See for example [this piece](#) on Google’s boson sampling experiment

Martin Giles. “The US and China are in a quantum arms race that will transform warfare — technologyreview.com”. In: (2019). [Accessed 26-08-2024]. URL: <https://www.technologyreview.com/2019/01/03/137969/us-china-quantum-arms-race/>

- MIT technology review opinion piece, discusses potential military applications of quantum technology and related geopolitical tensions for quantum technological development

Emma McKay. *From the land to the lab: researchers and extraction — emma.m.mckay*. [Accessed 26-08-2024]. URL: <https://medium.com/@emma.m.mckay/from-the-land-to-the-lab-researchers-and-extraction-94b20b28f249>

- An opinion piece discussing ethical issues with the extraction of resources used in research, using Indium as a case study

8 Philosophy of Science Background

Julian Reiss and Jan Sprenger. “Scientific Objectivity”. In: *The Stanford Encyclopedia of Philosophy*. Ed. by Edward N. Zalta. Winter 2020. Metaphysics Research Lab, Stanford University, 2020. URL: <https://plato.stanford.edu/archives/win2020/entries/scientific-objectivity/>

- A summary of philosophical approaches to scientific objectivity

Helen E. Longino. *Science as Social Knowledge: Values and Objectivity in Scientific Inquiry*. Princeton University Press, 1990

- A foundational text in feminist philosophy of science which uses a broadly empiricist theory of knowledge to center the role of community consensus in creating scientific objectivity

Sandra Harding. *Whose Science? Whose Knowledge? Thinking From Women’s Lives*. Cornell University, 1991

- Another foundational text in feminist philosophy of science. Harding makes many similar points to Longino but uses a standpoint theory of knowledge. Harding discusses the objectivity of an individual researcher, as well as the objectivity of a research community. This text also contains a strong critique of “pure” science and centers the role of technological innovation in driving even abstract research

Sabina Leonelli. *Philosophy of Open Science*. 2023. URL: <https://philsci-archive.pitt.edu/21986/>

- Discusses challenges, strengths, and unique ethical questions of large, ‘open science’ initiatives

Sven Ove Hansson. “Risk”. In: *The Stanford Encyclopedia of Philosophy*. Ed. by Edward N. Zalta and Uri Nodelman. Summer 2023. Metaphysics Research Lab, Stanford University, 2023. URL: <https://plato.stanford.edu/archives/sum2023/entries/risk/>

- A summary of philosophical approaches to risk. Section 3 discusses inductive risk in philosophy of science

Heather Douglas. “Inductive Risk and Values in Science”. In: *Philosophy of Science* 67.4 (2000), pp. 559–579. DOI: [10.1086/392855](https://doi.org/10.1086/392855)

- Discusses the role of individual judgment in research and the risks that can arise from the value or technical judgments in inescapably subjective cases. Takes up ‘inductive risk’ as a problem to the objectivity of science

P. W. Anderson. “More Is Different: Broken symmetry and the nature of the hierarchical structure of science.” In: *Science* 177.4047 (Aug. 1972), pp. 393–396. ISSN: 1095-9203. DOI: [10.1126/science.177.4047.393](https://doi.org/10.1126/science.177.4047.393). URL: <http://dx.doi.org/10.1126/science.177.4047.393>

- A now standard text from a Nobel Laureate and condensed matter theorist, criticizing an often invoked hierarchy of science wherein highly abstract, mathematical work is perceived as more complex or useful than other disciplines

Joseph D. Martin. “Prestige Asymmetry in American Physics: Aspirations, Applications, and the Purloined Letter Effect”. In: *Science in Context* 30.4 (Dec. 2017), pp. 475–506. ISSN: 1474-0664. DOI: [10.1017/s0269889717000242](https://doi.org/10.1017/s0269889717000242). URL: <https://www.jdmartin.org/prestige-asymmetry-in-american-physics>

