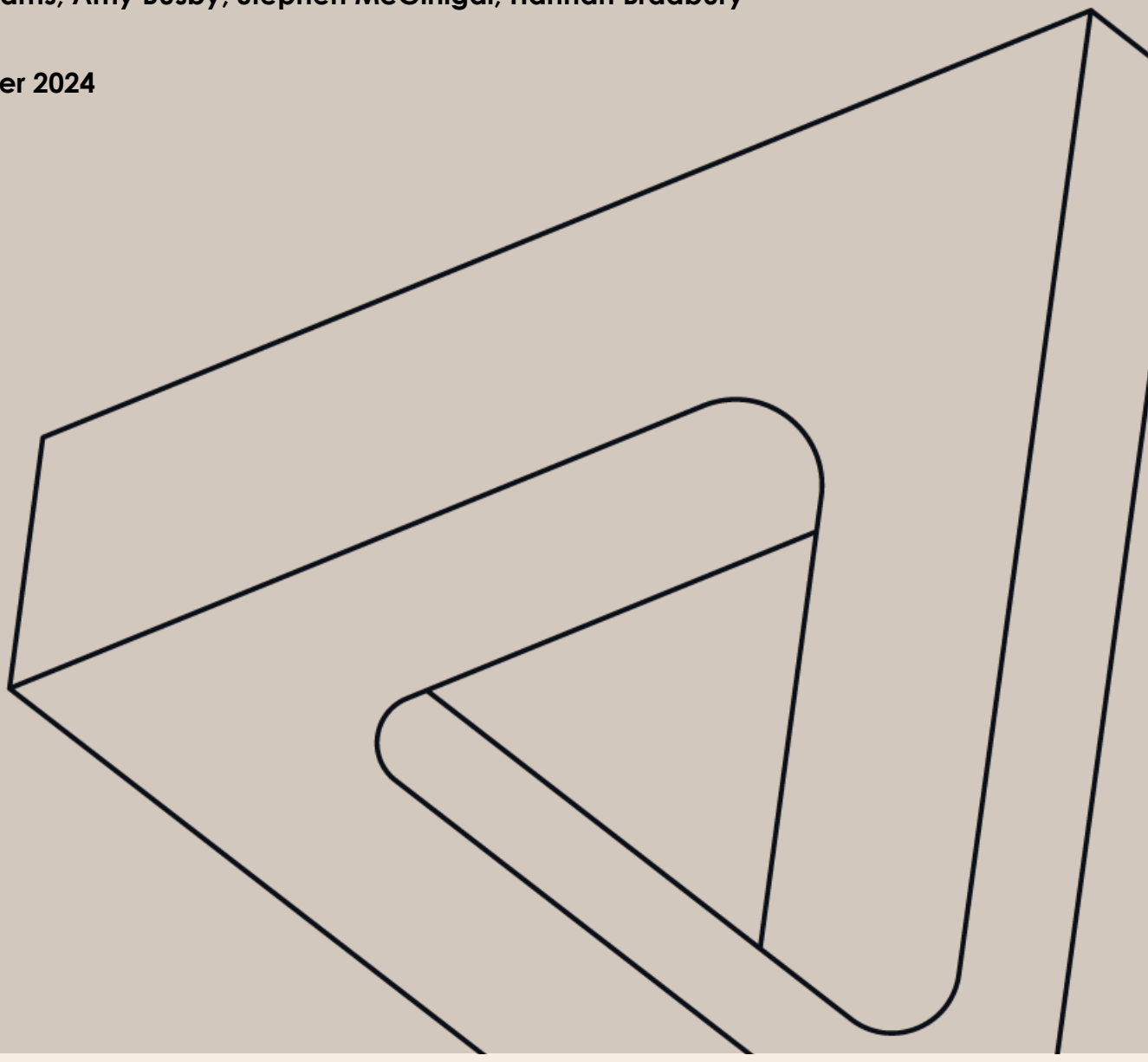
Public Dialogue on Quantum Computing

Lucy Williams, Amy Busby, Stephen McGinigal, Hannah Bradbury

September 2024



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Quantum Computing & Simulation Hub

Responsible Technology Institute

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1. Executive Summary

1.1. Background and methodology

The UK National Quantum Technologies Programme (NQTP) is a £1billion collaboration between industry, academia and government, established in 2014. The programme includes four research hubs, funded by the Engineering and Physical Sciences Research Council (EPSRC). One of these, the Quantum Computing and Simulation Hub, focuses on the critical research challenges facing quantum computing across a range of hardware and software disciplines.

The purpose of this public dialogue research was to provide the Quantum Computing and Simulation Hub and the Responsible Technology Institute with up-to-date insight on the UK public's knowledge of and attitudes towards quantum computing, to support on-going engagement work in this space.

The research consisted of an online survey, followed by online deliberative workshops. The online survey of 1013 people informed the content of the four half-day online workshops, which were held with 45 participants from across the UK.

1.2. Key Findings

Overall, there were high levels of recognition of the term 'quantum computer' across the UK, but low levels of knowledge and understanding of the technology. Six in ten (60%) survey respondents said they had heard of or had knowledge of quantum computers; three in ten (31%) said they knew hardly anything about quantum computers but they had heard of them, 18% said they knew a little about quantum computers, 6% a fair amount and 5% a lot. Similarly, in the workshops there was wide recognition of the term 'quantum computer', but most participants had no or very low levels of knowledge of what they are.

Overall, participants were excited about quantum computers and enthused by the benefits they could offer society. Their priorities were for quantum computers to be used to solve important and pressing issues facing society today, such as:

- Improving health outcomes, such as improving cancer treatment and developing new medicines and personalised medical treatments
- Supporting responses to climate change, such as supporting the development of clean energy, creating new sustainable materials, reducing the use of plastics, and improving the health and cleanliness of oceans.
- Security and defence purposes. Despite widespread concern about the use of quantum computers for security and defence purposes, participants also saw this use-case as a priority area for development in the UK because they worried about the UK "*falling behind*" other countries' quantum computing defence capabilities, which could mean the UK could not protect itself from threats.

