Quantum Technologies
Public Dialogue Report

EPSRC
Engineering and Physical Sciences Research Council
UK Research and Innovation

Contents

Please note:
Appendix is a separate document which can be supplied on request from UKRI EPSRC.

EPSRC would like to thank all members of the public and researchers who took part in this project. We would also like to thank Professor Richard Jones FRS, Chair of the Oversight Board and the Oversight Board for all of their guidance and support.

The public dialogue and this report was delivered by

KANTAR PUBLIC=

In compliance with their certificate to ISO 9001 and ISO 20252 (International Service Standard for Market, Opinion and Social Research).

The report was compiled and written by Dr Amy Busby, Dr Ali Digby and Emily Fu from Kantar Public =

The public dialogue process was evaluated by 3KQ

The evaluation report, which was carried out in order to ensure that the dialogue was robust, is available from UKRI EPSRC.

Foreword

Philip Nelson
EPSRC Chief Executive

New systems, devices and products that make use of the quantum properties of particles and atoms are beginning to emerge from earlier investments in science and engineering; and they promise to change many aspects our lives, from banking to construction, security to healthcare.

EPSRC has been funding research in this field for over twenty years and is a key partner in the UK National Quantum Technologies Programme (UKNQTP) to which the UK government allocated £270 million five years ago in 2013.

EPSRC as part of UKRI is committed to Responsible Research and Innovation (RRI) and has established a Responsible Innovation Framework. Researchers can use the Framework as a tool as they develop research and consider its implications.

As part of our commitment to RRI we decided that Quantum Technologies was an area that was still sufficiently new to the wider world that it would be appropriate to gauge what people perceived and how they felt about the potential impacts of new systems, devices and products involving quantum principles.

That is why we commissioned an independent company to carry out a public dialogue over a three month period. The full report is available on the EPSRC website but this summary gives the key findings and recommendations.

I hope you find it useful and informative and that it demonstrates how science and engineering can progress in an open and inclusive environment and promote understanding among society.

1. Executive Summary

1.1 Background, aims and method

In 2013, the UK government announced a £270 million investment in the UK National Quantum Technologies Programme (UKNQTP). Despite national investment and interest in this area, until now there has been little work exploring public views on this emerging area of technology[1]. In 2017, the Engineering and Physical Sciences Research Council (EPSRC) commissioned a public dialogue to:

- Understand public perceptions of quantum technologies (QTs), in terms of people's spontaneous, unprompted views, and more considered opinions in response to information and discussions;
- Explore public values in relation to QTs, including their aspirations and priorities, and concerns or dilemmas – uncovering the principles that underpin views;
- Engage the public in a dialogue with experts and researchers.

The dialogue was multi-stage and consisted of a stakeholder workshop followed by two waves of (reconvened) full-day public dialogue workshops in four locations (Oxford, Glasgow, Birmingham and York). Between the workshops, participants took part in an interim activity. The workshops were held between September and November 2017 and 77 participants completed both workshops. The participants were recruited to include a range of demographics to reflect the UK population and capture a diversity of views. As qualitative research, the aim of the dialogue was to explore participants' in-depth views and responses, rather than to provide statistically representative views. A detailed methodology, as well as all the stimulus materials, can be found in the Appendix.

1.2 Key findings

- There was wide familiarity with the word 'quantum' – however beyond this there was low knowledge of what quantum was or about QTs. Participants generally held a limited set of surface-level associations, broadly relating to 'advanced technology' and science/ physics. No one talked about quantum being 'spooky' or 'weird' – as some stakeholders had anticipated.
- Limited exposure to information about QTs had led to an initial feeling of neutrality towards them which meant that participants were yet to develop an emotional response to the topic. Significant minorities felt otherwise: participants with lower engagement with science tended to express some anxiety going into the start of the dialogue, and those more interested in science generally felt curious and excited.
- Greater exposure to information about QTs generally saw participants become more engaged and excited by the range of potential benefits associated with QTs – particularly once they understood how various QTs could impact upon and be relevant to their own lives. Whilst no participants became more negative about QTs, there was a small number of participants who felt disengaged from science and their level of interest remained unchanged (notably in Birmingham).
- QTs were seen to have a wide range of benefits for individuals and society. The most engaging QTs were those which participants understood to have the greatest potential impact on individuals and society – in terms of saving or extending life (i.e. health technologies and humanitarian applications); finding cost-efficiencies in healthcare; and improving national and financial security.
    - o While participants were often excited about these benefits, the technologies were regarded as an incremental improvement, rather than new and revolutionary
    - o Participants hoped that benefits would be realised for the public good, rather than private profit (particularly in the context of the NHS [do we need to spell out NHS, for

1 See http://www.sciencewise-erc.org.uk/cms/public-attitudes-to-quantum-technology

international readers in particular?]] – and did not cite wider economic growth as a benefit of the technologies.

- Some concerns were raised throughout the dialogue about the development and use of QTs, some of which related to the development of technology more widely:
  - Who controls the development of QTs – and how far decisions would be driven by company profit, potentially at the expense of the public interest;
  - Who would have access to QTs – and whether uneven access could drive a greater and less surmountable divide in society;
  - Automation and job losses – this was an emotive and salient issue and job losses in driving, analytical, and logistical roles were seen as an immediate and relevant risk;
  - Environmental damage – participants questioned QTs' overall contribution to climate change.
- Other concerns raised were more specific to the QTs discussed and included:
  - Whether QTs would spark a defensive international arms race – where nations felt compelled to invest in quantum computers defensively to ensure their security. While the development of this technology was thus perceived to be inevitable – not a matter of choice – participants were keen that the UK was at the forefront of quantum computing, and so supported investment;
  - Misuse of QTs for the purposes of hacking and cyber warfare;
  - Misuse of encryption technology to hide criminal activity (e.g. terrorism, organised crime, paedophilia, and tax evasion);
  - Misuse of imaging technologies by criminals, companies and the state.
- Whilst concerns were raised, overall participants were not overly concerned about the development and use of QTs and the risks associated with them. They saw the benefits as worthwhile and as positive progress for society. The following considerations also helped to alleviate participants' concerns:
  - The risks associated with QTs were not perceived as new, but rather built on already existing risks with which participants were familiar (though quantum computing was the exception to this);
  - The risks were not necessarily specific to QTs – but were seen to relate to technological advancement more widely;
  - Misuse of new technology was seen to be inevitable.
- Outstanding concern about access and control in the development and use of QTs could be mitigated through the establishment of governance mechanisms to reassure participants:
  - Participants had assumed that societal implications were considered as standard by academics, which underpinned their high level of trust in this group. When discovering this was not currently the case, participants felt strongly that wider public interest should be considered as standard in the development of QTs as well as company profit;
  - Participants wanted to see an oversight body comprised of multiple voices to ensure the public interest was considered in development decisions;
  - Participants wanted to see that forms of misuse that pose a threat to individuals or society would be planned for, deterred and punished. Restricting public access to some QTs was seen as appropriate when participants felt the risks of public access outweighed benefits.
- Whilst good governance was important to participants, they did not want to see regulation stifle innovation in and advancement of this area or disadvantage the UK in the international area.

1.3 Recommendations from the dialogue

The following recommendations for the quantum community emerged from analysis of the dialogue data. They are summarised here and more detail is provided in the conclusion regarding each of them:

- Participants wanted to see the UK investing in QTs and leading on this in the international arena, because they saw the benefits as providing progress for individuals and society and to ensure the security of the nation if other countries were developing the technologies.
- The neutrality felt by participants towards QTs suggests there is an opportunity and growing need for the quantum community to tell its own story and establish positive associations with QTs.
- Participants were excited about the potential benefits associated with QTs and there was interest in more information about these – particularly the QTs which have health, humanitarian, security and efficiency benefits.
- Discussions suggested there is a need to address concerns about quantum computing and encryption as these are seen to present the greatest step change and potential threat to society and therefore induce public fear.
- Discussions suggested it would be helpful to consider engaging with wider debates regarding concerns associated with technological advancement including automation, privacy and surveillance, and climate change – and the contribution QTs can make to these debates.
- There was a desire for governance mechanisms to be created which consider the public interest as well as profit; consider wider societal implications; and ensure there is adequate regulation and enforcement in place prior to commercialisation of QTs to deter and punish perpetrators (including the government and public bodies as well as individuals and companies).
- Researchers should take responsible research and innovation more seriously.

In addition to these recommendations, some lessons regarding how to communicate effectively with the public about QTs; the possibilities and limitations of dialogue on this topic; and how participants wanted to be involved with decision-making regarding QTs in the future were drawn from the dialogue. These can found in Appendix 1.

2. Introduction and research design

2.1 Background

In 2013, the UK government announced a £270 million investment in the UK National Quantum Technologies Programme (UKNQTP), championed by the Quantum Technologies Strategic Advisory Board (QT SAB)[2]. As part of the Programme, the Engineering and Physical Research Council (EPSRC) launched a national network of four Quantum Technology Hubs in October 2014. The four hubs focus on different areas of quantum research and technological development: Sensing and Metrology Hub led by University of Birmingham; Quantum Enhanced Imaging Hub led by University of Glasgow; Networked Quantum Communications Hub led by Oxford University; and Quantum Communications Hub led by York University. The aim of the hubs is to work with academics and industry to exploit the potential of quantum by developing emerging technologies, ultimately to benefit the UK.

Despite national investment and interest in this area among the academic, technology and policy-making communities, up until now there has been very little work to explore the public views on this topic[3]. In December 2016 EPSRC commissioned social research agency Kantar Public to carry out a public dialogue to understand how the public views quantum technology (QT).

2.2 Aims of the dialogue

The overall aim of the dialogue was to explore public views on QTs, devices, and applications. Specifically, the objectives were to:

- Understand public perceptions of QTs, in terms of people's spontaneous, unprompted views, and more considered opinions in response to information, discussions, stimuli, etc.
- Explore public values in relation to QTs, including their aspirations and priorities, and concerns or dilemmas – uncovering the principles that underpin views
- Engage the public in a dialogue with experts and researchers, in order to:
  - Inform the public about the technology, services and devices which may emerge from the UKNQTP and wider community
  - Inform the quantum community of public views (through the dialogue and its outputs) about the social and ethical implications of quantum research and technologies

The dialogue was highly exploratory in nature – contributing the first substantive knowledge of public attitudes to QTs and their applications.

2.3 Why public dialogue?

Public dialogue is an approach that invites citizens and scientists together to deliberate, reflect and come to conclusions about emerging issues relating to science and technology that are often complex, sensitive, or controversial[4]. Evidence shows that providing people with the right information, enough time and the right conditions can broaden perspectives and help people take on new knowledge about complex topics, such as emerging technologies. Further, discursive interaction can help promote understanding, encourage 'public-mindedness', and potentially develop or change opinions – for participants and the researchers involved[5].