- A case study of the public perception of condensed matter physics and high energy physics in the 20th century United States of America. A strong difference in perception is identified between the two fields, loosely between “applied research leading to near-term technologies” and “fundamental research leading to new abstract knowledge which might lead to novel technologies in the long term.” Tangible differences in funding structures in the two fields are identified and suggested to be exacerbated by this perception difference

S. Andrew Schroeder. “An Ethical Framework for Presenting Scientific Results to Policy-Makers”. In: *Kennedy Institute of Ethics Journal* 32.1 (2022), pp. 33–67. DOI: [10.1353/ken.2022.0002](https://doi.org/10.1353/ken.2022.0002)

- Problematizes current ethical standards for researchers summarizing their research publicly. Provides an alternative framework inspired by bioethics theory on how clinicians should counsel patients in informed consent models

Peter P.C.C. Verbeek. “Morality in Design: Design Ethics and the Morality of Technological Artifacts”. Undefined. In: *Philosophy and Design: from Engineering to Architecture*. Ed. by Peter Kroes et al. Germany: Springer, 2008, pp. 91–103. ISBN: 978-1-4020-6590-3. DOI: [10.1007/978-1-4020-6591-0_7](https://doi.org/10.1007/978-1-4020-6591-0_7)

- A proposal for how to understand the ways in which technology impacts human moral agency, along with a discussion of how this could impact the ethics of design

9 Emerging Technology Ethics

René von Schomberg. “Why responsible innovation?” In: *International Handbook on Responsible Innovation*. Edward Elgar Publishing, July 2019. ISBN: 9781784718855. DOI: [10.4337/9781784718862.00006](https://doi.org/10.4337/9781784718862.00006). URL: <http://dx.doi.org/10.4337/9781784718862.00006>

- Defines several challenges to responsible innovation, which are specifically tied to contemporary scientific practices. Also somewhat of a road map for science and scientific industry partnerships

Steven Umbrello et al. “From Speculation to Reality: Enhancing Anticipatory Ethics for Emerging Technologies (Ate) in Practice”. In: *Technology in Society* 74 (2023), pp. 1–11

- Reviews anticipatory technology ethics (ATE) for emerging technologies through its application to a particular project. ATE distinguishes three layers to the ethical discussion of emerging technology - technology, artifact, and application levels - which require distinct analytic approaches. Applying ATE as an analytical framework to the European Commission-funded project TechEthos, four points of difficulty are raised and then corrected. They finally suggest a modified version of ATE

Steven Umbrello. “The Moral Psychology of Value Sensitive Design: The Methodological Issues of Moral Intuitions for Responsible Innovation”. In: *Journal of Responsible Innovation* 5.2 (2018), pp. 186–200

- Design for value theories are ethical frameworks that emphasize the designer’s moral intuitions. Using value-sensitive design, the paper argues that cognitive biases weaken this approach to technology ethics but can be controlled through the use of heuristics to examine cognitive biases

10 Tangential Science Ethics

Jon Alan Schmidt. “Changing the Paradigm for Engineering Ethics”. In: *Science and Engineering Ethics* 20 (2013), pp. 985–1010. URL: <https://api.semanticscholar.org/CorpusID:29177230>

- Virtue ethics-based proposals for ethics in engineering. In contrast to other popular ethical theories (consequentialism and deontology), virtue ethics focuses on an individual whose ethical competence can be cultivated through the development of good values.

Eddie Conlon, Diana Adela Martin, and Brian Bowe. “Holistic Engineering Ethics?” In: *Proceedings of the Engineering Education for Sustainable Development Conference*. 2018

- A survey of existing approaches to engineering ethics, some problems with these, and suggestions for refocusing ethics. In particular, the focus on the actions of an individual is raised as a significant shortfall of existing approaches to engineering ethics

J. B. van Grunsven et al. “How to Teach Engineering Ethics?: A Retrospective and Prospective Sketch of Tu Delft’s Approach to Engineering Ethics Education”. In: *Advances in Engineering Education* 9.4 (2021)

- A retrospective of twenty years of experience embedding ethics into engineering courses at TU Delft. The primary method of instruction was dedicated ethics courses with tutorials, however modules embedded into pre-existing courses were also used. Ongoing and future program development is discussed