Workshop participants were concerned that quantum computers could pose a range of risks to society and participants were commonly quite sceptical that the technology would be used to positively impact citizens' everyday lives (and commonly assumed they were more likely to instead financially benefit large companies). However, despite these concerns, participants generally decided that the potential benefits of quantum computers would likely outweigh the risks. It is important to note that pre-existing concerns about the impacts of other advanced technologies

(notably AI) shaped participants views and concerns about quantum computers. The following concerns were commonly reported:

- Participants were concerned that businesses would benefit disproportionately from quantum computers by focusing on using quantum computers to generate profit, rather than on how they can positively impact society and people's everyday lives.

- Participants worried about other countries using quantum computers for security and defence purposes, which could make the world a more unstable and unsafe place, with more dangerous "high tech conflicts".

- Wide scale job losses caused by quantum computers automating processes traditionally done by humans, particularly through quantum enabled artificial intelligence (AI), was a key concern, with many participants spontaneously raising this concern before they were shown information about it.

- Participants regularly referred to perceived negative impacts of other technologies (particularly AI and social media) and were concerned quantum computers might have similar negative effects, especially if quantum computers are used to enhance AI. For example, participants were worried about the danger of removing humans from processes and replacing them with technology because participants felt technology can get things wrong and that humans could be more trustworthy when making important and complex decisions, such as deciding the outcome of court cases.

As a result of these concerns, there was a strong consensus that the development and use of quantum computers should be regulated to mitigate these concerns and that a range of people (including the public) should be involved in creating regulation.

Survey respondents were asked, based on what they knew or had heard about quantum computers, if they supported or opposed the UK developing and using this technology. Respondents were far more likely to support (41%) than oppose it (7%), with four in ten (39%) neither supporting nor opposing it. Survey respondents were informed that in 2023, as part of the National Quantum Strategy, the Government committed to invest £2.5 billion in quantum technology (such as quantum computers) over the next ten years. Respondents were more likely to support (46%) than oppose it (10%), with three in ten neither supporting nor opposing it.

Similarly, at the end of the workshops, there was also broad support for the development and use of quantum computers in the UK and of the National Quantum Strategy. This was because, after carefully considering the potential benefits and risks of quantum computers, participants generally decided that the benefits would likely outweigh the risks and they also did not want to see the UK "left behind" if other countries were developing the technology. These reasons drove widespread support for the amount of funding the UK government was committing to spend over the next 10 years on the National Quantum Strategy and led some participants to think that the amount (i.e., £2.5billion) was too small because of the importance of developing the technology.

2. Background and research design

2.1. Background

The UK National Quantum Technologies Programme (NQTP) is a £1billion collaboration between industry, academia and government, established in 2014. Its vision is to create a quantum enabled economy and it supports ideas, innovation and investment to secure UK opportunities in this technology area. The programme includes four research hubs, funded by the Engineering and Physical Sciences Research Council (EPSRC). One of these, the Quantum Computing and Simulation Hub, focuses on the critical research challenges facing quantum computing across a range of hardware and software disciplines. A National Quantum Strategy published in March 2023 outlined the UK's ambition over the next decade and was followed later that year by a series of quantum technology missions, including a computing mission that states: "By 2035, there will be accessible, UK-based quantum computers capable of running 1 trillion operations and supporting applications that provide benefits well in excess of classical supercomputers across key sectors of the economy."

Whilst there is a significant body of research on public attitudes to new technologies, little has been conducted on views about quantum computing specifically. The EPSRC's 2017 dialogue run by Verian (formerly Kantar Public) found low levels of awareness and knowledge of quantum technologies and initially neutral attitudes, but that more information about benefits could engage participants, particularly around health, humanitarian, and security applications. Whilst there was broad positivity about the potential of quantum computing specifically, there were concerns around access and misuse. Given there have been significant developments in quantum computing since then, including increased investment and involvement of the industrial sector, and increased media coverage of wider technological developments (notably AI), it was deemed important to engage again with the public on this topic.

2.2. Research objectives

The purpose of this research was to provide the Quantum Computing and Simulation (QCS) Hub and the Responsible Technology Institute (RTI) with up-to-date insight on the UK public's knowledge of and attitudes towards quantum computing, to support on-going engagement work in this space. The dialogue created the opportunity to bring together the public and stakeholders (from the Quantum Computing and Simulation Hub, RTI and UK Quantum) to engage in informed discussions about quantum computing and particular social and ethical implications of the development and use of this technology. This report is also a resource for the wider quantum community.

Specifically, the research objectives were to:

- Understand public perceptions of quantum computing and priorities and concerns about this technology domain.
- Explore social and ethical issues related to research in this area.

2.3. Method

A mixed-method public deliberative dialogue approach was used to explore the research objectives. Deliberative dialogues bring together the public, researchers and stakeholders to engage in informed discussions about complex topics. The public dialogue consisted of an initial online survey, followed by online deliberative workshops. The online survey of 1013 people informed the content of the four half-day online workshops, which were held with 45 participants from across the UK.

2.3.1. Online survey

The survey was conducted from 15th – 17th April 2024. The survey explored a range of topics including: respondents' prior level of knowledge of quantum computers; attitudes towards the potential benefits and risks of quantum computers; support for the development and use of quantum computers in the UK; and attitudes to the regulation of quantum computers in the UK.

Respondents were recruited using Kantar Profiles online panel. The sample was nationally representative and reflected a mixture of ages, genders, UK regions and socio-economic status. The data was weighted to be representative of region, age, gender and socio-economic grade.

2.3.2. Public dialogue workshops

Following the survey, the four online half-day deliberative workshops were held via Zoom in July 2024[1]. The workshops explored a range of topics including: awareness and knowledge of quantum physics and quantum computing; attitudes to potential quantum computing use-cases; attitudes to potential risks of quantum computers; attitudes to the National Quantum Strategy; and attitudes to regulating quantum computers in the UK.

The workshops enabled more informed discussions about the development and use of quantum computers. Stimulus materials were used throughout the workshops to develop participant knowledge and move discussions beyond initial, instinctive reactions, to more informed and considered views. The materials created by Verian were reviewed by the Quantum Computing and Simulation Hub and the Responsible Technology Institute to ensure they were accurate, up to date and presented a balanced perspective. To ensure the workshops were engaging for participants with different learning styles, a variety of virtual stimulus materials and activities were used including presentations, videos, polling, and a drawing exercise.