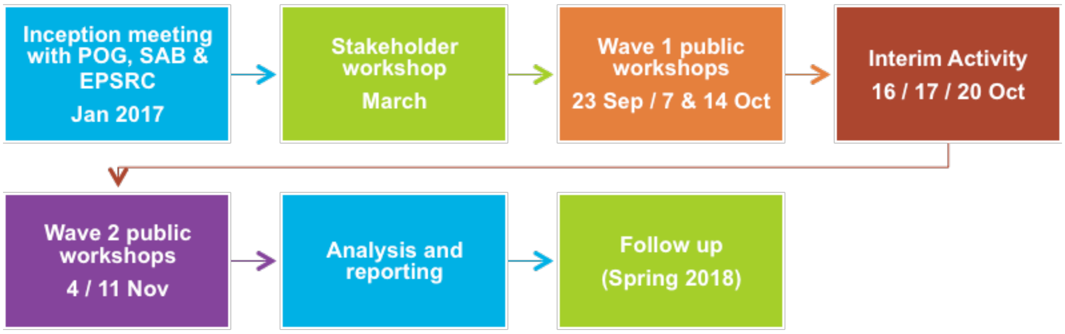
2 The QT SAB was set up to provide a visible focus for QTs in the UK and to act as a co-ordinating body for UK interests. It has an oversight of the UK NQTP and has drawn up a strategy for quantum technologies in the UK.
3 See Sciencewise, Public attitudes to quantum technology (May 2014), Section 2, p3, from http://www.sciencewise-erc.org.uk/cms/assets/Uploads/Quantum-Technology-Social-IntelligenceFINAL.pdf, accessed 9th November 2016
4 See Sciencewise (2013): The Government's Approach to Public Dialogue on Science and Technology
5 Ibid. pp. 5-6

Dialogue aims to open up discussions 'with' rather than one way communication 'to' the public, allowing citizens to have genuine impact on the policy process. In turn, this makes for policy that is more socially informed, more publicly acceptable and more cost-effective in the long term.

2.4 Methodology

Figure 2.1 below provides an overview of the dialogue approach. Further information about the method, recruitment process, stakeholder attendees, stimulus materials, and analysis process are provided in Appendix 2.

Figure 2.1. Overall approach



The dialogue began with an inception meeting involving members of the POG (the NQTP Operations Group, the SAB (Strategic Advisory Board), EPSRC and Kantar Public. This meeting aimed to shape the process of the dialogue. This meeting was followed by a stakeholder workshop, attended by 40 stakeholders – including academics, representatives from technology companies and policy makers –to inform the development of the research materials (see Appendix 6 for a full list of attendees).

The fieldwork involved two waves of reconvened workshops with the public. The workshops were held in the four lead hub locations – Birmingham, Glasgow, Oxford and York. Participants were recruited using free-find methods and recruiters' own networks. The sample reflected as far as possible the UK population including a range of ages, genders, social grades, educational qualifications, interest in science and ethnicities. Overall, a total of 77 participated in both waves of the dialogue. Participation was voluntary and participants were informed that their views would be anonymous and confidential. Individuals undertook a short screening questionnaire to assess eligibility (see Appendix 3 for the final achieved sample).

The first wave of workshops explored participants' spontaneous knowledge of and associations with quantum and QTs, before exploring participants' aspirations and hopes, as well as their concerns and fears for QTs.

Participants were then invited to take part in interim activities held in each of the four locations to sustain engagement between workshops, and to prompt participants to consider issues outside a research environment. These were unique to each area and involved:

- Birmingham: a tour of the sensors and metrology hub and a talk on gravity sensors
- Oxford: a tour of the laboratory, live experiments and a lecture on quantum computing

Figure 2.2. Wave 1 in Glasgow: exploring the quantum roadmap.

- Glasgow: an exhibition in the science centre which included pictures, text, and interactive exhibits about various practical applications of quantum
- York: a lecture with visual projections and video feeds demonstrating Quantum Key Distribution (QKD) enabled (quantum enabled encryption).

The second wave of workshops aimed to understand if and how participants' views had changed since the initial workshops; understand in detail participants' aspirations and concerns about the technologies; explore participants' views on how they want quantum researchers, industry and government to respond to the issues they've raised; and suggest how the public ought to be included in future dialogue on QTs.

3. Stakeholder expectations

This section summarises discussions in the stakeholder workshop, including expectations of public perceptions of QTs prior to the public workshops taking place. It briefly reports stakeholder views on the potential impacts of QTs on individuals and society, which informed the development of the public workshop materials.

Key findings

- Stakeholders expected that the public would have low knowledge of and interest in QTs, a narrow range of associations and many misconceptions of quantum and QTs.
- They assumed the public would have had minimal exposure to information about QTs and that they would be put off by scientific language, previous negative experiences of science, and by not seeing QTs as relevant to them – and that they therefore would not actively seek further information. Some of these assumptions did emerge in the public workshops.
- Stakeholders anticipated that members of the public would have some associations with quantum, relating to popular culture linking quantum with space or time travel, and stereotypical associations of 'mad scientists' and Einstein. They also thought people might see quantum as something new and revolutionary – and a 'big step forward'. Stakeholders guessed that if people had heard of any particular QT, it would most likely be quantum computing or cryptography.
- Some stakeholders suspected that the public would perceive quantum as 'spooky' or 'weird' and that this might prove to be a barrier to engagement.

3.1 Stakeholder expectations of public perceptions of QTs

Overall, stakeholders expected that the public would have relatively low awareness and knowledge of, and interest in, quantum physics and the potential applications of the science. This view was based on the following assumptions:

- With the exception of self-selecting audiences who already actively attended science-related events, the public would not have been exposed to information about QTs.
- The public would likely be 'turned off' by scientific concepts and the language associated with quantum, undermining their willingness to engage with the topic.
- The public may be scared or anxious about quantum – and that this would be driven by perceived negative experiences of maths or science at school.
- The public may not see quantum and QTs as relevant to or 'for' them - instead seeing them as only relevant to scientists and 'experts'.

Based on these assumptions, stakeholders thought the public would have a relatively limited set of perceptions about quantum and QTs (see Figure 3.1). The associations stakeholders thought the public would hold included:

- Associations with the use of the word in popular culture including sci-fi films and TV shows (e.g. Quantum of Solace, Quantum Leap, telepathy and psychic powers) – which could lead to associations with teleportation and space travel, existence and consciousness, and nuclear weapons
- Associations with Einstein and the image of the 'mad'/'crazy' scientist
- Quantum as 'revolutionary and new' and 'a big step forward'
- Quantum as 'spooky' or 'weird'.

Stakeholders anticipated that more informed members of the public (meaning those who had a personal or professional interest in science and/ or technology) might have some knowledge and awareness of quantum computing and cryptography.

Figure 3.1. Stakeholder expectations of public perceptions of QTs.

There was general agreement that communicating QTs to the public would be difficult due to the complexity of the subject matter, and that consequently the focus of the dialogue should be about the applications rather than the science and theory. Those who had been involved in public engagement in the past on quantum (e.g. laboratory open days) were more optimistic that the public would be interested in and engaged by QTs once they learned more about the various applications.

> ***"[I do] lots of outreach...people don't care how something works, but what it can do." (Stakeholder)***
>
> ***"From a civil engineering point, it is just another sensor, I can explain to them how it works, but most of the time that's not what they're interested in. When it comes to the market what does it do compared to existing sensors, how much money will it save them? Those sorts of questions drive them." (Stakeholder)***

Stakeholders felt that the public would be most engaged by technologies that were seen to directly impact their lives and thought that technologies that had clear health benefits were most likely to capture the public's imagination. Some also thought the public would be interested in space travel and discovery, particularly if they already had an interest in these topics.

Stakeholders anticipated that the public would have a number of concerns about QTs – although these were not specific to QTs but regarding technological development more widely. These included the potential loss of jobs due to automation; fear of automated technologies such as driverless cars; potential threats presented to security (both individual and national) and concern about use of brain scanners to read their thoughts. Nevertheless, they tended to conclude that once the public learned more about the range of positive impacts of QTs for themselves, family and friends then the positives would outweigh the negatives.

> ***"When people see potential to help themselves and loved ones [referencing the medical possibilities] they can really see the benefits and shut down the negatives that often come from the media." (Stakeholder)***
>
> ***"Individuals could benefit that their identities remain secure . . . much more willing to purchase things over the internet. . . kind of enhancements quantum may give you." (Stakeholder)***
>
> ***"I think there are going to be a lot of questions about the ethics. . . is there going to be someone reading my thoughts ... are you programming my brain?" (Stakeholder)***

Despite these assumptions, stakeholders expected the public would communicate a wider range of associations than they did and still overestimated the public's familiarity with quantum (see chapter 4).

Figure 3.2. Stakeholder workshop.

3.2 Stakeholder views on the impacts of QTs

Stakeholders believed QTs could impact individuals and society in the future in a range of ways. They thought that all in society stood to benefit from advances in particular technologies, such as those related to health (and more efficient NHS resource allocation) and advances in computing through increasing efficiency around problem solving. Stakeholders anticipated that developments would lead to increased data security for all and job creation in certain industries.

Stakeholders also identified risks and concerns including issues around who would benefit from QTs. Stakeholders expected that at an individual and organisational level, this would be related to access and affordability, and that those without access may be disadvantaged as a result of being 'left behind'. They thought the same applied at the international level - countries that decided (and were able) to invest in QTs would see an increase in productivity, efficiency, competitiveness and profitability – and other countries would likely be disadvantaged accordingly.

Some stakeholders expressed concern that the development of QTs could contribute to a greater societal and international divide. Concerns were raised around access to security specifically, with an increasing gap between those that have access to quantum enabled encryption offering 'security' and those that did not. Moreover, stakeholders anticipated some job losses as a result of increased automation, particularly in the transport sector (e.g. drivers being made redundant due to driverless cars) and in analytical sectors (e.g. efficiencies in resource allocation and accountancy). Concern was also raised about the potential de-humanisation of sectors of the economy associated with the development of robots and Artificial Intelligence (AI) – such as the loss of 'the human touch' in care roles and healthcare decision-making. Importantly, however, stakeholders acknowledged these concerns were not necessarily specific to quantum but often related to technology more widely. Despite raising these concerns, stakeholders generally believed that with the appropriate regulation in place, the public would generally benefit overall from the development of quantum technologies.

4. Participants' perceptions of Quantum Technologies

This section explores spontaneous awareness, knowledge and feelings in relation to quantum and QTs, before participants received any information. These perceptions provided the starting point for the dialogue journey.

Key findings

- Although there was familiarity with the word 'quantum', knowledge about quantum and QTs was generally limited to surface level associations.
- Linked to this lack of awareness of what quantum is, feelings were generally neutral about the topic and participants tended to begin with a relatively 'blank canvas' regarding QTs.
- Information (and thus associations) were derived from a relatively narrow range of sources and - outside of those with a personal or professional interest in science or technology - participants were generally not motivated to actively seek further information about QTs.
- The anticipated association of QTs with 'spookiness' did not emerge.

4.1 Perceptions/associations in relation to quantum and QTs

There was high awareness of the word 'quantum' across all of the dialogue locations and demographic groups. However, the meaning of the word was not precisely known or understood, and participants offered uncertain associations and guesses which were generally related to what they understood to be 'advanced' science and physics. When applied to technology, participants primarily associated quantum with the idea of being 'advanced' or 'cutting-edge', with some connecting quantum with space, fast computing or processing. Less commonly, participants guessed that QTs would be used in the fields of medicine, telecoms and/or defence - perhaps linked to their perception of these fields as themselves being 'advanced'.

> ***"MRI scans but I don't know if that's Quantum. I was just thinking the medical side of things, machines that are used…I imagine that they'd use it because they'd be so cutting edge…" (Wave 1, Oxford)***
>
> ***"I can imagine people in like the Pentagon in the States sat using that, talking about that kind of stuff." (Wave 1, York)***

As QTs were not well known or understood, participants tended to communicate a narrow range of surface level associations with the term, including:

- Advanced science, physics, maths, and 'pure' science
- References to the term in popular culture, including films (e.g. Quantum of Solace, Back to the Future), and TV shows (e.g. Quantum Leap, Big Bang Theory, University Challenge)
- Space and planets
- Technological gadgets (including iPhones, watches and fast computers)
- Household appliances and products which used the term 'quantum' in their branding and marketing (e.g. kitchen appliances and cleaning products).

Less commonly, participants conceived of quantum as:

- Time travel
- A kind of force or power
- A measure of size – including very large or very small
- Processes of miniaturisation

- Something that speeds up processing
- Teleportation
- Links between particles.

