

PAPER • OPEN ACCESS

Bridging the quantum divides: a chance to repair classic(al) mistakes?

To cite this article: Carolyn Ten Holter *et al* 2022 *Quantum Sci. Technol.* **7** 044006

View the [article online](#) for updates and enhancements.

You may also like

- [How just and just how? A systematic review of social equity in conservation research](#)
Rachel S Friedman, Elizabeth A Law, Nathan J Bennett et al.
- [A comprehensive survey on 3-equitable and divisor 3-equitable labeling of graphs](#)
A. Parthiban and Sangeeta
- [-excellence in graphs](#)
D Lakshmanaraj, L Muthusubramanian and V Swaminathan



IOP | ebooks™

Bringing together innovative digital publishing with leading authors from the global scientific community.

Start exploring the collection—download the first chapter of every title for free.

Quantum Science and Technology



PAPER

OPEN ACCESS

RECEIVED
17 February 2022

REVISED
19 July 2022

ACCEPTED FOR PUBLICATION
30 August 2022

PUBLISHED
15 September 2022

Original content from
this work may be used
under the terms of the
[Creative Commons
Attribution 4.0 licence](#).

Any further distribution
of this work must
maintain attribution to
the author(s) and the
title of the work, journal
citation and DOI.



Bridging the quantum divides: a chance to repair classic(al) mistakes?

Carolyn Ten Holter^{1,*} , Philip Inglesant¹ , Rupesh Srivastava² and Marina Jirotko¹

¹ Department of Computer Science, University of Oxford, Oxford, United Kingdom

² Entangled Positions, Chelmsford, United Kingdom

* Author to whom any correspondence should be addressed.

E-mail: carolyn.ten.holter@cs.ox.ac.uk

Keywords: responsible innovation, quantum computing, equitable access to computing, international collaboration

Abstract

Classical computing, which has transformed the world in unprecedented ways, has not always been deployed in ways that prioritise ethical values such as fairness, justice, and equity. The Western-focused, Silicon-Valley-centric 21st-century-computing model creates digital ‘haves’ and ‘have-nots’. Quantum computers promise to be exponentially more powerful than classical computers for some classically hard problems, potentially transforming application areas such as chemistry, drug discovery, and machine learning. However, if access and control over quantum computing is not shared equitably, then this may serve to amplify existing inequalities and create even deeper divides. Here we consider some of the possible implications for responsible quantum computing, looking ahead to ways in which the rollout of quantum computing could centre ethical principles such as fairness and equity, in order to prevent the mistakes of the ‘classical-only’ past. The issues raised in this paper will be of interest to those engaged in quantum computing research and to those concerned with the societal implications of this major new technology.

1. A fast-moving technology

Recent events have shown huge strides in the development of gate-based quantum computers, exceeding 100-qubits for the first time in superconducting and neutral atom systems³. The remaining problems to be solved—although far from insignificant—are largely within the realm of engineering, rather than fundamental science (Almudever *et al* 2017, Inglesant *et al* 2021). The focus is now on the design, manufacture, control, and manipulation of larger assemblies of qubits; and a corresponding software effort to reduce errors, optimise algorithms, and create better tools for research and industry.

It is possible that within three years an inflection point may be reached whereby quantum computing starts to become useful, with more powerful systems anticipated by the end of the decade⁴. There is also increasing interest in applications that might be possible with quantum computing that is available now, or will be in the next few years (Preskill 2018). Although there is no consensus on exact timescales, there is agreement that quantum technologies are likely to offer substantially different forms of computing than those that are currently available. These may include use-cases such as quantum chemistry (Reiher *et al* 2017), machine learning (Biamonte *et al* 2018), and drug discovery (Cao *et al* 2018)—all of which present the possibility of significant societal impacts.