One workshop was held for each of the following four regions to ensure coverage from across the UK: England North, England South and East, England Midlands, and Scotland/Wales/Northern Ireland. In total, 45 participants, reflecting key demographics of the UK population and a range of attitudes to new technologies, took part in the dialogue process[2]. Workshops were held on two consecutive Saturdays and each lasted four hours. The moderators of each workshop followed a topic guide to ensure consistency across all workshops. Each workshop had 10-12 participants who spent most of the time in one of two smaller break-out discussion groups of 5-6 people to ensure everyone had time to contribute their views; there were eight small groups in total. Most groups were accompanied by an expert stakeholder, who observed the session and answered participants' questions.

2.4. How to read this report

In each chapter, we present the results of the initial survey before discussing the workshop findings, as the materials for the public dialogue were informed by survey results. It is important to note when considering the survey and workshop findings that participants who took part in the workshops were provided with detailed information about quantum computers. Survey participants were provided with limited information. Verbatim quotes are used throughout the report to illustrate key findings and are attributed as follows: "*Quote.*" (Gender, Age, Region).

[1] Deliberative workshops were held on the 6th and 13th July 2024, with two workshops taking place concurrently on each date.
[2] Participants were not recruited from the survey.

3. Awareness of and associations with quantum physics and quantum computers

There were high levels of recognition of the terms 'quantum' and 'quantum physics' across survey respondents and workshop participants – however, knowledge and understanding of these beyond recognition was low. Whilst there was some recognition of the term 'quantum computer', most had no or very low levels of knowledge of what they are. A small number of workshop participants knew slightly more about quantum computers, these participants often had an interest in science and technology, worked in IT, or had studied science to a degree level.

3.1. Awareness of and associations with quantum physics

Nine in ten (92%) survey respondents said they had heard of or had knowledge of quantum physics; 52% said they knew hardly anything but had heard of quantum physics, 25% a little, 9% a fair amount and 6% a lot.

Survey respondents were given a list of things related to quantum physics to see which, if any, they were familiar with: 56% said they had heard of quantum mechanics, 35% Schrödinger's cat, 19% the many-worlds theory, and 19% Heisenberg's Uncertainty Principle. One in four (26%) had not heard of any of these things.

At the start of the workshops, participants were asked what they knew about and associated with the terms 'quantum' and 'quantum physics'. There was high recognition of the terms, but participants generally had low levels of understanding of what they meant.

- Some participants had no understanding of or associations with the terms.
- Participants commonly offered uncertain associations and guesses. They said words such as the following came to mind when they heard the words 'quantum' and 'quantum physics': small, fast, science, powerful, tiny, space and energy. Some said they thought it was to do with complicated things that they were unlikely to understand. Some mentioned associating the terms with the films Quantum Leap and Quantum of Solace. Others said they knew about Schrödinger's Cat from the TV show The Big Bang Theory and that it was to do with quantum physics but were unclear how.
- Some participants knew that quantum physics was to do with atoms and a small number remembered the double-slit experiment from school.

  "*I've always assumed it's around…how atoms work at a very … specific tiny level.*" (Female, 55+, Midlands)

- A small number of participants with an interest in science and technology (who read science books/articles and/or watched science documentaries and YouTube videos) knew of the term 'superposition', Max Planck, and that quantum physics is to do with probabilities.
- A small number of participants who had studied science degrees, or who worked in certain sectors (such as IT), had more in-depth knowledge, such as what entanglement was and how quantum physics differs from classical physics.

Workshop participants were given a basic introduction to quantum physics, superposition and entanglement. This information was generally found to be difficult to understand and was not particularly engaging for participants. Some said the information broadly made sense and reminded them of information they had previously learnt but not realised was to do with quantum physics (such as Schrödinger's Cat). Some expressed confusion about how quantum physics could be applied to computers, and some were excited to understand what computers using quantum physical principles could do.

"I think that I did already know all of this, but I didn't realise it was quantum physics in a sense." (Female, 35-54, Midlands)

3.2. Awareness of and associations with quantum computers

Six in ten (60%) respondents said they had heard of or had knowledge of quantum computers; three in ten (31%) said they knew hardly anything about quantum computers but they had heard of them, 18% said they knew a little about quantum computers, 6% a fair amount and 5% a lot.

Whilst there was high recognition of the term 'quantum computer', most workshop participants had no or very low levels of knowledge of what they are. Based on their associations and understandings of what 'quantum' and 'quantum physics' are, participants commonly guessed that quantum computers are fast computers with high processing power, and used by experts and scientists to solve complex problems. Many guessed they would be particularly big computers. However, others thought that quantum computers would be smaller than traditional computers, in line with the way other technologies have developed to be smaller (such as smartphones being smaller than landline phones) or because quantum physics is to do with atoms.

Some participants knew slightly more about quantum computers from reading about them in the news, and in science articles. These participants often had a particular interest in science and technology, worked in IT, or had science degrees. 'Qubits' were mentioned, along with an awareness that quantum computers pose a risk to current encryption methods and that there is a race to make the first powerful quantum computer.

Participants were asked to draw what they thought a quantum computer would look like, after they had been given a basic introduction to quantum physics. Some drew big computers (like supercomputers), while others drew small computers (for example, one person thought quantum computers would be the size of a mobile phone, while another said they thought a quantum computer would fit on the head of a pin). Other drawings highlighted how quantum computers would use atoms to function.

"I just assumed that it would be tiny, something that would fit on a pin head... I just think that as technology gets better and more advanced everything seems to shrink in size". (Female, 55+, Midlands)

Participants were shown information that gave a basic introduction to how quantum computers use entanglement and superposition to work and the history of their development. There were mixed responses to the information and participants:

- Were excited about what quantum computers could do and how powerful they would be. They felt that quantum computers could help solve complex problems, such as developing new medical drugs and reducing environmental impacts.

"It does sound quite exciting at the minute. It feels like everything's going to speeding up exponentially, like science and stuff is getting quite fast, so it's quite an exciting time to be alive" (Male, 18-34, England South & East)

- Were worried quantum computers could have negative social impacts and pointed to the effects of other digital technologies (as described further in section 4).

- Were concerned about how powerful quantum computers might be, the fragility of quantum 'bits', and that it was not yet clear what these computers would be used for. Participants were nervous this could make quantum computers difficult to control and that they could even become "*uncontrollable*", especially if used with AI.

  "AI [springs to mind], the way computers are so much more powerful, I mean are they going to supersede us? Are they going to become so clever, so super-powerful?" (Female, 35-54, Wales)

- Found it difficult to imagine what quantum computers might be able to do and understand how quantum computers worked.