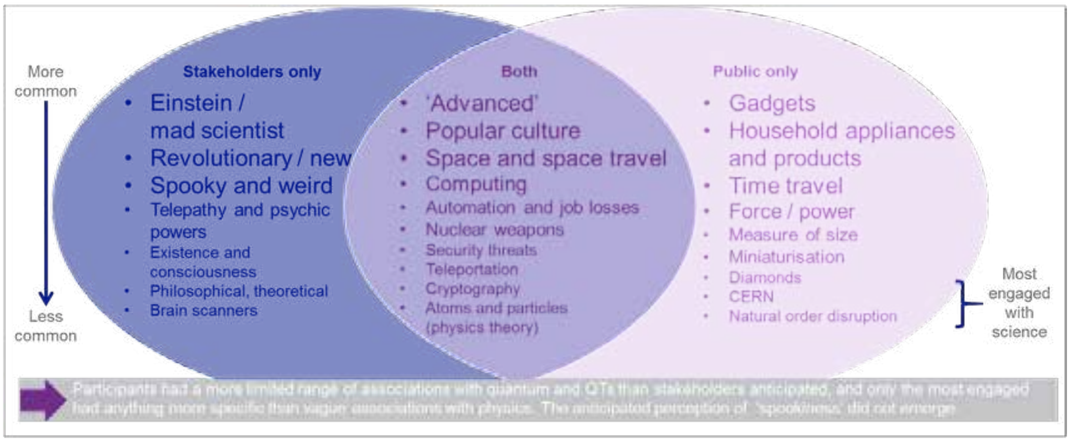
> ***"Back to the Future film ... Is this a bit 'quantum', because it's do with that DeLorean car that can travel through time?" (Wave 1, Birmingham)***

Those who had a greater (personal or professional) interest in science and/or technology associated quantum with the terms and ideas of atoms and particles, but they generally had little further knowledge beyond this. The associations that emerged from some groups in the Oxford workshops were more 'technical' or 'scientific' in nature. Here some participants had friends and family working in STEM industries as well as some having a greater interest in science than others, with some actively seeking information on the latest scientific developments as part of their usual interests. These ranged from associations with physics, theories, the science of small particles, the European Council for Nuclear Research (CERN), diamonds, and quantum as something unpredictable or counter intuitive, or 'a disruption of the natural order'. There was some awareness in Oxford of a small number of QTs such as banking security, teleportation and un-hackable computers.

> ***"It's very futuristic, the cutting edge of physics so I think the idea of two particles can be in two places at the same time which conjures up science fiction like teleportation, that kind of thing." (Wave 1, Oxford)***

Despite stakeholders expecting that the public would have a narrow range of associations with QTs, this was found to be more limited than they anticipated. Some of the associations stakeholders anticipated did not emerge, notably quantum being 'spooky' and 'weird'. Participants did not possess enough understanding of quantum to have reached this conclusion.

Figure 4.1. Participant perceptions of QTs and stakeholder expectations of public perceptions of QTs.



Overall, there was generally a feeling of neutrality about QTs – on the basis that people felt they did not have enough information about this topic to have developed an emotional response to it.

With regards to their emotional response, participants tended to cluster into three groups. The first group felt neutral towards QTs, tending to claim that they could not (and were reluctant to) communicate feelings about a topic they knew little about and which they did not see as relevant to their lives. These participants were confident but lacked knowledge and experience regarding QTs.

> ***"Not knowing much, or anything, about the topic, I struggle to have much of a feeling about it." (Workbook, Wave 1, Birmingham)***
>
> ***"When it crosses into your job, or health, something that affects you personally, then we will have feelings about quantum technologies." (Wave 1, Birmingham)***

The second group felt worried and anxious about quantum, with these negative emotions being driven by fear of talking about a topic they knew little to nothing about and which was seen to be for clever experts and beyond their abilities (particularly in Birmingham). These people tended to have lower levels of qualifications and interest in science.

> ***"[It is] too advanced for the average person." (Wave 1, Birmingham)***
>
> ***"It's for clever people only. And it would take a quantum effort to learn about it! And I'm lazy." (Wave 1, Glasgow)***
>
> ***"I literally don't know anything about it." (Wave 1, York)***

For a third group however, this 'not knowing' was exciting and they were eager to learn about something new in what was considered to be a supportive environment. Those who were more interested in science and technology were excited about advancements associated with quantum – in particular, technologies that they believed would likely impact their lives (e.g. banking security, teleportation and un-hackable computers).

> ***"I'm curious about the subject, perhaps a little apprehensive?" (Wave 1, Oxford)***
>
> ***"I didn't want to be completely in the dark cos I had no idea what it was...." (Wave 1, York)***
>
> ***"I'm not certain what it is or what applications it has. I am interested to find out because it sounds amazing." (Wave 1, Birmingham)***

4.2 Sources of knowledge

Some participants had never heard of QTs. Knowledge and awareness for those who were familiar with quantum and QTs had generally been derived from:

- Popular science TV shows and documentaries (involving Brian Cox, Dara O'Briain and Stephen Hawking and including The Big Bang Theory);
- Popular culture references (including sci-fi films);
- The media (including radio, TV, internet news, and newspapers).

Whilst some awareness had come from media reporting on QTs, participants commented that they hadn't paid much attention to the detail in these articles or actively delved any further. There was some awareness of wider risks and issues relating to QTs derived from the media; such as threats related to hacking and job losses associated with increasing automation and Artificial Intelligence (AI). However, these issues did not only relate to quantum, but technological advancement more widely.

Having close family and friends working in science or technology industries or academia had sometimes provided participants with the opportunity to hear more about QTs. This was particularly the case in Oxford where there is a presence of scientific and technology industries. These participants started with a slightly higher base level of knowledge and confidence regarding the discussions.

Those who had a greater interest in science and/or technology generally had learned about quantum and QTs from a range of educational sources such as YouTube videos, science/technology podcasts, magazines and documentaries. Whilst engaging with these kinds of materials meant people were more familiar with quantum and the kinds of technologies being developed, and felt more confident discussing the topic, they had not necessarily engaged much with the science behind the technologies, which they perceived as an area for 'the experts'.

> ***"I remember listening to a podcast and Neil Tyson DeGrasse was on there and he was trying to explain things in layman's terms and the process of trying to measure the atom, it's not what it was, so I'm already confused! The process of trying to measure it affects it." (Wave 1 Oxford)***

There was also an assumption among some older participants that young people were probably learning about quantum at school and would therefore know more about the subject than they did when this was not necessarily the case. No participants mentioned learning about quantum at school.

5. Dialogue Journey: how participants' views evolved

This section provides an overview of participants' 'journey' through the dialogue, in terms of initial views and feelings when entering the dialogue, how these evolved at different stages and where participants' 'ended up' at the end of the dialogue. Throughout this section, any similarities or differences in the overall journeys across the four locations are highlighted.

Key findings

- Participants' starting points depended on their level of interest in and confidence regarding science and technology.
- In the first wave, participants generally expressed surprise and excitement about the range and nature of QTs, and were particularly engaged by QTs with health and security benefits. Key concerns focused on access to QTs and who would control development decisions.
- Greater exposure to information about QTs (and their practical applications) generally saw participants become more engaged and excited by the range of potential benefits associated with the technologies – particularly once they understood how various QTs could impact upon and be relevant to their own lives.
- Whilst concerns were raised, overall participants were not overly concerned about the development and use of QTs and the risks associated with them. They saw the benefits associated with QTs as worthwhile and as positive progress for society.
- Whilst no participants became more negative about QTs, there was a small number of participants who felt very disengaged from science, whose level of interest remained unchanged (notably in Birmingham).
- Some differences emerged across the four research locations regarding starting points and levels of engagement, with greater overall scepticism being expressed in Birmingham, and greatest optimism emerging in York and Glasgow.

5.1 Overall dialogue journey

Participants generally entered the dialogue with the perception that quantum and QTs were complicated, difficult to understand and for experts only. This resulted in slightly more confident and interested participants' feeling excited and enthusiastic about learning more and, conversely, less confident or less interested participants' feeling slightly anxious or less engaged.

The perception that quantum was for clever experts only was somewhat overridden by exposure to some of the potential applications presented in wave one which participants recognised as relevant to them. And, more generally, as participants learned more about quantum, they became more positive and interested.

> ***"It's quite an exciting thing that it's the next stage of technological development round the corner..." (Wave 2, Oxford)***

Participants were often surprised and excited by the range and nature of QTs (most of which they were previously unaware of) and became more excited upon learning that some QTs are currently being used.

Figure 5.1. Participants discussing the quantum technologies roadmap (in Glasgow).

After briefly discussing the history and origins of quantum physics in the context of the development of science, some participants described having heightened expectations for the ground-breaking potential of its applications. However, most of the QTs discussed were seen as representing incremental, evolutionary change rather than being particularly new or revolutionary. This was in part because participants saw QTs as building on and improving existing technologies (e.g. creating faster computers) rather than representing a new form of technology, with a distinct purpose. Despite this, participants were still excited about the possibilities of technologies they believed would have positive impact on themselves, their friends/family and on society. Stakeholders tended to be surprised by this view from participants and had assumed they would see QTs as revolutionary and a big step forward.

By the end of the wave one workshop, participants had raised a number of questions, including:

- Who has control over funding and development?
- Who profits and benefits from quantum technologies (i.e. will it just be large companies)?
- Will development of quantum computers result in an 'arms race' (particularly around hacking)?
- What happens if code-breaking computers are developed before quantum enabled encryption?
- Will the development of quantum technologies divert the focus away from renewables?

Workshop one also raised some concerns, namely that:

- QTs might fall into the wrong hands (e.g. terrorists, hackers, other criminals and rogue states)
- Unequal access could lead to a growing gap in society and among nations
- The development of surveillance technology could undermine individual privacy
- The development of QTs could lead to job losses and de-humanisation (e.g. driverless cars).

Despite these concerns, participants recognised that government investment in this area was valuable. They did not want the UK to fall behind others and were eager to ensure the country was protected against attacks (e.g. hacking or terrorist).

Following the interim activity, which was unique to each location, participants in York, Glasgow, and Oxford reported feeling more or slightly more interested and excited about QT, whereas those in Birmingham reported feeling neutral, confused, or slightly less enthusiastic. This depended largely on the extent to which the activities brought technologies to life – e.g. through talks using simple, non-scientific language with a focus on the practical applications or through visual demonstrations where participants could see something happening (see section 9.2. for information on ways to engage people in quantum technologies). Participants in Birmingham reported feeling a little confused by some of the terminology used by speakers and not being able to see a gravity sensor 'in action'.

As such, participants in York, Glasgow and Oxford generally entered the wave two workshops excited and enthusiastic; whereas participants in Birmingham felt either a little excited or neutral about technologies. At the same time, participants in Birmingham questioned the purpose of the technology generally and some questioned the need for the technology. Moreover, participants were confused about the 'science' and were not totally clear about the ways in which quantum could impact individuals.