The rapid pace of technological development mean that researchers, governments, and commercial organisations need to keep up-to-date with progress, build know-how and capacity, and assess potential

³ E.g. IBM <https://research.ibm.com/blog/127-qubit-quantum-processor-eagle>, QuEra—<https://fastcompany.com/90698019/quera-quantum-computing-startup>.

⁴ IBM Quantum roadmap: <https://research.ibm.com/blog/ibm-quantum-roadmap>, Google Quantum Computing Journey: <https://quantumai.google/learn/map>.

impacts and implications. Not all institutions have the resources to do so. There are also other drivers of behaviours within national and international developmental marketplaces, such as desiring first-mover advantage⁵, or the dual-use⁶ aspects of quantum computing. Quantum computing has been a relatively small and expert field, but the time is now appropriate for wider, non-specialist audiences to be invited to engage with the questions and challenges presented by this technology, and for those already involved in quantum computing to work with others to consider these important broader questions.

2. Responsible innovation

This type of engagement among wider groups is a foundational pillar of anticipatory governance approaches (Guston 2014). Responsible innovation (RI) requires consideration of the impacts on society of novel technologies, and provides a framework to support these efforts (Stilgoe *et al* 2013). It therefore takes a long-term view, drawing on the aspects of responsibility that relate to the future, such as ‘taking care’ (Pellizzoni 2004). Essential elements of RI include wide-ranging consultation with stakeholders, working collectively to anticipate outcomes, reflecting on the decisions being taken, and responding to the results of these consultations and reflections—not assuming that publics need to be educated, but rather engaging in dialogue with them (e.g. Winickoff 2017). Through these means, RI seeks to open up conversation between science and wider society, to incorporate diverse viewpoints and understandings, to consider any concerns revealed by these engagements, and to respond to problems and challenges. This is for several reasons—to increase the likelihood of a better ‘fit’ with society; to improve the technologies themselves; and to try and anticipate and ameliorate negative effects.

There have already been some RI activities in quantum computing (e.g. Inglesant *et al* 2021, Khan 2021) in order to ensure ongoing assessment of societal impacts. A commissioned report in the UK sought to engage in dialogue with a wide section of the public (EPSRC 2017). (Coenen and Grunwald 2017) argued for a ‘strong’ approach to inform public policy and decision-making around quantum technologies as a whole, drawing on their experiences with nanotechnologies.

To date, however, responses in mainstream outlets have tended to focus on some of the more negative potential impacts, such as the likelihood that quantum computing may permit breaching of current cybersecurity protocols (Biever 2013)—there is already growing awareness in civil society of the likelihood of this.

Cybersecurity breaches are of course a serious risk, but it is the more positive benefits of gaining access to quantum computing, such as work on new drugs and materials, that are the source of excitement and investment, and a responsible innovation approach must therefore also investigate societal impacts—including possible negative effects—of breakthroughs in these areas.

3. Haves and have-nots

Access to technology can be starkly divided between geographical regions. For example, smartphone penetration in the USA is at 81.6%, but in Pakistan that figure is only 18.4%⁷. Even within countries there are major digital gaps, as the Covid-19 pandemic demonstrated—one in four primary-school children in Argentina’s poor ‘barrios populares’ abandoned their schooling at some point during 2020 because of lack of internet connectivity⁸.

In similar fashion, access to quantum computing is not likely to be equitably distributed among nations and thus the benefits of new discoveries are unlikely to be evenly shared. Rich Western nations, global big tech companies, and China, will be the first to be able to access and utilise relatively stable quantum computers. There are many reasons for this including supply-chains, infrastructure, capacity, and access to finance—and just as there will be many factors in successfully creating a stable quantum computer, there will be many factors at play in inequitable distribution, not solely access to resources. It is likely also to be driven by factors such as lack of familiarity with the possibilities offered by the technology—engagement efforts such as the UK’s Public Dialogue (EPSRC 2017) found that popular understanding of quantum remains relatively limited, and often associated with semi-magical or philosophical themes (Dihal 2017). Using quantum computing effectively also requires specialist skills and research that are concentrated in

⁵ ‘A first mover is a service or product that gains a competitive advantage by being the first to market with a product or service’. <https://investopedia.com/terms/f/firstmover.asp>.