After these initial discussions, the workshops moved on to consider specific use-cases for quantum computers and their potential benefits and risks.

4. Priorities for and concerns about quantum computers

While being shown information about uses cases and risks associated with quantum computers, workshop participants expressed a range of views about the development and use of quantum computers. Participants were excited about the possibility of quantum computers being used to solve important and pressing issues facing society today. For example, they were particularly excited about use of quantum computers to improve health outcomes and support responses to climate change (as described in section 4.1).

However, there was widespread concern among participants about the risk's quantum computers could pose to society. Participants were particularly concerned that businesses would focus on developing use-cases which generate the most profit rather than those that benefit citizens most (as described in section 4.2). Participants regularly referred to what they saw to be negative impacts of other technologies (particularly Artificial Intelligence [AI)] and social media) and were concerned quantum computers might have similar negative effects. It is important to note that views and concerns about AI influenced views about quantum computing throughout these sections of the workshops.

4.1. Priorities

Survey respondents were provided with a list of potential future benefits of quantum computers and asked which they thought were the main benefits. They could select up to three answers. The two benefits selected most were that the technology could help develop new medicines (39%) and the technology could solve complex logistical problems, such as how to transport goods in the most efficient way (27%).

Workshop participants were shown information about six potential uses of quantum computers and the benefits they could provide for society. They discussed the use-cases, as well other ways quantum computers could be used, and considered what they felt should be a priority if quantum computers were developed and used in the UK. Participants' detailed responses to the specific use-cases are provided below (in section 4.1.1). Overall, participant priorities were for quantum computers to be used to:

- Improve health outcomes, such as improving cancer treatment and developing new medicines and personalised medical treatments.
- Support responses to climate change, such as supporting the development of clean energy, creating new sustainable materials, reducing the use of plastics, and improving the health and cleanliness of oceans.
- Protect national security as other countries and actors might develop the technology too for security and defence purposes.
- Reduce inequality in the UK and poverty in developing countries.

"[I would like quantum computers to] right some of the wrong we have created with the oceans and all of the amount of problems we have with greenhouse gases." (Female, 55+, Midlands)

Across the discussions, there was a strong sense that quantum computers should be developed and used to benefit citizens and society. For example, participants wanted the public and NHS to be able to access medicines that quantum computers had helped to develop, rather than pharmaceutical companies disproportionately profiting by charging high fees.

4.1.1. Use-cases shown to workshop participants

Workshop participant responses to the six potential uses of quantum computers they were provided information on are show below, ordered by how appealing participants found them to be. The use-case they wanted prioritised most was the development of new medicines. The use-case that participants were most concerned about was the use of quantum computers to further develop AI.

Development of new medicines: *Information shown to participants described that pharmaceutical companies could use quantum computers to study complex biological data and understand how molecules interact in new ways. This could help them to discover new medicines much more quickly and cheaply.*

Participants were most positive about and engaged by this use-case. They were very excited about how quantum computers could be used to improve health and prolong people's lives. For many, the benefits this use-case could lead to outweighed some of their concerns about quantum computers because of the important health impacts it could have. They also felt this use-case could lessen the strain on the NHS by reducing the number of NHS appointments people need.

"In theory it's a great idea in that if it helps people be healthier and manage different diseases then that's great." (Male, 35-54, Scotland)

Participants also voiced some concerns about this use-case. Many felt pharmaceutical companies might use quantum computers to develop the drugs that create the largest profits, rather than those which improve public health the most. Similarly, some were concerned that pharmaceutical companies might not sell these drugs at affordable prices and therefore questioned how accessible the drugs would be.

"I just hope that everybody benefited and that the quicker and cheaper [drugs development] doesn't just stay with the pharmaceutical companies, that it actually does push through to the end users and that the people that are suffering with these diseases are able to access it." (Female, 55+, Midlands)

Security and defence: *Information shown to participants described how Quantum computing could create new ways to analyse data, making it possible to decrypt "bad actor" communications. It could also improve logistics, making it safer to deploy personnel in conflict zones.*

Participants saw this use-case as a priority area for development in the UK. This is because they felt there was a risk of the UK "*falling behind*" other countries and actors' quantum computing capabilities, which could mean the UK could not protect itself from threats.

Despite this, participants were generally very concerned about the use of quantum computers for security and defence purposes and ideally did not want this to be a use of quantum computers in the UK or globally. This is because participants thought there was a risk that other countries and "bad actors" might use this technology against the UK or for other negative purposes. As a result, participants worried that the development of this use-case might overall make the world a more unstable and unsafe place, with more dangerous "*high tech conflicts*". Some likened it to nuclear weapons and the nuclear arms race, which has made conflict more dangerous.

"I think there are benefits, but there is a lot of risks involved. But if we don't do it in the UK, it is going to be developed elsewhere and then we will be at a disadvantage and we will be unsafe, so we need to keep up with technology." (Female, 35-54, Midlands)

Development of new materials: *Information shown to participants described that scientists could use quantum computers to simulate how atoms and molecules interact very accurately. This would help with the discovery of new materials for use in a range of technologies, such as longer-lasting batteries (for electric vehicles) and lighter, more efficient aircraft materials.*

Some participants were excited about this use-case, especially if it contributed to producing materials that reduce environmental impacts (such as better batteries for electric vehicles). A small number of participants who had seen a decline in manufacturing employment in their local areas, caused by the closure of steelworks, felt this use-case could help replace lost jobs if the new materials are made in these post-industrial areas. One person who had recently completed studies in civil engineering said they could see the benefits of this to engineering.

However, some participants found it difficult to understand why new materials might be useful or how they could be used. Additionally, there was little support for developing materials that make air-travel more energy efficient, as generally participants felt focus should instead be placed on changing transportation habits to those which are more sustainable in the long term.

"Does that mean it could find ways to make the production chain more sustainable and energy resources? Because I think that's quite a big [important] thing…because global warming is going up, essentially the world is just going to collapse." (Male, 18-34, South England)

Organising transportation: *Information shown to participants described that transport and delivery companies could use quantum computers to find new ways to handle large amounts of data to find the best routes and schedules for vehicles in real time. This would help to improve delivery services and the management of traffic (e.g. turning traffic lights green at the best times).*

Despite some interest in technology that could help solve congestion issues, many participants found it difficult to understand how quantum computers could improve transport on UK roads. Some wondered how quantum computers could work alongside poor UK road infrastructure. One person living in a rural area, with uncongested roads, could not see how technologies to manage traffic would benefit them. Another person who had worked in transportation optimisation believed that companies already had systems in place to find the most efficient routes and was unclear how quantum computers could add value.