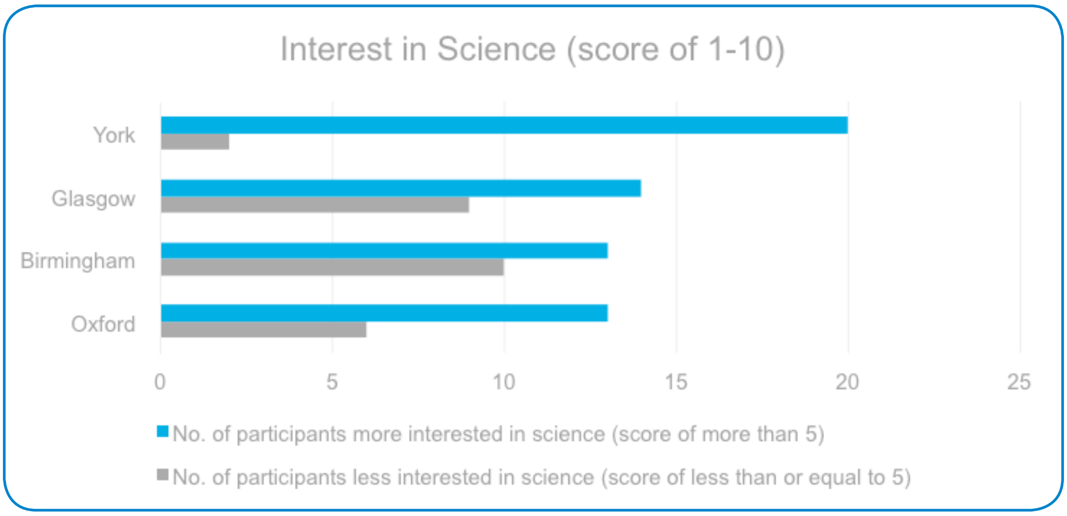
> ***"I am still a little unsure of where we are going with quantum science and how this will affect me personally." (Birmingham, Wave 2)***
>
> ***"It all seems very complicated and science-y. It's difficult to appreciate it not having a science-y brain." (Birmingham, Wave 2)***

However, following further discussions around some of the applications raised in wave one, participants across all four locations generally became excited and engaged, commenting on the range of benefits. Concerns raised in wave one tended to become less prominent towards the end of wave two, with participants believing that the benefits generally outweighed the risks. However, concerns about quantum falling into the wrong hands and unequal access continued to dominate discussions in wave two relative to other concerns. Nevertheless, participants believed that an appropriate system of oversight and regulation could overcome these concerns; whilst at the same time ensuring regulation did not stifle growth or innovation in this area.

5.2 Dialogue journey by area

Analysis of participants' journeys in the four areas revealed important similarities and areas of divergence from the overall 'story'. On the whole, there was little divergence from the overall journey in Oxford, York and Glasgow; whereas there were a number of points of divergence in Birmingham. Birmingham participants entered the dialogue with less interest (and confidence) in science and technology than other locations. This was reflected in participants' responses to the question around level of interest in science included in the recruitment screener. When asked to rate their own level of interest in science from 1 to 10 (1 being uninterested; 10 being extremely interested); 50% of participants in Birmingham were less interested in science (with a rating of 5 or lower). Figure 5.2. below shows the proportion of participants in each location that were more (rating or over 5) or less (rating of 5 or lower) interested in science.

Figure 5.2. Participant interest in science by location.



As a result, there was some initial resistance in Birmingham to engaging fully with the topic and materials. While in other locations participants tended to leave the wave one workshop feeling even more enthusiastic and excited than when they started, this was not universally the case in Birmingham. The topic was considered by participants to be complex and difficult to understand – a feeling that was compounded by the perceived complexity of the interim activity. As such, some participants entered the wave two workshop with less enthusiasm than in other locations. However, it appeared that, by the end of the second workshop, Birmingham participants had 'caught up' with participants in other locations and ended the dialogue noticeably more enthusiastic about QTs and the impact they could have on their lives.

As mentioned above, the interim activities in each location were unique and tended to focus on a particular technology or technologies which may have influenced the way participants approached the content of the second workshop. In addition, a range of academic experts with different specialisms attended workshops in different locations which may have steered conversations in particular directions, potentially contributing in differences. However, there were between 6 and 8 stakeholders in each location in wave two, meaning each group had access to stakeholders with a range of areas of expertise. Moreover, stakeholders were encouraged to rotate around the different breakout groups to ensure participants had exposure to a range of subject areas.

5.2.1 Birmingham

In Birmingham, participants tended to enter the dialogue with less confidence and/or less interest in science and technology compared to other locations. As such, initial responses to quantum were either confusion, uncertainty, mild interest or disengagement. This was compounded by the initial perception that quantum technologies were inaccessible (for experts only) and were not really relevant to participants' lives. This was reflected in how participants felt about the topic, with people either feeling neutral or anxious, confused and a little nervous. Moreover, participants communicated that they were 'not really science-y' and did not actively seek information on science or technology.

Following the interim activity – a tour of the sensors and metrology hub and a talk on gravity sensors – participants were often still confused, disengaged or neutral and communicated finding the topic difficult to understand. Some participants claimed to be a little more interested, especially as they could see how some of the applications – in particular medical imaging – could impact their lives. Others remained confused and unclear (especially in relation to quantum computing and communications), with some raising concerns about technologies falling into the wrong hands.

By the end of wave 2, participants were generally more positive and excited about the range of technologies associated with quantum. A few remained mystified and a couple uninterested or disengaged (primarily because they had very low interest in science and technological development generally); however, on the whole, participants left the wave two workshop feeling positive about developments and quantum technologies overall, despite some remaining concerns about technology falling into the wrong hands.

5.2.2 Oxford

In Oxford, initial associations were more technical and scientific in nature compared to other locations. This was, in part, due to participants who had friends and family working in STEM industries as well as personal or professional interests in science and/or technology. Some were aware of quantum technologies, commenting on their interest in banking security and un-hackable computers. While many were positive overall, they were generally more excited about applications that could directly benefit them – for example, medical applications, banking security, driverless cars and improved search and rescue.

Following the interim activity – a tour of the lab, live experiments and a lecture on quantum computing (which participants found engaging) – participants were excited to learn more about the benefits of quantum. In response to an experiment showing how an atom can be made 'sleepy' by helium for example, one participant claimed to understand applications better.

> ***"Once I could see the atom was effectively suspended it all fell into place a lot better." (Wave 2, Oxford)***

By the end of the second workshop, participants were very positive about the developments and possibilities associated with quantum technologies; whilst at the same time, (as in other locations) raising concerns around access and misuse.

5.2.3 Glasgow

In Glasgow, participants entered the dialogue with relatively high levels of interest in science and technology compared to Birmingham and were generally aware of the word quantum and referenced a range of popular culture sources. A few had additional knowledge about, for example, particles and incredibly fast computers. Irrespective of level of initial knowledge, participants were very interested to learn more and, by the end of the first workshop, claimed to be genuinely excited about what they had heard & the possibilities for the future in terms of the impact on their lives, as well as on industry, the NHS and others. Participants' enthusiasm was also supported by the space in which the workshops took place (the Glasgow Science Centre) because it was an accessible and visual public space.

Participants were very positive about the interim activity – an exhibition in the science centre which included interactive and multi-media exhibits about various practical applications of quantum. The visualisation of applications particularly supported participant understanding and engagement.

By the end of the dialogue, participants were fully engaged and excited about being kept informed and educated about developments in this field, whilst also feeling reassured that regulation and oversight – preferably led by an independent regulatory body - could prevent technology falling into the wrong hands and ensure government and industry were not working to their own agendas.

5.2.4 York

In York, participants' initial feeling towards quantum technologies was generally one of interest and intrigue, despite the view that the science itself was very complicated. Following information presented during the first workshop, participants felt they understood more about quantum and claimed to be excited about the potential benefits.

The interim activity – a lecture with visual projections and video feeds demonstrating quantum enabled encryption, accompanied by a lecture – was described as 'fascinating' and 'brilliant'. Participants felt they had a clear understanding of quantum enabled encryption and were excited to learn more about the other technologies.

By the end of the second workshop, participants were positive about the possible advances in technologies, especially those that could save lives and protect national security. There were concerns raised about a 'tech race' between countries and the importance of the UK staying ahead – with a particular emphasis (perhaps as a result of the focus of the interim activity) on the need to prioritise encryption technology in the wake of developments in quantum computing.

6. Priorities and aspirations for quantum technologies

This section explores participants' considered responses to QTs – in particular, their priorities, hopes and aspirations for QTs in the future, and the values that underpin this.

Key findings

- QTs were seen to have a wide range of benefits for individuals and society. The most engaging QTs were those which participants understood to have the greatest potential impact on individuals and society.
- Participants most prioritised QTs that: improved health (saving or extending lives); contributed to humanitarian efforts; increased efficiencies (i.e. creating cost savings, particularly for the NHS); improved security; and helped to tackle climate change.
- Whilst participants appreciated that QTs could be beneficial, they saw the changes and technologies as incremental and building upon technologies which already exist – and making technology better, faster, and cheaper - rather than QTs as something 'new and revolutionary'.

6.1 Priorities and aspirations

When asked about initial unprompted feelings, participants often responded by asking questions such as "how does it benefit society" and "will it help me?" As participants became more informed about the technologies, these initial framings and considerations continued to drive views and ultimately how people prioritised particular technologies. As such, discussions tended to emphasise the benefits of technologies that were seen to have the greatest positive impact on individuals and society.

> ***"I am really excited about quantum. There [are] a lot of new and interesting things happening to benefit society." (Wave 2, Glasgow)***

Conversely, less attention was given to potential benefits of those technologies that "would make no difference to the man on the street" (York, Wave 1). Participants tended to think about applications such as more accurate 'time-stamping' for financial institutions and the use of quantum computing services for high value problems (e.g. image recognition, financial trading) in this way.

Of the technologies which were understood to have a positive impact on individuals and society, participants prioritised those that were seen to improve quality of life, extend life, or actually save lives over those that were seen to make life easier or safer – seeing the former as having greatest relative value.

> ***"Some are more interesting and beneficial than others…" (Birmingham, Wave 1)***

As a result, participants were most excited about the benefits of health-related technologies (e.g. magnetic imaging) and technologies with a humanitarian focus (e.g. search and rescue) because they were seen to have the potential to save lives.

Technologies also considered beneficial were those that made life easier, safer or generally better such as those that created efficiencies and saved money, increased security (personal, financial and national), tackled climate change, furthered human knowledge or increased internet speed (5G).

Participants also prioritised QTs which furthered the UK's global reputation, with participants noting the importance of the UK staying ahead of other countries in this area to uphold or enhance the UK's reputation as a global leader.

> ***"Nobody wants to be the 'poor man' of the world, do they?" (Wave 2, York)***

Figure 6.1. Summary of participants' priorities and aspirations for QTs.

6.2 Improving health

As is often the case in public evaluation of scientific applications[6], the most overwhelmingly positive reaction was in response to technologies that had health-related applications. This was primarily because there was a strong sense that they directly impacted participants and their loved ones.

> ***"[Because they are] close to home" (Birmingham, Wave 1)***
>
> ***"We all suffer from health issues..." (Birmingham, Wave 2)***

For example, the potential for magnetic imaging to provide earlier and more sensitive detection of dementia received an extremely positive response across all areas. This was presented as a case study alongside four other case studies in wave one and received by far the most positive response (see Appendix 11). Positive reactions were amplified in Glasgow and Birmingham where participants learned from stakeholders that magnetic imaging could also increase our understanding of how the brain works generally which opened up discussions about the positive impact of greater understanding and diagnosis of mental health conditions.

> ***"It seems it can be used for the detection of any neurological condition." (Glasgow)***

Participants felt they could relate the most to this technology as they claimed they themselves or people they knew were affected by mental health issues or dementia. At the same time, participants were enthusiastic that (as highlighted in the case study) the introduction of magnetic imaging could save the NHS money, citing the growing numbers of people affected by dementia (and the growing cost to the NHS). They were positive that this money could be used elsewhere in the service, ultimately improving health outcomes for all.