⁶ ‘Technology that can be used for both peaceful and military aims’ https://en.wikipedia.org/wiki/Dual-use_technology.

⁷ Newzoo Global Mobile Market Report 2020.

⁸ <https://prensa.argentinosporlaeducacion.org/en-barrios-populares-uno-de-cada-cuatro-estudiantes-interrumpio-su-escolaridad-en-202>

only a few places across the globe. It is likely that the availability of quantum computing will be ‘democratised’ by cloud-style remote access, and is already being used for research and learning (Devitt 2016) but this is likely to remain challenging in many countries, even if it is not actually blocked, and will still require high levels of expertise. Such varying distribution means that the impacts of quantum computing will vary widely across countries and communities.

Quantum computing is likely to be a powerful tool, and questions around power always generate tensions and contested spaces—for example if nation states have access to quantum computing but their citizens do not, how does that affect the balance of power in that country? and what impact does that have on democracy? Big tech firms are already data-hungry—what would be the effect on already-threatened data privacy if they had access to quantum computing?

The present authors therefore echo calls from those such as De Wolf (2017) and Ten Holter *et al* (2021) that a broader perspective is required, and that any consideration of the social impacts of quantum computing needs to address these questions of access and accessibility. Equitable access to the benefits of quantum computing can also draw on established protocols from other emerging technologies such as genetic and biological research (Laird and Wynberg 2016) and nanotechnologies (Guston 2014). Some of these divides have their roots in pre-20th century colonialist mindsets, or unaddressed social inequalities, but responsible innovation, with its pre-emptive approach, anticipates the likelihood that, if quantum computing remains the preserve of China, the West, and the rich, such divides will continue to be exacerbated. This will create yet more generations of populations cut off from the benefits that new technologies can offer. Anticipating that this is a likely outcome of the current direction of travel in technological development, a responsible innovation mindset requires us to think in potentially more creative ways about national approaches, ownership of such technologies and protectionist or nationalistic approaches.

4. Protectionist impulses

The affordances that a quantum computer could offer are likely to significantly affect global geopolitics, and there is already a recognised trend towards nationalistic approaches in quantum computing, as states focus on the links between security, prosperity, and quantum computing (Ten Holter *et al* 2021a, Roberson *et al* 2021). This has been allied to a rise in protectionism around certain technologies, seen in regulation such as the UK’s National Security & Investment Act⁹. This is an additional layer to existing international export controls such as the multi-state Wassenaar arrangement¹⁰, and the US’s ITAR regulations¹¹, and is designed to control investment in ‘sensitive’ technologies and ensure national interests are protected. International agreements such as the *UK-US Joint Statement on co-operation in QIST* are similarly aligned along lines of national interest¹², and within the USA, for example, individual companies may be required to sign tailored National Security Agreements. These developments are concerning because they reduce international co-operation and collaboration and, instead, encourage competition between powerful nations in a quantum ‘race’ (Roberson *et al* 2021).

5. Bridging the divides

This short summary demonstrates that there are likely to be many challenges, between regions, between nations, and between rich and poor within nations, around creating more equitable access to quantum computing. Some initiatives have already been put in place—largely from private or non-governmental sources—that attempt to widen access: IBM provides special educational programmes, and has offered free public online access to its Yorktown facility since 2016¹³; qubit by qubit is teaching quantum computing to 10 000 students globally¹⁴. Amazon Web Services offers its Braket service commercially¹⁵; one author of this article is involved with an English-for-quantum-computing initiative (ETIQUETTE) in Argentina and its societal impact¹⁶. Initiatives such as these, however, while they may go some way towards broadening access (albeit for commercial reasons such as tying in a customer base), cannot rebalance the scales towards equity