Some participants were worried about transportation systems that overly rely on technology rather than humans, and quantum computers' involvement in this (such as if quantum computers are used to create technology infrastructures that support driverless cars). Some mentioned digital airport systems failing, leading to flight cancellations, as well as smart motorways causing fatalities as examples of why systems need human input.

"With… any device you get bugs… It will malfunction sometimes with this…what are the chances of it also getting a bug or malfunctioning [when being used to manage traffic]." (Male, 18-34, South England)

Participants also felt that using quantum computers to improve delivery services by finding the best routes and schedules for delivery vehicles would likely lead to companies making larger profits, rather than cost savings being passed down to consumers.

Finance and banking: *Information shown to participants described that finance companies could use quantum computers to run complex financial models and analyse data much faster. This would help improve investment strategies (including for pensions), manage portfolios, and perform high-frequency trading better.*

This use-case was commonly unpopular as participants often held quite negative views of banks and the finance sector. They commonly felt company decisions were primarily focused on increasing profits, and that the banking sector has been poorly regulated (referring to financial 'crashes' as evidence). As a result, participants thought banks and the finance sector would be unlikely to focus on using quantum computers for activities that benefit the public.

Additionally, participants felt that those who might benefit from increased returns on investments by using quantum computers to run complex financial models, would likely be already wealthy individuals, rather than "*normal*" citizens. Participants did not think uses that do not benefit everyday citizens should be prioritised.

"It's only going to make the rich richer, the 1%." (Female, 35-54, Wales)

The potential for quantum computers to increase pension pots was not seen as particularly exciting or relevant to most participants. Participants mentioned the rising pension age and felt that they would be unlikely to have access to adequate pensions even if quantum computers were used to try and increase them.

A lack of knowledge about financial processes and banks caused some participants to have a neutral response to this use-case, as they struggled to understand how quantum computers could be used for finance and banking. However, some participants, including one participant who worked in finance, saw benefits of this use-case.

Enhancing AI: *Information shown to participants described that quantum computing could significantly speed up the training of AI technologies. This would help improve the power of existing AI systems, across a range of different sectors where AI is used to do tasks.*

There was widespread concern across the workshops about the potential negative impacts of AI for society, and therefore there was a generally negative response to the idea of quantum computers being used to increase AI capabilities. Some participants were very worried about a future where AI is used across many sectors and areas of life, while others felt AI capabilities were more limited and mitigations would be developed to manage the technology's negative impacts.

Concerns about quantum-computer-enhanced AI included:

- **AI causing job losses by automating processes traditionally done by humans**. Participants were concerned about the economic consequences for those whose jobs are lost. They also felt that jobs give people a sense of purpose and identity, and they worried about the effect of widespread job losses on people's mental health and wellbeing.

  "It sounds like it could put people out of jobs, and we all know how AI is affecting people, so if this [quantum computers] improves AI, then it will do things even quicker and easier, so I'm not sure if this is a good thing or not." (Female, 18-34, North England)

- **The danger of removing humans from processes and replacing them with AI**. This is because technology can get things wrong, and participants thought humans could be more trustworthy when making important and complex decisions, such as deciding the outcome of court cases.

- **AI removing the need for people to think and learn**. This is because AI can complete tasks for humans, such as writing school essays for children. Participants saw this as concerning as they thought it may mean humans might stop thinking as critically.

  "[Quantum computers] It's taking away from true learning, isn't it? We're going to have a population of people who haven't learned anything, who can't speak for themselves, or form a sentence. It's going to be quite, well, who knows what will be like, but it doesn't look good at the moment that we can just outsource all of our thinking to a computer." (Female, 35-54, South England)

- **Algorithms being biased**. This is because biased algorithms can cause certain groups (such as women and ethnic minority groups) to be disadvantaged by systems (see section 4.2 for more information).

- **AI developing consciousness**. Some participants worried that advanced AI could be used to control humans and take over society.

However, some participants also recognised the potential benefits of AI, especially those who had used AI applications in their jobs and could see benefits of enhanced AI systems. They described how using AI allows them to save time completing certain tasks, such as writing speeches and emails.

4.2. Concerns

Survey respondents were provided with a list of potential concerns about quantum computers and asked which they thought were the main risks. They could select up to three answers. The two concerns selected most were that the technology could create risks to online security and privacy by breaking current encryption methods (38%) and that in some industries, the technology could lead to job cuts (29%). Two in ten (19%) respondents said they did not know which were the main risks.

All workshop participants had some concerns about the development and use of quantum computers in the UK. Overall, key participant concerns were that quantum computers might not be used to benefit citizens and could present risks to online security. Participants were shown information about five specific risks and their responses are provided below (in section 4.2.1). For many participants, pre-existing concerns about the impacts of other advanced technologies (notably AI) and the conduct and perceived lack of regulation of private companies (notably social media companies) shaped how they felt about quantum computers and their risks.

Overall, common concerns included:

- **Private companies were seen to prioritise activities that generate the most profit rather than those that benefit citizens.** Participants particularly referred to large and international businesses when describing this view and it led many to feel sceptical about businesses using quantum computers. They felt some businesses would primarily focus on using quantum computers to generate large profits, rather than thinking about how to use them to have positive societal impacts. Similarly, participants felt that the wealth companies made from quantum computers would likely not benefit the public.

- **Previous regulation was perceived to have failed to ensure that digital technologies protect and benefit the public**. For example, participants pointed to the perceived failure of social

media regulation and the negative impacts social media has had on mental health, especially children's. Participants lacked confidence in government to regulate new technologies successfully and as a result, participants were nervous about who would use quantum computers and how.

- **Digital technologies can have negative impacts on people's wellbeing by causing job losses and reducing everyday social interactions.** The technology particularly top of mind during the workshop was AI and participants were concerned that quantum enhanced AI might lead to wide scale job losses. Participants felt that jobs were an important part of individuals' identity and sense of worth, and that job losses might have negative mental health impacts. Participants were also concerned about job losses where technology removes people from the service sector, such as replacing cashiers with self-service check outs. They worried this was leading to a decline in everyday social interactions which are important for wellbeing. Participants similarly worried that quantum computers might cause job losses by automating processes and by increasing the computing power available to AI.