> ***"I like the magnetic imaging one...Just the potential for life changing results because something like Alzheimer's affects a huge amount of people. If you detect it early you can have a better quality of life. So the applications of that are priceless, almost." (Wave 2, Birmingham)***
>
> ***"I spoke to my dad and my mum actually suffers from dementia...that really fascinated me. The fact they can do tests so early on...they've got the prototype. That really fascinated me...because it's something that's so close to life and something I can relate to." (Birmingham, Wave 2)***

6 *Healthcare and medical applications are often accorded highest value in dialogue on emerging technologies, as healthcare tends to be perceived as a fundamental 'social good' (especially in the context of treating people with existing diagnosed illnesses), and is perceived to have fewer problematic or complex externalities than other applications (e.g. environmental). However, deliberation often reveals important caveats related to use, choice, and safety. See for example Kantar Public (previously TNS BMRB)'s report on public views of Synthetic Biology (http://www.bbsrc.ac.uk/documents/1006-synthetic-biology-dialogue-pdf/).*

Similarly, participants were enthusiastic that quantum enhanced imaging could be used for new non-damaging biological microscopes that could see dynamic processes. For example, distinguishing between cancer cells and healthy cells and monitoring cells changing. This application was presented as part of the 'quantum roadmap' stimulus alongside a range of other applications and was the technology participants generally claimed to be most excited about. Similarly, this application was commonly selected across all locations by participants during the 'quantum for good' activity where they were asked to select applications they most wanted to see used for 'good'. Participants anticipated that this technology would make cancer diagnosis more efficient and reliable, reducing waiting times between tests.

> ***"With the medical side of this that resonates with just about everybody especially things as serious as cancer because as I am getting older pretty much everybody I talk to cancer has took someone in some way, whether it be a family member or friend." (Wave 2, Birmingham)***

Participants were also positive about the ability, using quantum simulators, for scientists to develop and test new drugs on a computer, rather than manufacturing them and then testing them in the lab. The main focus of the discussion lay in the potential to speed up the process of drug development; reduce costs for the NHS (although some were sceptical that pharmaceutical companies would pass on cost-savings); and ultimately the ability to treat patients quicker.

> ***"Anything that can help the medical profession, that can detect various diseases early and possible cures, can only be a good thing." (Wave 2, York)***

There was also a strong sense this application would protect animals and people from the process of drugs testing – a consideration which participants raised spontaneously.

> ***"This will help save lives without hurting people or animals." (Wave 2, Oxford)***

Whilst participants were generally excited and positive about the health benefits of these technologies, some had reservations about the use of early diagnostic technology. Participants generally agreed that earlier detection is better but, this was on the proviso that there would actually be a cure or treatment options available. For example, people were ambivalent about the ability to diagnose dementia early, if there was nothing a patient would be able to do about it – due to the potential negative effects of someone knowing they will get ill. Some participants questioned whether they would want to know that they had a disease if there was no way of curing it, or no treatment options that would significantly change outcomes.

When prompted by stakeholders and moderators about some of the possible negative uses of magnetic imaging – for example by employers to screen employees (e.g. health screening for potential employees) or other countries for immigration purposes – participants were less concerned and focused more on what were perceived to be the overwhelming health benefits of the technology[7].

7 In one of the sub-groups in Birmingham, the issue as to whether magnetic imaging technology would allow the user to 'read the minds' of individuals was raised spontaneously by participants. This gave rise to a discussion about the potential positives (e.g. learning more about criminal minds) and negatives (e.g. labelling someone a criminal because of their neurological make up) of such an application. However, participants did not take the conversation further and settled on the positive impacts of earlier diagnosis of diseases such as dementia rather than pursing concerns about brain scanners and reading minds.

6.3 Contributions to humanitarian efforts

Participants were also positive about humanitarian-related developments. For example, one of the key factors underpinning participants' decisions about which technologies they would most like to see used for good during the 'quantum for good' activity was the extent to which they contributed to humanitarian efforts.

> ***"They all have a humanitarian theme, it's people's lives." (Wave 2, Oxford)***

The possibility of better detection in disaster zones - for example earthquake and volcano monitoring – through gravity sensing resonated with participants across all locations. Participants cited the frequency of and devastation caused by natural disasters across the world.

> ***"The early detection of natural disasters could prevent loss of life." (Glasgow)***
>
> ***"Natural disasters are becoming more frequent and more deadly. Quantum technology seems to be a major 'positive' in... preventing such major death and destruction." (York wave 1)***

Similarly, when presented with a range of technologies as part of the quantum roadmap, participants were particularly positive about the ability to image through smoke in order to locate victims of fires. They felt this would result in positive benefits both for victims and in improving safety for fire-fighters. This application was particularly meaningful to participants for whom the Grenfell incident was 'top of mind', with a few participants mentioning the ways in which this technology could have helped to save lives.

> ***"Firefighters can be safer and quicker to save people." (Glasgow, wave1)***
>
> ***"The Fire Service in Grenfell for example, something like this could have saved many more people's lives potentially." (Wave 2, York)***

While 3D imaging was considered beneficial in the context of natural disasters and emergency scenarios, the same technology raised concerns that misuse could undermine privacy by enabling users to see around corners or see through walls (see section 7.6). However, in the end participants generally concluded that the benefits of 3D imaging if used to save lives outweighed the risks to privacy. Those who remained concerned were reasonably trusting that the risks of misuse could be addressed through appropriate regulation.

6.4 Increasing efficiencies and money saving applications

A key driver of positivity around technologies related to the ability to increase efficiency and save money for individuals and public organisations such as the NHS and, to a lesser extent, businesses. Efficiencies resulting from improved health care were noted by participants as hugely beneficial to the NHS, so long as technology companies and pharmaceutical companies developing the technology and drugs passed on cost-savings to the NHS rather than increasing profits.

Faster and more powerful computers were viewed as potentially time-saving, particularly in terms of processing tasks which would ultimately result in efficiencies for government and some businesses. Moreover, participants were optimistic that improved efficiencies in data processing could help to solve socially important problems – in particular, if used to combat crime or for resource allocation in the NHS (e.g. resourcing ambulances, an example given in the quantum computing case study).

> ***"I think that speed today is crucial whereas you go back to The Ripper everyone was going through flip cards trying to correlate this with the other. If there had been a***

computer so many girls' lives would have been saved. It's the speed, what it can do to help people." (Wave 1, York)

"It can take the strain away from the NHS so that maybe they can concentrate their efforts on other things, like dementia." (Wave 2, Birmingham)

There was also recognition of benefits of quantum enabled navigation to the transport sector (e.g. allowing trains to be packed more closely on tracks) – an application participants became aware of through the 'quantum roadmap' stimulus. Participants valued and spontaneously mentioned benefits associated with this application as commuters – such as increased reliability, reduced stress and in the positive impact on the environment of fewer people driving.

"People will be happier, I mean what else is there than satisfaction and happiness because people get very stressed when they're trying to get from A to B." (Wave 1 Oxford)

At the same time, participants communicated concerns around who would benefit from efficiencies and money saving applications. These included concerns that big companies would benefit from increased profits rather than individuals, the public or the NHS. Queries were also raised around whether QTs generally would actually save individuals money, with participants worrying that they would be prohibitively expensive to buy. Nevertheless, in the main, participants tended to trust that they would realise at least some of the benefits of efficiencies as consumers of both private and public-sector goods and services.

6.5 Increasing security

Quantum enabled encryption was perceived to be particularly complex by participants and they generally took a while to understand this technology – particularly with regards to the relationship between encryption and computing. Nevertheless, participants eventually understood that quantum enabled encryption increased security of the transfer of data. When quantum enabled encryption and the relationship between the development of quantum computers and quantum enabled encryption, was understood, participants tended to recognise the importance and benefits of secure data transfers.

"The fact it can show any attempted interruptions is very useful..." (Birmingham, Wave 1)

Moreover, it was understood by those that viewed cybercrime as a genuine threat (either because they had experience of it or because it was 'top of mind' following media reportage) that quantum enabled encryption was important for secure banking and the secure transfer of personal information. This was regarded as important, relatable and personally relevant. There was also recognition that, at the national level, the UK would benefit from quantum enabled encryption to ensure that the UK was not vulnerable to cyber-attacks. There was particular concern around the UK being open to attacks by states (e.g. North Korea) or terrorists.

"We need to try and be a world leader, try and be prepared in it." (Wave 2, York)

At the same time, quantum enabled encryption did not alleviate all participants' fears as they were still worried criminals would find other ways to hack their data. Moreover, participants claimed that quantum enabled encryption did not tackle other kinds of threats such as phishing, bribery and physical theft. However, the main concern participants communicated related to the inability of security services to intercept data sent by criminals – in particular, terrorists.

6.6 Furthering human knowledge and discovery

Some of the discussions about benefits related to the importance of furthering the UK's knowledge base. For example, participants commented on ways in which enhanced imaging (e.g. seeing and exploring underwater life) could be used to push the boundaries of discovery. This was considered in the context of popular documentaries such as Blue Planet II which was 'top of mind' for participants.

> ***"We need to keep on moving. Changes will happen, we have to go with the flow. Yes, there will be pros and cons, but we have to learn and develop." (Wave 1, Glasgow)***
>
> ***"I think it is encouraging that the UK government is funding this sort of research, you've always got to spend money on research and if you can push technology as far as you possibly can that to me is a good thing." (Wave 1, York)***

6.7 Tackling climate change

Another driver of positivity around technologies was the extent to which they were considered to be addressing climate change. Participants who were interested in and enthusiastic about protecting the environment generally commented on the importance of applications being 'green'. For example, when considering the 'quantum roadmap', some participants in Glasgow noticed the fact that quantum computer components could run on lower energy – a consideration which was important to them because of the positive impact on the environment.

> ***"One of the things that stood out for me was fighting the effect of climate change because my personal opinion is that it's one of the biggest challenges the world faces..." (Wave 1, York)***

The use of gravity sensors to monitor changes in climate was seen by some as enabling the development of new ideas with respect to tackling climate change.

> ***"Monitoring climate change can hopefully lead to ideas or solutions.... can be developed to make positive changes" (York, wave 2)***

Figure 6.2. Birmingham participants completing the 'quantum for good' game.

Moreover, participants spontaneously noted the positive impact of gravity sensors on the environment, explaining that having a more detailed picture of what is underground would result in greater precision of exploration when searching for natural resources and less damage to the environment (e.g. drilling a few holes into the ground rather than hundreds).

6.8 Faster internet/5G

Although viewed as an incremental technical advance, a few participants were excited about the personal benefits of faster internet or 5G. They viewed this as a positive improvement for companies, industry and government, making processes more efficient. Faster internet could also support more remote working and reduce emissions from, for example, travelling to work.

> ***"Finally, they've been saying this for like 3 years now.... Faster internet speeds on the go and better communication, like no dropping off when you're talking to someone in a different country far away,.." (Wave 1 Oxford)***

However, there was some concern around issues of access to 5G networks, potentially widening the gap between rural and urban dwellers given the assumption that rural communities would be the last to benefit.

7. Concerns about the development and use of quantum technologies

This section explores concerns about and reported risks associated with QTs, the principles driving their fears and what informed their views. It also reports on how they weighed these concerns up against associated benefits and what participants wanted to see done to address these risks and reassure them.

Key findings

Some concerns were raised throughout the dialogue about the development and use of QTs, some of which related to the development of all technology and were general points:

- Who controls the development of QTs – and how far decisions would be driven by company profit, potentially at the expense of the public interest;
- Who would have access to QTs – and whether uneven access could drive a greater and less surmountable divide in society;
- Automation and job losses – this was an emotive and salient issue and job losses in driving, analytical and logistical roles were seen as an immediate and relevant risk;
- Environmental damage – participants questioned QTs' overall contribution to climate change.

Other concerns raised were more specific to the QTs discussed, and included:

- Whether QTs would spark a defensive international arms race
- Misuse of QTs for the purposes of hacking and cyber warfare;
- Misuse of quantum enabled encryption technology to hide criminal activity
- Misuse of imaging technologies by criminals, companies and the state.