⁹ <https://legislation.gov.uk/ukpga/2021/25/contents/enacted>

¹⁰ https://en.wikipedia.org/wiki/Wassenaar_Arrangement

¹¹ <https://gov.uk/guidance/exporting-military-goods-to-the-united-states>

¹² <https://gov.uk/government/publications/uk-us-joint-statement-on-cooperation-in-quantum-information-sciences-and-technologies>

¹³ <https://research.ibm.com/quantum-computing>

¹⁴ <https://qubitbyqubit.org/>

¹⁵ <https://aws.amazon.com/braket/>

¹⁶ <https://onequantumargentina.substack.com/p/argentina-on-the-quantum-world-stage>

and global social justice. We argue that a high-level responsible innovation approach, anticipating the impoverished outcomes for many sectors of the world's population that could result from restricted access to quantum computing, can serve as part of a framework for broader international co-operation. Engagement with stakeholders and communities in various groupings, responding to concerns around impacts and societal 'fit'—these are approaches that require co-operation at the highest levels.

A responsible innovation approach also necessitates interdisciplinary work that recognises the value in and draws on fields like humanities, social sciences, law, and others, in helping to understand the impacts of novel technologies. Non-STEM (science, technology, engineering and mathematics) fields often struggle for funding even in wealthy countries¹⁷, while the technological development of innovations such as quantum computing, which are perceived to be economically beneficial, are well supported. But maximising societal benefit implies the need to draw together holistic views of societal wellbeing that go beyond economic impacts. GDP (Gross Domestic Product) cannot be the only metric for success.

At the same time, democratisation of these technologies could create a broader user base and, in turn, a greater probability of new discoveries and development, perhaps in a new 'maker movement' (De Wolf 2017). Once these technologies become more widely available, new applications, and new transformative discoveries from quantum simulators, for example (Preskill 2018), beyond what we can currently imagine, are likely to emerge. This could lead to further justification for commercial and public investment in the technology. However, this requires not only access to physical computer power but also access to knowledge; open science rather than hoarding of patents and know-how by companies (De Wolf 2017). This is a necessary *but not sufficient* condition: the Internet as we know it—built on the highest principles of openness and open standards—nevertheless rapidly came to be dominated by a small number of powerful actors.

Some leading commentators in the field, such as Professor Ian Walmsley (former head of the UK's quantum computing hub), are calling for global co-operation on the development of quantum computing¹⁸. We believe that such calls need to go further, and that to work towards a vision of a truly global quantum computing effort that can bridge social and digital gaps there is a need for co-operation across political, disciplinary, and sectoral divides in the following areas:

- (a) Government-level **international effort to ensure equitable access** to quantum computing. Only worldwide action with partners and collaborators can ensure that ethical concerns around fairness, access, and equity are not subsumed into technology arms races.
- (b) **Agreements between national governments and Big Tech companies** to create more equitable access. Tech companies benefit enormously from national education programmes that train their future employees, as well as research and funding infrastructure, and so it is reasonable to expect that they should co-operate with governments on the democratisation of such a key technology.
- (c) International **collaborative research efforts** focussed on responsible and ethical approaches to quantum computing that can connect researchers investigating these challenges.

It is not, of course, the sole responsibility of quantum physicists to resolve all these challenges. But quantum scientists, social scientists, and all involved in the development of the quantum computing sector worldwide, can recognise that quantum mechanics does not discriminate and neither should those developing its use. Democratising access to quantum computing might be an opportunity to overcome some of the digital divides of the past, and perhaps create a more equitable—quantum-enabled—future.

Acknowledgments

This work was supported by the Engineering and Physical Sciences Research Council, Grant Number EP/M013243/1.

Data availability statement

No new data were created or analysed in this study.

¹⁷ E.g. <https://theguardian.com/education/2022/jun/27/sheffield-hallam-university-suspends-low-value-english-literature-degree>.