- **The unknown potential of some technologies and what they might be used for in the future.** For example, some participants were worried AI and robotic technologies would be used to create robots with consciousness who could rule over humans. This worry was heighted by the speed of technological developments, which participants felt makes it more difficult to adequately consider technologies' potential impacts. As a result, they worried that technologies could become difficult to manage and that they could even become "*uncontrollable*". This view made participants concerned about how quantum computers might be used given their high processing power and broad potential applications.

"[AI] It's either going to really further human technology or it's going to wipe human life out as we know it." (Male, 18-34, North England)

4.2.1. Risks shown to workshop participants

In the workshops, participants were shown information about five potential risks associated with the development and use of quantum computers and their responses to these are outlined below. There was some level of concern about all of the risks shown.

Societal disruptions: *Information shown to participants described the possibility of quantum computers causing job losses where processes are automated.*

Wide scale job losses caused by quantum computers, particularly quantum enabled AI, was a key concern to participants, with many spontaneously raising this concern before they were shown stimulus information about it, as described further in section 4.2.

"What if they're not needed to work? What do humans do then?" (Female, 35-54, South England)

Participants felt strongly that mitigations need to be put in place to assist those who lose jobs because of quantum computers. They suggested that training schemes could be created to provide individuals with skills for alternative jobs and that there should be investment to create alternative jobs. However, there was generally low trust in government to take such actions or ensure that companies using quantum computers invest in these mitigations.

Some participants did not think that quantum computers would cause job losses. They referred to what they perceived to be previous incorrect scares of wide-scale job losses from other technologies, such as classical computers. Some participants felt there could be benefits for workers if quantum computers replace repetitive and unfulfilling jobs.

Spending trade-offs: *Information shown to participants described that government investment in quantum technologies leaves less money for other services and programmes.*

Many participants were comfortable with government funding being spent on quantum computers rather than other services. Overall, most participants felt that the £2.5 billion being spent by the National Quantum Strategy over the next decade was relatively small in comparison to government spending in other areas. Additionally, participants felt that developing quantum computers would require significant amounts of money, so it would be challenging to spend less and experience the benefits of quantum computers. However, some participants were concerned about funds being diverted away from the NHS and schools.

Cyber security and hacking: *Information shown to participants described that quantum computers may be able to crack current encryption methods, allowing cyber attackers to access sensitive data. Whilst this is not possible now, many experts think it could happen within the next decade. Quantum computers might also be able to "forge" digital signatures, allowing them to access and alter sensitive information such as legal or financial data.*

There was concern about this risk across the sample. Participants saw online data as vulnerable to hacks (such NHS patient data) and misuse (with participants citing Cambridge Analytica's use of personal data during the 2016 American election as an example) and felt quantum computers could increase its vulnerability. This could lead to negative impacts for individuals if their personal information is stolen and national security if hostile countries use this technology to illegally access other governments' information.

However, some participants were less immediately concerned by this risk. Some felt data is already vulnerable and that therefore this is not a new risk and others felt that previous hacks had not led to largescale disruption and were confident that the UK government would develop appropriate technologies to secure UK information.

> *"I'd presume a counter technology will exist to be prepared for this. It's worrying but the problem does already exist."* (Male, 35-54, Northen Ireland)

Competition and uneven access: *Information shown to participants described that early global development of quantum computing has been open, with findings published and prototypes shared. However, given the potential economic and military advantages, some experts expect a new era of competition rather than collaboration, like a new 'space race'. Also, the high cost of developing quantum computing may widen inequalities and leave developing countries without access, with access potentially limited to a handful of private companies and government bodies.*

Participants were concerned about other countries developing quantum computers and not collaborating to share findings, especially countries who had governments they felt they could not trust. Participants were particularly concerned about other countries developing quantum computers for security and military purposes. Participants also worried that countries not collaborating would allow some nations to have a monopoly on the technology, which would limit the ability of other countries to develop quantum computing industries and benefit from the technology. Participants were also concerned that quantum computers could contribute to widening global inequalities. Participants were shown information about the estimated levels of funding some countries have already invested in developing quantum computers; China was shown as the highest investor, which led some participants to feel concerned about what China was using quantum computers for.

As a result of their concerns, participants ideally wanted to see countries collaborate to share quantum computing technology developments and work together to ensure that quantum computers are not used for military and security purposes that negatively impact other countries and

citizens. Some said collaborations could be through organisations like the EU and UN organisations. However, many felt that realistically, collaboration was unlikely and that competition was inevitable as countries would lose out on strategic and economic advantage.

"Could be used for war. It could bring the economy down. This is why you need to collaborate with these countries to ensure we learn from them… and keep it friendly." (Male, 35-54, Midlands)

Bias in AI training using Quantum Computers: *Information shown to participants described that quantum computing could make AI more powerful and complex, which could make problems with algorithmic bias worse and lead to discrimination of people from minority backgrounds.*

This risk was shown to participants to highlight that AI has risks around bias associated with it. Before this information was shown, participants spontaneously raised several concerns about AI, as described previously in section 4.1.1. Some were very concerned and worried about a future where AI is used across many sectors and areas of life, while others felt AI capabilities were limited and mitigations would be put in place to mitigate the technology's negative impacts.

Some participants were worried about bias in AI and that it could lead to individuals or groups in society being treated unfairly or in ways that deepen existing inequalities. They said it was important there is transparency around what algorithms are used in systems and that people from different backgrounds and ethnicities are involved in the creation of algorithms to help prevent bias. However, others felt bias did not have to be an issue if systems are designed correctly and thought mitigations would be put in place to prevent this risk for impacting individuals in the future. It is important to note that only high-level information was provided to participants on this specific issue rather than an in-depth exploration.

"Talking about the algorithmic bias and I thought that quantum computing could make it better and more accurate, but if it has the potential to just make it worse that that's really scary as a consumer and just in general." (Male, 18-34, Midlands)

5. Attitudes towards regulating quantum computers

There was broad consensus that the development and use of quantum computers in the UK needs to be regulated. Workshop participants wanted conversations about regulation to start now to ensure effective regulation is in place when needed.

5.1. Attitudes towards regulating quantum computers

Seven in ten survey respondents (72%) thought the development and use of quantum computers should be regulated in the UK, while17% neither agreed nor disagreed, 2% disagreed and 8% said they did not know.