Barbara J. Grosz et al. *Embedded EthiCS: Integrating Ethics Broadly Across Computer Science Education*. 2018. arXiv: [1808.05686](https://arxiv.org/abs/1808.05686) [cs.CY]. URL: <https://arxiv.org/abs/1808.05686>

- A report on a Harvard pilot program in the computer science department. Rather than running a full ethics course, topical ethics modules are integrated into conventional computer science courses at both undergraduate and graduate levels. They found the response from both students and faculty was overwhelmingly positive

Gregor Große-Börling, Lukas Scheppach, and Andreas Mühlhng. “The Place of Ethics in Computer Science Education”. en. In: (2023). DOI: [10.25932/PUBLISHUP-61598](https://doi.org/10.25932/PUBLISHUP-61598). URL: <https://publishup.uni-potsdam.de/61598>

- A survey of existing strategies for teaching ethics in German computer science programs. Presents a defense of the importance of ethics education in computer science and reports on the outcome of a dedicated ethics course at Kiel University

ACM Code of Ethics and Professional Conduct. [Accessed 27-08-2024]. 2018. URL: <https://www.acm.org/code-of-ethics>

- The Association for Computer Machinery Code of Ethics, a standard guideline for ethics in computer science

11 Quantum Physics Pedagogy

Kristin A. Oliver et al. *Education for expanding the quantum workforce: Student perceptions of the quantum industry in an upper-division physics capstone course*. 2024. arXiv: [2407.07902](https://arxiv.org/abs/2407.07902) [physics.ed-ph]. URL: <https://arxiv.org/abs/2407.07902>

- Report on an undergraduate model course at UC Boulder for upper-level physics, mainly comprised of interviews with a small number of undergraduate participants. Students were questioned on a variety of points, including their pre-existing knowledge of the quantum industry, their opinion of the industry, their interest in pursuing a career in quantum technologies

Joan Étude Arrow, Sara E. Marsh, and Josephine C. Meyer. “A Holistic Approach to Quantum Ethics Education”. In: *2023 IEEE International Conference on Quantum Computing and Engineering (QCE)*. IEEE, Sept. 2023. DOI: [10.1109/qce57702.2023.20332](https://doi.org/10.1109/qce57702.2023.20332). URL: <http://dx.doi.org/10.1109/QCE57702.2023.20332>

- QEP paper with a working definition of quantum ethics and discussion of pedagogical strategies

Zeki C. Seskir et al. “Quantum games and interactive tools for quantum technologies outreach and education”. In: *Optical Engineering* 61.08 (July 2022). ISSN: 0091-3286. DOI: [10.1117/1.OE.61.8.081809](https://doi.org/10.1117/1.OE.61.8.081809). URL: <http://dx.doi.org/10.1117/1.OE.61.8.081809>

- A survey of existing quantum game proposals

Quantum — resources at the Perimeter Institute for Theoretical Physics. [Accessed 27-08-2024]. URL: <https://resources.perimeterinstitute.ca/collections/quantum>

- Compilation of educational resources on quantum science for middle-high school grades

Chanda Prescod-Weinstein. *The disordered cosmos*. en. New York, NY: PublicAffairs, Apr. 2021

- An essay collection, which is part memoir and part decolonial theory infused political and social theory. A great resource for readers who want to understand what land rights, unions, and public transportation have to do with access to physics research and education

12 Demographic Surveys in Physics

Eden J. Hennessey et al. *Canadian Physics Counts: An exploration of the diverse identities of physics students and professionals in Canada*. 2024. arXiv: [2403.04679](https://arxiv.org/abs/2403.04679) [physics.ed-ph]. URL: <https://arxiv.org/abs/2403.04679>

- A national survey on the make-up of Canadian physics researchers

Diversity: Statistics & Reports — American Institute of Physics — aip.org. [Accessed 26-08-2024]. URL: <https://www.aip.org/diversity-initiatives/statistics>

- American Physics Association diversity reports