Whilst concerns were raised, overall participants were not overly concerned about the development and use of QTs and the risks associated with them. They saw the benefits associated with QTs as worthwhile and as positive progress for society. Concerns were also alleviated with considerations that: (1) the risks associated with QTs were not perceived as new; (2) not necessarily specific to QTs; and (3) and misuse of technology was seen to be inevitable.

7.1 Risks and concerns

7.1.1 Access and an increasing gap in society

Access to QTs was commonly raised as a concern across the dialogue waves, locations and demographic groups. Concern about the potentially unequal distribution of benefits was raised early in the dialogue in response to the roadmap and persisted throughout the process, particularly in response to stimulus materials which talked about health technologies. Concern about access to QTs was driven by a fear that they could create and increase the gap in society between those who do and do not have access to technology. There was an assumption that QTs would be expensive, and therefore wealthy individuals and large corporations would have access to them whilst poorer people would be 'left behind' (particularly in Glasgow). There was some acceptance among participants that rich people and companies would have access to the technologies first (as they believed this was always the case and inevitable), but there was a concern about whether the technologies would create a more persistent and less surmountable divide in society. Similarly, participants expected that it would take time for those in rural locations to benefit from advances in computing technology, including 5G, and felt this was unfair.

> ***"All your normal computers are more vulnerable until the majority have caught up for which the likes of us could be a long time, could be a few years until it filters down to domestic level." (Wave 2, York)***

Participants were particularly concerned about large corporations having access to the technologies and profiting from this, to the detriment of smaller companies and/or at the expense of the public/consumers. There was particular concern about medical companies having access to the technologies if the NHS did not or this was detrimental to the NHS and its users in some way (meaning they did not have access). Again these fears seemed to be driven by a fear that through their benefits of increasing speed and efficiency, QTs could increase the gap in society.

> ***"It will be big governments or big hospital trusts or whatever can see that but availability worldwide to Joe Public I can't see happening in my lifetime." (Wave 2, York)***

To address this concern, participants felt there should be governance mechanisms in place to ensure that development of QTs would not just result in large profits for companies and be in the interest of wealth creation, but would also be directed towards the public good – e.g. the NHS (see chapter 8).

There was concern about an increasing gap at the international as well as the national level. Participants believed that countries that chose to, and were able to, invest in and buy QTs would have an advantage over countries who do not. Participants seemed concerned about this outcome, and this seemed to be driven by a sense of concern for those who would be disadvantaged. However, participants were clear that they wanted the UK government to invest in QTs so that the UK would not be left behind.

Figure 7.1. Participants completing the 'Quantum for undesirable purposes' task (in Birmingham).

7.1.2 An international 'arms race' and defensive investment

Concern was raised early about whether the development of QTs may trigger a new type of international 'arms race' between nations. Participants mentioned being concerned about development by China, the US, Russia and sometimes North Korea, as countries they saw as likely to be able to afford and have a military and defence interest in developing QTs. This concern emerged after participants were exposed to stimulus materials about quantum enabled encryption and computing and the relationship between them and those which referred to military uses of the technologies – e.g. 3D imaging.

Participants expressed concern that the UK (and other countries) may feel the need to invest in developing a quantum computer to prevent another country doing so before us to prevent the

UK being a victim of hacking. Therefore the financial investment would be primarily defensive, rather than to realise the positive benefits associated with the technology. There was also a concern about the relationship between quantum enabled encryption and computing may lead to a snowball effect and countries being locked into a cycle of pressure to develop the next technology rather than be a victim to another country doing so first.

Whilst this was an important issue in wave 1, it dissipated over the course of the dialogue and participants did not continue to express strong concerns about the 'arms race'. Concern reduced as they learned more about the benefits of quantum computing and encryption and understood their value to individuals and the public more fully. However, participants also moved away from this concern as they accepted that the 'arms race' to some extent seemed inevitable and seemed to already be underway, and the types of threats they might face if another country developed the technology first (notably hacking of financial systems). They therefore prioritised the UK investing in QTs to protect citizens and the government against attacks from other countries. In this sense they became more nationally rather than internationally focused. Participants also wanted the UK government to help ensure that UK companies and the state would benefit from development work done in the UK (particularly in universities) rather than this advantage being bought by companies in other countries (particularly in York where previous incidences of this in other sectors were discussed with stakeholders).

Figure 7.2. Wave 2, Stimulus 5Theft of information through hacking and cyber warfare.

One of participants' primary concerns across the areas throughout the dialogue was about the misuse of quantum computing technologies if they were employed for hacking and other forms of cyber warfare. These concerns were raised in response to stimulus materials about quantum computing in waves 1 and 2, including the hub introductory videos, and the interim activity in York. Participants commonly thought of countries such as China, Russia and North Korea as potential perpetrators as well as terrorist and criminal organisations – perhaps because they had heard these countries mentioned with reference to these types of issues in the mass media. They were concerned about this threat at the individual and national level. The types of cyber warfare they were concerned about was theft of money, data and identities; theft of information for the purpose of bribery; the shutting down of systems (personal, corporate, financial and government); and manipulation of financial markets. Participants essentially imagined this in terms of the theft of individual information, rather than the use of the super computer for aggregate data analysis in ways in which might affect individuals as the stakeholders suggested (e.g. for 'pre-crime' analysis and for use in the insurance industry as suggested in the stakeholder workshop).

The hacking and cyber warfare threat generated high levels of fear among participants that they as individuals, banks, or the UK government and its bodies (notably the NHS) could become victims of hacking. This seemed to be a particularly frightening prospect for those with lower technology skills who found it harder to envisage how they and others could protect themselves against this complex threat. This risk may have been prioritised because it was more tangible and seemingly more immediate because participants were aware of current hacking attacks from recent media coverage of large scale incidents (e.g. the recent malware attack which affected the NHS, global corporations and Ukrainian metro in 2017). Concerns were heightened when participants discovered that quantum computers could crack encryption codes that are commonly used today and therefore their information stored and transferred today could be decrypted in the future if it is stolen and stored. This implication was not raised spontaneously by participants, but prompted by stakeholders (particularly in York) and it perhaps increased fear levels as participants had not been able to work this out for themselves and because they realised they were currently vulnerable without being aware of this.

> ***"That's [the super computer] a serious problem for security military wise, national wise, financial institutions...because we are then vulnerable." (Wave 2, York)***
>
> ***"If computers come before encryption then that's massively, massively dangerous." (Wave 2, York)***

In order to counter this issue and provide reassurance to the public, participants wanted to see government prioritisation of quantum enabled encryption, particularly through funding of the development of this quantum technology before and above others (including the super computer), to provide protection from the hacking threat. Despite some initial difficulty understanding quantum enabled encryption, participants were generally reassured by explanations provided by stakeholders and stimulus materials that quantum enabled encryption could not be broken by quantum computing (although there was some initial suspicion about this). Some participants in York raised concerns that, following Brexit, the UK may be excluded from European efforts to develop quantum enabled encryption and ultimately to protect the UK and its citizens – fearing that the UK may be left behind in the aforementioned arms race.

> ***"I think it's really vitally important, especially the secure communications, that the country keeps working on that as a priority." (Wave 2, York)***
>
> ***"I'd say encryption has to come first...it needs to be developed before the computers." (Wave 2, York)***

Whilst participants prioritised the development of quantum enabled encryption as a way to protect against hacking and quantum cyber warfare - they also understood that quantum enabled encryption could only be part of the defence. They also felt it was important for people to be aware of and understand the threat of hacking and do more to protect themselves – for example by not clicking on infected links in emails and by using secure passwords. This discussion was prompted and taken further by stakeholders in York. Participants generally felt the government and other knowledgeable organisations urgently need to do more to educate the public about how to protect themselves and their workplace from cyber-attacks. There is also a need for clarity regarding what protection quantum enabled encryption can provide and the limitations of this approach, given participants initial difficulty in understanding this complex technology, how it works, and its limitations with regards to providing a solution to the problem of hacking.

7.1.4 Hiding crime through the misuse of encryption technology

Quantum enabled encryption was seen as key to defending the UK and its citizens from hacking by other countries and criminal organisations and participants therefore wanted to see its development prioritised. However, encryption technology was not itself without challenges: while it provides security to some institutions, it was also perceived as providing cover to illicit communications. The use of quantum enabled encryption to hide criminal activities was an early concern raised by participants which persisted throughout the dialogue. There was concern that quantum communication technologies could be used to transfer information and data for nefarious purposes by terrorists (such as plans for terrorist attacks which were of primary concern), organised criminals (e.g. money launderers and other international criminal networks); paedophiles (transferring images); and tax evaders (transferring money to tax havens). These debates were sparked by stimulus materials about quantum enabled encryption in waves 1 and 2 and the interim activity in York, and particularly the 'quantum for undesirable purposes' activity in wave 2.

> ***"If you want to plan any attacks, if any part of your organisation wants to communicate with each other you can do it total secrecy, no-one will ever eavesdrop on anything you've got to say so you will get 100% of your intended impact without anyone knowing." (Wave 2, York)***

Whilst this issue was important to participants, they acknowledged that it was not a new risk and that quantum enabled encryption would be a new tool for crimes and criminals which already existed rather than creating a new form of crime. However, quantum enabled encryption did present a new angle because it would mean that information and data could be transferred and not detectable by the police and security services. This was particularly an issue regarding terrorist communications which were of high salience to participants across the locations. This sparked a debate among participants about whether there should be a 'backdoor' to quantum communication technologies, particularly any made available to the public, so that the government could investigate terrorist activities. Overall, participants were generally prepared to trade off this level of privacy to help tackle terrorism, particularly among those with higher trust in the government who claimed they had 'nothing to hide'. This was a more difficult trade-off for those with lower levels of trust in the government and regulatory bodies (e.g. the police).

Compared to some of the other applications explored in the dialogue, quantum enabled encryption was found to be more conceptually complex by participants, meaning some initially had difficulty grasping how it worked. Following further discussion and explanation from stakeholders, participants were better able to engage with the ideas – particularly following the interim activity in York which included a demonstration of the technology which brought it to life for participants. Following further explanation, some participants still questioned how secure quantum enabled encryption was, with some voicing scepticism that it would stand up to future developments in hacking technology and techniques. For some this was driven by the common trope that technology will always continually evolve and supplant previous models. For others, this scepticism was driven by engagement with the stimulus materials about quantum mechanics shown in wave 1 which explained how quantum physics challenged classical physics. Some participants in Birmingham and York were sceptical that quantum theory represented the final and ultimate understanding of matter, questioning whether new theories could lead to new technologies which could break quantum enabled encryption. Here participants made the parallel with Newtonian physics and quantum physics, claiming that physicists thought Newtonian physics was the 'ultimate' understanding before quantum was discovered.

> ***"Until we know how things are not going to be hacked by quantum, I won't be convinced." (Wave 2, Oxford)***
>
> ***"There is a level of cynicism about it isn't there ... Experts say 100% guarantee is based on the laws of physics ... 'It may be a long way off but there will still be someone who will break it." (Wave 2, Birmingham)***

As explored above, participants questioned the usefulness of quantum enabled encryption when learning from stimulus materials and stakeholders that it protected the transfer of data, but not the storage of data. Concerns were then raised about the vulnerability of data being stored at each end of a transfer.

Moreover, whilst participants understood the value of encryption for financial, corporate and government and national security information transfers, they questioned whether their own personal communications needed to be quantum encrypted (for some this was driven by the belief that they were not and never would be doing anything wrong). As a result, some thought that the technology should be restricted to use by the government, banks and other organisations. Generally they concluded that this could help to address the issue of quantum enabled encryption being used for criminal purposes.