Additionally, three in four (75%) agreed that regulation of new technologies is necessary to ensure public benefit and protection, while 17% neither agreed nor disagreed,2% of disagreed and 6% said they did not know.

Survey respondents were also asked how much they trusted people developing quantum computers working for different groups to follow any rules and regulations which apply to quantum computers (see table 4). Respondents were most likely to trust those developing quantum computing working for universities in the UK / research organisations, with six in ten (61%) saying they trusted them a great deal or a fair amount. This was followed by those working for the UK military (57%), those working for the UK Government (55%), and those working for private companies in the UK (45%).

Workshop participants wanted the development and use of quantum computers to be regulated in the UK to ensure the technology is used to benefit citizens and focus on their priorities (as described in chapter 4), as well as to limit the potential risks quantum computers pose to citizens and society. More broadly, participants wanted the UK government to be involved in ongoing conversations that consider new and developing technologies and their impacts, to ensure technologies have positive impacts on society.

> *"Just needs to be measured and careful when developing it. We are aware of the risks we need to put steps in place to stop it becoming a bigger thing, and if this is done that the benefits will outweigh the risks."* (Female, 35-54, Midlands)

Participants wanted to see a regulatory system that:

- **Ensures quantum computers are used to tackle important and pressing issues**, such as improving health outcomes and supporting responses to climate change.
- **Limits negative impacts quantum computers might have on society**. For example, participants mentioned having regulation that: requires algorithms used by quantum computers to be scrutinised to check for bias against certain groups; protects public and government information from security threats posed by quantum computers; and creates new jobs where quantum computers have automated processes previously completed by humans.

- **Ensures companies developing and using quantum computers do not disproportionately benefit from them**, such as by charging unfairly high fees that make quantum computer developed drugs unaffordable to the NHS and public.

However, it is important to note that participants did not want to see regulation stifle innovation and development in this area, as they wanted to see the UK gain the potential benefits of this technology.

Participants had a strong desire for conversations about regulation to start now, given that quantum computers that are able to solve highly complex problems may be developed within the next decade. Participants recognised the difficulties in creating, implementing and enforcing digital technology regulation, and pointed to the challenges being faced by those seeking to regulate children's and young people's use of social media. They felt that if regulation of quantum computers is to be successful, work to create the regulation needs to start now, before quantum computers are available.

At a high level, participants wanted to see:

- **A range of people involved in designing and implementing legislation**. Some participants were concerned that if only businesses or government were involved, regulation might be designed so that quantum computers disproportionately benefit these groups, rather than the public. To ensure this does not happen, participants wanted those involved to include businesses, government, experts in the technology, the public and human rights organisations/charities. Many felt strongly about the public's involvement to ensure the needs and wants of citizens are represented.

- **The enforcement of regulation to include strict punitive measures** to deter individuals and businesses from breaking rules and standards, such as fines and prosecutions.

- **Legislation to be easy to understand** and use plain English.

As well as UK regulation, participants also spontaneously said that they wanted international regulation to ensure each country's use of quantum computers does not negatively impact other countries. For example, one participant suggested an international licencing scheme for those using quantum computers They especially wanted international regulation to help prevent conflict which might arise from the development and use of quantum computers for security and defence purposes. However, participants also felt sceptical that this would happen and that all nations would comply with international legislation.

"There's got to be a global agreement. There's no point us putting all the safeguards in place and then [a hostile country] going off on a tangent." (Female, 35-54, Midlands)

Finally, despite broad support for regulation, participants questioned the UK government's ability and motivation to successfully create and implement regulation that ensures quantum computers work for citizens. This scepticism was because some felt government has recently shown little interest in holding big businesses to account, such as when they "*dodge taxes*" or have negative environmental impacts (such as water companies who have been illegally discharging sewage into rivers and seas). This was also reported in the context of the government's perceived failure to regulate social media effectively.

6. Support for the development and use of quantum computers in the UK

Survey respondents primarily supported the UK developing and using the technology and the National Quantum Strategy, or neither supported nor opposed it. Workshop participants were also broadly supportive because they wanted the UK to gain the benefits of quantum computers. They also wanted the UK to develop quantum computers because of the importance of protecting the country from data hacks that use quantum computers and other countries who might use quantum computers for security and defence purposes to negatively impact other countries.

Survey respondents were asked, based on what they knew or had heard about quantum computers, if they supported or opposed the UK developing and using this technology. Four in ten (41%) said they supported it, or neither supported nor opposed it (39%), while less than one in ten (7%) opposed it and 13% said they did not know.

Survey respondents were informed that in 2023, as part of the National Quantum Strategy, the Government committed to invest £2.5 billion in quantum technology (such as quantum computers) over the next ten years. Almost half (46%) of respondents supported this amount of funding and three in ten neither supported nor opposed it (31%), while one in ten (10%) opposed it and 13% said they did not know.

6.1. Support for the development and use of quantum computing

By the end of the workshops, there was broad support for the development and use of quantum computers in the UK. This was because, after carefully considering the potential benefits and risks of quantum computers (as discussed in chapter 4), participants generally decided that the benefits would likely outweigh the risks. They wanted the UK to see the benefits from quantum computers, especially because they felt they could be used in ways that substantially improve people's lives, such as improving health outcomes and reducing environmental impacts. They also wanted the UK to develop and use quantum computers because of the importance of protecting the country from quantum computing enabled hacking. They did not want the UK to "fall behind" other countries' quantum computing capabilities because it might mean the country cannot protect itself from cyber security threats.

"I think there are benefits, but there is a lot of risks involved. But if we don't do it in the UK, it is going to be developed elsewhere and then we will be at a disadvantage and we will be unsafe, so we need to keep up with technology." (Male, 35-54, Midlands)

Participants suggested that they would be more supportive of the development and use of quantum computers in the UK if: good regulation is created to mitigate some of the key risks (as described in chapter 5); and the UK government and other organisations collaborate internationally to create use-cases which benefit citizens and society.

Participants wanted the UK to collaborate to ensure that advances in the technology positively impact as many citizens around the world as possible. Participants ideally wanted to see the UK encourage countries to work together to solve important global issues, such as climate change, famine and poverty. However, participants felt that collaboration might not be a realistic goal as not all countries may want to take this approach.

Across the workshops, participants commonly wanted to see a range of bodies and organisations investing, developing and using quantum computers in the UK, including government, universities and private businesses.