¹⁸ <https://imperial.ac.uk/news/229513/imperials-provost-urges-global-collaboration-quantum/>

ORCID iDs

Carolyn Ten Holter  <https://orcid.org/0000-0001-8739-3211>

Philip Inglesant  <https://orcid.org/0000-0002-5265-8707>

Marina Jirotko  <https://orcid.org/0000-0002-6088-3955>

References

- Almudever C G *et al* 2017 The engineering challenges in quantum computing *Proc. 2017 Design, Automation and Test in Europe, DATE 2017* pp 836–45
- Biamonte J, Wittek P, Pancotti N, Rebentrost P, Wiebe N and Lloyd S 2018 *Quantum Machine Learning* **549** 195–202
- Biever C 2013 My quantum algorithm won't break the internet... yet *New Scientist* <https://newscientist.com/article/mg22029445-100-my-quantum-algorithm-wont-break-the-internet-yet/>
- Cao Y, Romero J and Aspuru-Guzik A 2018 Potential of quantum computing for drug discovery *IBM J. Res. Dev.* **62** 6:1–6:20
- Coenen C and Grunwald A 2017 Responsible research and innovation (RRI) in quantum technology *Ethics Inf. Technol.* **19** 277–94
- De Wolf R 2017 The potential impact of quantum computers on society *Ethics Inf. Technol.* **19** 271–6
- Devitt S J 2016 Performing quantum computing experiments in the cloud *Phys. Rev. A* **94** 032329
- Dihal K 2017 The stories of quantum physics: quantum physics in literature and popular science, 1900–present *PQDT—UK & Ireland* <https://search.proquest.com/docview/2189047121?accountid=8113>
- EPSRC 2017 *Quantum Technologies Public Dialogue Report* https://nqit.ox.ac.uk/sites/nqit.ox.ac.uk/files/2018-07/QuantumTechnologiesPublicDialogueFullReport_0.pdf
- Guston D H 2014 Understanding 'anticipatory governance' *Soc. Stud. Sci.* **44** 218–42
- Inglesant P, Ten Holter C, Jirotko M and Williams R 2021 Asleep at the wheel? Responsible innovation in quantum computing *Technol. Anal. Strateg. Manage.* **0** 1–13
- Khan I 2021 Will quantum computers truly serve humanity? *ScientificAmerican.Com* <https://scientificamerican.com/article/will-quantum-computers-truly-serve-humanity/>
- Laird S A and Wynberg R P 2016 Locating responsible research and innovation within access and benefit sharing spaces of the convention on biological diversity: the challenge of emerging technologies *NanoEthics* **10** 189–200
- Pellizzoni L 2004 Responsibility and environmental governance *Environ. Polit.* **13** 541–65
- Preskill J 2018 Quantum computing in the NISQ era and beyond <https://doi.org/10.22331/q-2018-08-06-79>
- Reiher M, Wiebe N, Svore K M, Wecker D and Troyer M 2017 Elucidating reaction mechanisms on quantum computers *Proc. Natl Acad. Sci. USA* **114** 7555–60
- Roberson T, Leach J and Raman S 2021 Talking about public good for the second quantum revolution: analysing quantum technology narratives in the context of national strategies *Quantum Sci. Technol.* **6** 25001
- Stilgoe J, Owen R and Macnaghten P 2013 Developing a framework for responsible innovation *Res. Policy* **42** 1568–80
- Ten Holter C, Inglesant P and Jirotko M 2021a *Creating a responsible quantum future: the case for a dedicated national resource for responsible quantum computing*
- Ten Holter C, Inglesant P and Jirotko M 2021b Reading the road: challenges and opportunities on the path to responsible innovation in quantum computing *Technol. Anal. Strateg. Manage.*
- Winickoff D 2017 Public acceptance and emerging production technologies *The Next Production Revolution* (Paris, France: OECD) <https://doi.org/10.1787/9789264271036-en>