"Seems something very under-handed about the personal data bit because other than people who work in classified industry I can't really see why you really want to be so secure that nobody can intercept it, other than people who are up to no good." (Wave 2, Birmingham)

7.1.5 Control and invasion of privacy

In the discussions about use of quantum enabled encryption technologies to assist terrorist and criminal activities, participants were generally prepared to surrender some degree of privacy to help address what they perceived as a greater risk. However, invasion of privacy through the use of QTs was itself a risk raised during the dialogue. Concerns about privacy were driven by questions about who had access to and was in control of the imaging technology and for what purpose and how images would be used. Whilst there was some concern about invasion of privacy, participants generally prioritised preventing what they perceived to be worse crimes through the use of these technologies.

Quantum imaging technologies that had capabilities to see through walls or clothes, or around corners were generally seen as exciting by participants, but at the same time raised concerns about surveillance and invasion of privacy. These discussions were prompted by stimulus materials about enhanced imaging technologies in the roadmap and 3D imaging in the discovery session. Participants' primary concern was about the technologies being used to see through the walls of their home and to monitor their activities. They were primarily concerned about misuse by criminals such as burglars or voyeurs or 'peeping Toms' or by security and surveillance companies (at home and at work). There were some discussions about whether footage could be misused to bribe people who were recorded breaking the law or doing something they would not wish to be made public. Whilst participants raised concerns, they also acknowledged that misuse of technologies for such purposes is not unique to quantum. This is a risk with all technologies, and they saw the risks as incremental builds on other technologies used for similar purposes (e.g. cameras, surveillance video cameras, and infra-red technology which can already see through walls).

"To a certain degree some of those concerns you can't overcome. As history has shown, the people who want to misuse technology get hold of it and misuse it." (Wave 2, Oxford)

There was some concern about state use of these technologies (e.g. by the police) if people were viewed or recorded incidentally when they were not the legal subject of surveillance or if other crimes were unearthed during an investigation which were not its primary purpose. Whilst participants mentioned these concerns about state use, there was generally a very low level of concern about state use of these technologies. Participants generally either had a high level of trust in the government with regard to use of surveillance technologies and/or regarded this as irrelevant if they saw themselves as 'not doing anything wrong' and tended to prioritise preventing what they perceived to be worse crimes through the use of these technologies. Participants also said that surveillance was not a new risk and they were accustomed to surveillance by the state (e.g. traffic cameras) and saw the quantum contribution to this area as incremental and not greatly more intrusive than other current technologies.

"Of all those people, the government have a lot more power in terms of saying what all the other groups can or can't do. It's almost like we have to trust them to do it...they're the only ones who can veto what all the others are doing." (Wave 2, Oxford)

However participants in Birmingham raised concerns that there would not be an opportunity for the public to further debate the implications of these technologies on privacy in an open and meaningful way as they did not believe it to be something they would see in the media. They also recognised that issues around privacy (like other issues) were not quantum-specific and played out in relation to a wide range of surveillance technologies and activity currently in use and debates currently underway.

Ultimately, concern about using QTs for surveillance was driven by uncertainty around who would have access to and control of the technologies and images and how they would be used. On the whole, participants felt that the general public should not have access to this technology because they did not recognise a need for it beyond criminal or immoral purposes. Some felt that their concerns around privacy would be addressed if access to imaging technologies was restricted and/or use of them was logged (e.g. via a secure system) to try to introduce a level of accountability when used by companies and the government – particularly those who were more concerned and had lower levels of trust in the government.

"It's the same with everything [to do with surveillance], you've got to be able to control it." (Wave 2, Oxford)

7.1.6 Job losses and de-humanisation

The risk QTs present to those working in certain sectors of the economy with regards to job losses was an emotive issue for participants. This was raised across the waves and locations of the dialogue. The issue of jobs lost to automation had a high level of salience, perhaps because of increasing recent media coverage meaning this tangible threat was perceived to be more immediate and relevant to participants and people with their social sphere. The issue was also heightened for participants as they struggled to think what the solution to this problem could be and also who was responsible for this issue and co-ordinating a response to it, particularly given the sense that this would be a large scale change for society and will affect many workers and sectors.

The issue of job losses was raised spontaneously by participants when they had low levels of knowledge about QTs beyond them being 'advanced'. This suggests that the public associates job losses with advancing technology more widely. Further discussions about job losses were stimulated by materials about data analysis in wave 1 and 2; the hub videos; and materials about driverless cars. As a result participants were concerned about job losses for drivers (e.g. lorry and taxi drivers), those working in analytical and logistical roles and also those with physical jobs which might be replaced by robots. A lower level of concern was registered about the de-humanisation of some sectors if decisions were made by computers rather than people.

Participants raised concerns specific to unmanned vehicles, both in terms of safety and job losses. Some thought that driverless cars may result in more errors and accidents. There was ambivalence and distrust in the technology's reliability – based on participants' experiences with other types of technology and how often these were found crash, freeze and malfunction (e.g. phones, computers and GPS/ sat navs). Participants in Birmingham questioned how a driverless car would approach a moral dilemma, for example whether driverless cars would be programmed to make a decision between the lesser of two evils (e.g. no option but to crash into a group of pedestrians or crash into one pedestrian). Participants in York raised concerns about whether unmanned vehicles could be hacked and controlled whilst passengers were inside.

> ***"I just think that driverless cars are a nonsense really. I just don't understand how a driverless car is going to drive on the same road as me...I don't get that. I don't think it is safe either...and we're talking about culpability on driverless cars. If I have an accident, whose fault is it?" (Wave 2, Birmingham)***

Whilst job losses was clearly an emotive issue for participants, they were also aware that this is an issue with regards to technology and rising automation rather than quantum specifically. However there was some concern that quantum accelerated this process by adding to the functionality of certain technologies (e.g. driverless cars) and the step change the super computer presented to analytics. However concern about this issue tended to dissipate over the course of the dialogue compared with the other issues.

7.1.7 The environment and green energy

A less commonly voiced concern was around the implications of QTs for the environment and climate change, and what their overall contribution would be in this area. As discussed in chapter 6, some QTs were seen to benefit the environment (e.g. lower energy components). However, others were seen to potentially contribute to damaging the environment; notably gravity sensors which could be used in the detection of oil and gas whose development may divert attention and funding away from renewable energy technologies. The use of any technologies to assist the progress of fracking was viewed negatively by the participants. Furthermore, use which was understood to benefit large oil and gas companies at the expense of the public was also viewed negatively. Ultimately, these participants felt that the government should incentivise, prioritise and fund QTs that have a positive impact on climate change and the environment rather than those that do not.

7.2 Trading off costs and benefits of QTs

These concerns about the development and use of QTs were raised consistently across the locations over the course of the dialogue. However, whilst participants were worried about these risks and issues, overall, they were not greatly concerned about the development of QTs and their impact on individuals and society. On balance, participants tended to believe that the potential benefits of QTs outweighed the risks associated with them and they generally concluded that it was important the UK invests in this area and were keen to see the UK (government and businesses) leading on QTs in an international context. Participants either thought the cost-benefit trade off associated with individual technologies tipped in favour of the benefits, or were able to suggest ways in which they thought specific risks could be mitigated to reassure the public.

This view was reinforced by a number of considerations. Firstly, concerns were alleviated by the fact that participants recognised that the risks associated with quantum were generally not 'new' risks, but mostly were issues they were already familiar with and in fact new forms of already-existing risks. This was particularly the case regarding hacking and surveillance which participants were already aware of due to media coverage of these issues. There appeared to be one exception to this which related to the quantum-specific risk of quantum computers code-breaking potential, perhaps because this seemed to present the greatest 'step change' to participants in terms of escalating this issue due to the increased power of the quantum computer. Participants therefore perceived the nature of the hacking risks associated with the quantum computer as a new type of threat for our society[8].

Secondly, participants saw some of the risks associated with QTs as about advances in technology more generally and widely rather than about QT specifically. A key example of this was job losses associated with QTs (e.g. due to driverless cars and analytical capabilities of the super computer) as participants recognised that this is a wider issue related to technological advancement in a number of areas.

Thirdly, and related to the last point, participants believed that, irrespective of the type of technology, there would always be people who would seek to misuse it and that misuse is not specific to QTs (e.g. of surveillance technologies). Participants believed that all technologies (from the knife to chemical and nuclear technologies) have always been and always will be misused by people, and that criminals would find and use something else if not QTs. This attitude tended to alleviate fears about forms of misuse of QTs which could cause harm to others. Participants felt that with any technological advancement, there was always a trade-off between the benefits to individuals, society and government and the risks associated with misuse.

Finally, some risks felt less tangible, relevant, or immediate to participants who were asked to imagine a technology that did not currently exist. Some risks were less tangible for participants, particularly those regarding data analytics by the super computer and how these might disadvantage some citizens (as they were less familiar with this concept). Other risks seemed less relevant to them; for example surveillance if they believed they were not doing anything wrong (although there were mixed views on surveillance in the sample). Other risks seemed less immediate if they were imagined to be further in the future and were therefore less top of mind than issues which participants currently saw reported in the mass media (e.g. hacking and job losses due to automation).

8 Discussion around this topic was stimulated by stimulus 5 in wave 2, which presented information about quantum computing and encryption and the relationship between them.

Figure 7.3. Summary of trade offs.

8. Governance of the development and use of quantum technologies

Key findings

- Outstanding concern about control in the development and use of QTs could be mitigated through the establishment of governance mechanisms to reassure participants that
  - o The public interest would be considered in the development of QTs as well as company profit (notably regarding health technologies)
  - o Access to the benefits associated with QTs and societal impacts related to this would be actively considered
  - o Misuse which poses a threat to individuals and society would be deterred and punished.
- Participants wanted to see governance mechanisms in place prior to commercialisation which were strong and independent (and therefore able to prosecute government and public body misuse)
- Restricting public access to some QTs was seen as appropriate when participants felt the risks of public access outweighed potential benefits (e.g. to encryption, surveillance technologies and those which could be misused to physically harm individuals)
- Whilst good governance was important to participants, they did not want to see regulation stifle innovation in and advancement of this area or disadvantage the UK in the international context.

8.1 Governance and regulation

Early in the dialogue, participants raised two specific questions about control regarding QTs: who was in control of development (and who would be profiting and benefitting) and who would have access to and be able to use QTs.

Regarding the development of QTs, concern was raised about the motivations of those who have control over decisions – and the extent to which those that made decisions about what is developed would ultimately benefit financially from the products. Participants raised concerns that large corporations would likely be making all the development decisions and that these would be driven by a strong profit motive rather than the public interest which may lose out as a result (particularly in Glasgow). Participants cited the pharmaceutical industry as a point of comparison, where they believed development decisions were made in the interest of company profit rather than patient and public health. There was particular concern about automation where companies were seen to profit at the expense of workers losing their jobs and in the case of health where decisions might benefit companies rather than public health.

Concern was also raised about who would have access to QTs, and whether they could be misused, particularly in ways which may disadvantage the public. This may be misuse by terrorists and criminal organisations, but participants were also concerned about use and misuse by large corporations and the government which could affect the public (e.g. surveillance misuse by the police or use by insurance companies which may disadvantage some customer groups).

As a result of these concerns, participants across all locations agreed that effective governance – ideally by an independent oversight body and regulator - was needed to ensure the public's interest was taken into account and protected. As the dialogue progressed, participants increasingly felt that governance and regulation that involved a range of actors was the best way to address their concerns because would help to ensure the public interest was taken into account.