Despite expressing concerns about private businesses using quantum technologies (as described in chapter 4), participants recognised that businesses have capital to invest in quantum computers and expertise to develop them. Participants commonly wanted to see universities and the government involved because they thought they would be more likely to develop and use quantum computers that benefit the public. Additionally, participants commonly did not want the use of quantum computers to be restricted to certain groups (especially if good regulation is created, as described in chapter 5) as this could limit the benefits experienced by the public.

6.2. Support for the National Quantum Strategy

There was broad support for the National Quantum Strategy across the workshops. Many participants thought the amount the UK government was committing to spend over the next 10 years was too little given the importance of developing the technology and other countries' high level of investment (and participants pointed to China's and the US's higher levels of investment). Participants liked that the strategy included collaborating with other countries.

> *"There's lots of benefits there [for quantum computers]. It just needs to be managed in the right way. They just need to have enough funding there because it is such a vast area of how it can help. It is something that they would be silly if they did not see if as a priority by UK government."* (Female, 35-54, Midlands)

A minority of participants were less supportive of the UK developing and using quantum computers and a few said they did not support the National Quantum Strategy. These participants felt:

- That the UK has other, more important priorities where government spending and effort should be focused, such as reducing inequality and improving the NHS and schools. These participants wanted to know that any money diverted from public services to the strategy will be regained.

- The UK does not have the required capabilities or funding to become a global leader in this technology (which is an aim of the National Quantum Strategy). These participants thought that the UK government does not have enough money to catch up with the amount that other governments have already invested. Additionally, they felt that EU countries are better placed to collaborate and share learnings, and therefore develop quantum technologies at a faster pace than the UK.

However overall, there was strong support among workshop participants for the development and use of quantum computers in the UK when this is done in a way which prioritises benefitting citizens and our society.

7. Conclusion

Overall, there was broad support from workshop participants for the development and use of quantum computers in the UK and for the National Quantum Strategy. Many participants even though the amount the UK government was committing to spend over the next 10 years was too little given the importance of developing the technology and other countries' higher levels of investment. Similarly, almost half (46%) of survey respondents supported the amount of funding for the National Quantum Strategy over the next 10 years and three in ten neither supported nor opposed it (31%), while only one in ten (10%) opposed it and 13% said they did not know.

Participants were supportive because, after carefully considering the potential benefits and risks of quantum computers, they generally decided that the benefits would likely outweigh the risks. They wanted the UK to see the benefits from quantum computers, especially because they felt they could be used in ways that substantially improve people's lives, such as improving health outcomes and supporting responses to climate change. They also wanted the UK to develop and use quantum computers because of the importance of protecting the country from quantum computer enabled hacking. They did not want the UK to "fall behind" other countries' quantum computing capabilities because it might mean the country cannot protect itself from cyber security threats.

However, it is important to note that participants were worried quantum computers could also pose a range of risks to society and participants were commonly quite sceptical that the technology would be used to positively impact citizen's everyday lives (and commonly assumed they were more likely to instead financially benefit large companies). It's important to note that pre-existing concerns about the impacts of other advanced technologies (notably AI) shaped participants views and concerns about the development of this technology.

As a result of these concerns, there was a strong consensus that the development and use of quantum computers should be regulated to mitigate these concerns and that a range of people (including the public) should be involved in creating the regulation. Participants also wanted the UK to collaborate with other countries to ensure that advances in the technology positively impact as many citizens around the world as possible and to ensure that quantum computers are not used for military and security purposes that negatively impact other countries and citizens.

Appendix 1: Lessons for future public engagement on quantum computers

At the end of the survey, respondents were asked how much they were interested or uninterested in quantum computers. Half (50%) of respondents said they were interested, almost a quarter were neither interested nor uninterested (23%) or were uninterested (23%) and 4% said they did not know.

Finally, those who said they were interested in quantum computers were asked how would they like to learn about them if they wanted to find out more in the future. The most selected answer were TV programmes (48%), followed by online articles/blogs (46%) and the news (40%).

Workshop participants felt it was important for the public to continue to be engaged on the development and use of quantum computers as the technology continues to evolve. Survey findings also show that there is public appetite for learning about quantum computers, with 50% saying at the end of the survey they were interested in quantum computers.

This chapter summarises some lessons for engaging the public on quantum computers in the future.

1. The public often find written information about how quantum computers work complex and abstract. Using pictures, videos and in-person demonstrations can help bring concepts to life and allow for more detailed understandings. For example, participants found a tour of a quantum computing lab during the last public dialogue on quantum computers very engaging.

2. Explaining how quantum computers work and are different from classical computers by showing information about certain principle of quantum physics (entanglement and superposition) is not always successful. Entanglement and superposition are difficult concepts to understand, and participants did not always find them interesting or engaging. If this approach is taken, it is important to user test materials.

   In comparison, explaining how quantum computers work and are unique to classical computers by showing information about potential use-cases may be a more effective way to engage the public. For example, workshop participants found information that explains how quantum computes could model complex molecules better than classical computers (which leads to the development of new drugs) very engaging. Use-cases that were found to be particularly engaging were those that improved health outcomes, reduced environmental impacts and reduced inequality.

3. It's important to explain the bounds and limits of quantum computing technology to avoid misconceptions about the potential social impacts the technology could have. Participants were concerned about certain digital technologies, particularly AI, and the negative impacts they have. These concerns shaped participants' views of quantum computers as they often worried quantum computers might have similar negative impacts. As a result, it is important to explain how quantum computers are similar and different to other digital technologies.

4. It is important to explain how businesses contribute to the development of new technologies and products. This is because participants were commonly sceptical about businesses using quantum computers because they felt that businesses are often primarily motived by profit rather than on what benefits the public. This was particularly thought to be the case for big and international businesses. Providing examples of how a range of businesses (including small and medium sized businesses) have previously contributed to the development of new technology and products could nuance public discussions.

5. The workshop participants generally had low levels of awareness and understanding of human manufactured materials, how they are created and how they can reduce environmental impacts; as a result, it's important to provide information on this quantum computing use-case if talking to the public about it. In this dialogue, high-level information about this use-case was provided to participants. Few participants found it engaging and it did not easily demonstrate to participants how new materials can reduce environmental impacts – a cause which participants were generally very enthused about and wanted quantum computers to be used for. Providing multiple different examples of new materials, with detailed information and pictures of products, could help bring this use-case to life more successfully.

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Engineering and Physical Sciences Research Council

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