8.2 Governance - the development of QTs

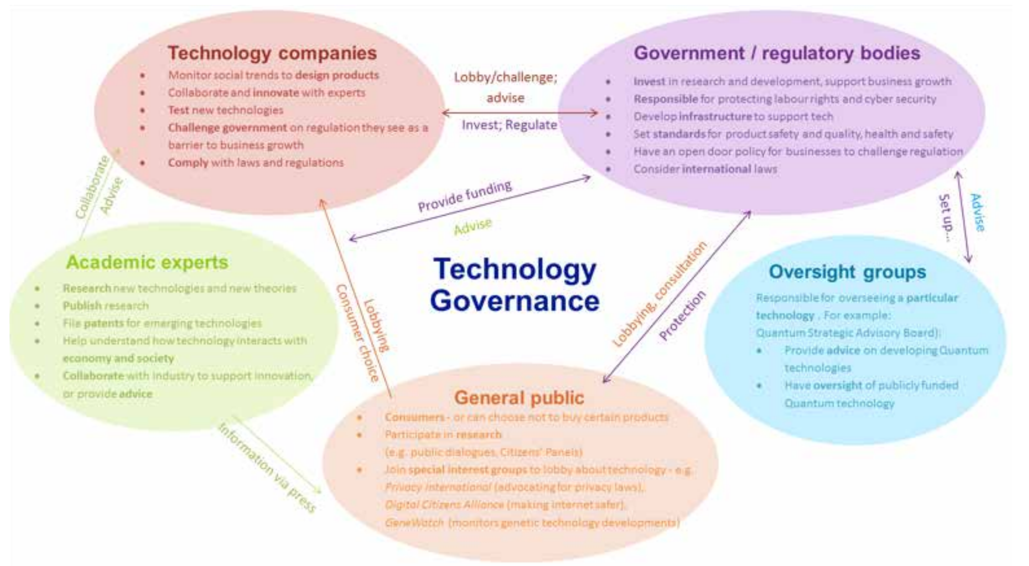
8.2.1 Decision-making around the development of QTs

There was generally agreement that good governance mechanisms around the development of QTs should be in place early – specifically in relation to funding decisions about which technologies should be developed – to ensure that decisions were not just made in the interest of large corporations for profit, but that the public interest was also considered.

> ***"I think the technology companies have probably got a bigger role than the government and that is quite concerning...because money talks and they've got the money...controlled by corporations whose ultimate goal is profit." (Wave 2, Birmingham)***

Participants were generally unaware of what the actual process of technological development typically looks like in practice– both in terms of how technologies are developed, who is involved in development, and what governance looks likes and who/which organisations would likely be involved. This was not a topic they were familiar with or had previously been exposed to.

Figure 8.1. Wave 2, Stimulus 2: Technology Governance.



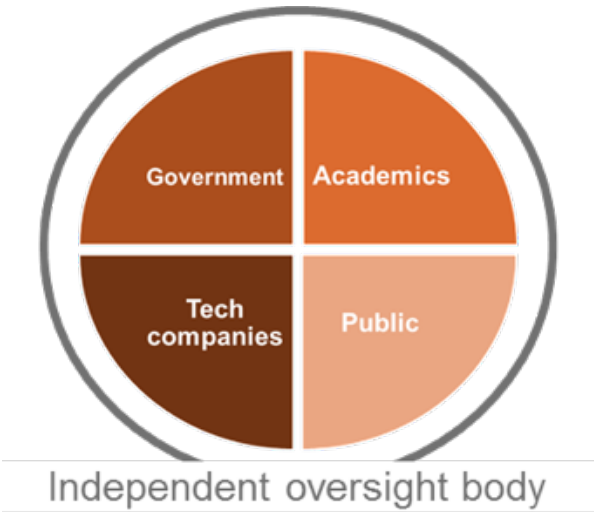
As is discussed in Chapter 2, the wave 2 stimulus materials were developed in response to widespread concern raised in wave 1 about who was in control of QT development. Discussions about control were supported with stimulus materials that aimed to depict some of the organisations involved and the relationships between them. The typical process for technology governance was clarified when participants were presented with a diagram summarising the types of organisations that are typically involved in the development of a technology and their potential roles (see Figure 8.1 above). Participants were reassured to see the range and types of organisations typically involved in the governance of new technologies. In particular, participants were relieved to see that development was not only driven by private companies, and that they worked together with academics and government. They were reassured to see that broader interests are represented by some of the organisations involved in the process.

> ***"It makes me more comfortable that they're sitting there and there's a mixture of people and they work with the government." (Wave 2, Oxford)***

Nevertheless, participants still had a range of questions around how funding decisions were made and who ultimately stood to benefit from these decisions. When asked what would reassure them about this, participants generally felt that it was important that an independent oversight body was involved. However, participants were generally confused by the role of the current oversight group as presented in the stimulus material - in terms of who was involved, how they were selected, what the oversight group actually does, what decisions it takes, and how strong a role it has. Participants in York and Oxford were concerned that an oversight board could be unelected, elitist and self-interested depending on its composition, diversity and selection methods. There was also some suspicion that this organisation (as an offshoot of government) was too 'cosy' with industry and questioned whether and how it promoted the public interest. This seemed to be due to an assumption the body would spend more time with industry than the public, and it was unclear whether there was a mechanism for accountability to ensure the public interest was considered at all.

> ***"'Oversight groups'? Don't really understand it at all." (Wave 2, Glasgow)***
>
> ***"There's a question mark really on whether the oversight group is independent and if they are independent surely they should be having conversations with the public." (Wave 2, York)***

Figure 8.2. Composition of an independent oversight body.



8.2.2 The composition of an independent oversight body

Despite the questions raised above, participants discussed the importance of having an independent oversight body to balance the power, voices, and multiple interests of key players. Ultimately participants felt that the key role of the oversight group was to make funding decisions that considered the public's interest. Participants wanted this body to have a strong voice to be able to stand up to companies and government, to ensure the public and national interest were represented. A diversity of voices representing and balancing different organisations and interests was the key characteristic of this body which would reassure the public that decisions were not being made in one party's interest. Participants in Oxford and York also felt that an oversight body should have an additional role and responsibility for communicating balanced and accurate information about quantum technologies to the public.

Participants wanted to see the government, technology companies and academics represented on the oversight body, as well as the public.

"We think the oversight group should have more teeth than they've got rather than just a paper tiger, more ability to say, even to the government, no, you can't do that." (Wave 2, York)

"Diversity, wide representation. Not just a group of 70 year old white men sat in a room going yes, that's a good idea. Got to have everyone. " (Wave 2, York)

Government

Participants across the groups felt strongly that the role of government in the oversight body was crucial to ensure the public's interest was reflected in decisions around technological development. Their role was crucial because they were seen to be able to represent the public interest and to be able to be held to account for this – especially the interest of more vulnerable members of society. Government was also perceived to be a check on decisions being taken in the interest of private profit. At the same time, however, participants felt that other organisations needed to be involved as the government was seen to have its own agenda, particularly in areas such as military and surveillance technology.

"If they are developing something that's going to be helpful to people but it's not going to be profitable, medicine for example, if those technology companies aren't investing because it's not going to be profitable at the end of the day ...potentially you're missing out on cures for illnesses because it's not profitable...that's where the government come in. Extra funding can be found if it is in the national interest." (Wave 2, Birmingham)

"What's important is that they look out for the people who don't exist yet because they're the ones who are going to be left with whatever happens." (Wave 2, York)

"At the moment we out our trust in the government and I think it would be a different body of people to oversee this." (Wave 2, Birmingham)

Technology companies

On the whole, participants recognised that technology companies played a crucial role in the development of QTs due to their expertise and manufacturing capabilities. Ultimately, they felt their interest in developing technologies for commercial purposes would ensure that products were thoroughly tried and tested and developed from the consumer's perspective (and would therefore be user friendly) and that they would be developed to meet consumer needs. There was a sense that technology companies were best placed to direct technological investment into commercially viable products - compared to government or within academia.

However, as discussed, there was a strong feeling that other organisations should be involved to ensure that decisions were not only profit driven and that not only the needs and views of 'consumers' (meaning consumers who could afford the technologies) were taken into account, but also the needs of citizens and society more widely. Participants viewed the involvement of other bodies and organisations as able to help curb this risk. Participants in Glasgow and Oxford tended to assume that ultimately technology companies would have the greatest influence over decisions because they were in control of manufacturing.

"My concern would be they're choosing what's going to make them the most money rather than what's actually going to benefit the public." (Wave 2, Oxford)

"You can't let them do whatever they feel is necessary, you've got to have some regulation and controls, it's getting that balance correct." (Wave 2, York)

Academics

Across the locations, there were high levels of trust in and respect for academics who were seen to be the most knowledgeable and least self-interested parties. There was a widespread assumption among participants that academics were actively considering the wider ethical and societal implications of their work and that this would be a standard part of the ethics process for academic research. The high levels of trust in academics in part were predicated on this assumption. Academic stakeholders engaged in this conversation suggested that this was not always the case and that ethical considerations were often limited (e.g. to whether or not people or animals were physically harmed during experimentation) and that wider societal implications are rarely considered in academic ethics processes. In light of this, participants communicated that they wanted academics and technology companies to be actively thinking about and addressing wider ethical issues associated with technologies they were working on – particularly in relation to the development of QTs which may result in job losses or misuse or which could be used to cause physical harm. However they were unclear about how this would work in practice. Some stakeholders involved in the dialogue commented that they were concerned by the high levels of trust the public placed in them and their assumptions about academic ethical processes which were seen by them to be inaccurate (particularly in York).

> ***"These are the people [academics] who know most, and we should let them get on with it." (Wave 2, Glasgow)***

> ***"Both the academic experts when they're discovering the technologies and the technology companies when they're developing it always need to have this in the back of their heads, the innovations need to work alongside the solutions to potential problems." (Wave 2, Oxford)***

> ***"They [academics] should have a duty of care to say: 'It can do this, but it can also do this'." (Wave 2, Oxford)***

Participants thought it was important technology companies and the government were also involved in funding decisions to ensure that public money was not only being spent on developing 'theory' rather than being in touch with public need. Participants acknowledged that academics needed to work closely with technology companies to make sure their work was useful. Additionally, participants recognised that academics were often required to work closely with technology companies where industry provided their funding. However some participants in Oxford questioned the transparency of financial agreements between academic institutions and technology companies and whether the public interest was considered in these arrangements.

The public voice

Generally participants wanted the public voice to be heard and considered in funding decisions. However, they found it hard to see how the public could be directly involved in this a meaningful way, given the public's low level of knowledge about QTs. Therefore they saw representation via the oversight group as the most appropriate avenue for the public voice to be represented. Some participants wanted members of the public to be involved directly with the oversight body, particularly in Oxford and to a lesser extent in York. Others in Birmingham suggested the idea of a 'panel' where the oversight board and policy makers would be held accountable to the panel, comprised of members of the public. However they acknowledged that the public would need to be educated to be able to play a meaningful role. They wanted reassurance to know and to trust that the public interest was represented and considered in this space, but acknowledged that the public needed educating about QTs more widely (see chapter 7).

> ***"We need to trust in the system. We have to trust because there is nothing the public can do." (Wave 2, Glasgow)***

"Probably I'm being a bit cynical here but the government and technology companies with the public down here. I just think the public don't have much say in what happens." (Wave 2, Oxford)

"I think it's important to have the general public…because with new technology we don't generally hear about it, what's coming out, until we hear about it on the TV or marketing. So basically we are the last to hear.' (Wave 2, Oxford)

"The public lead trends and interests in new tech, so let them be more aware." (Wave 2, Birmingham)

"We will have very little input at all and I don't know what input you can have…" (Wave 2, York)

Some participants recognised the value of lobbying groups to represent the public interest; although there was a sense that by the time they were involved, technological development and use was inevitable and their activities would be less effective (particularly in York). Some participants also questioned the extent to which lobbying groups actually represent the public interest as a whole rather than their own, niche interests.

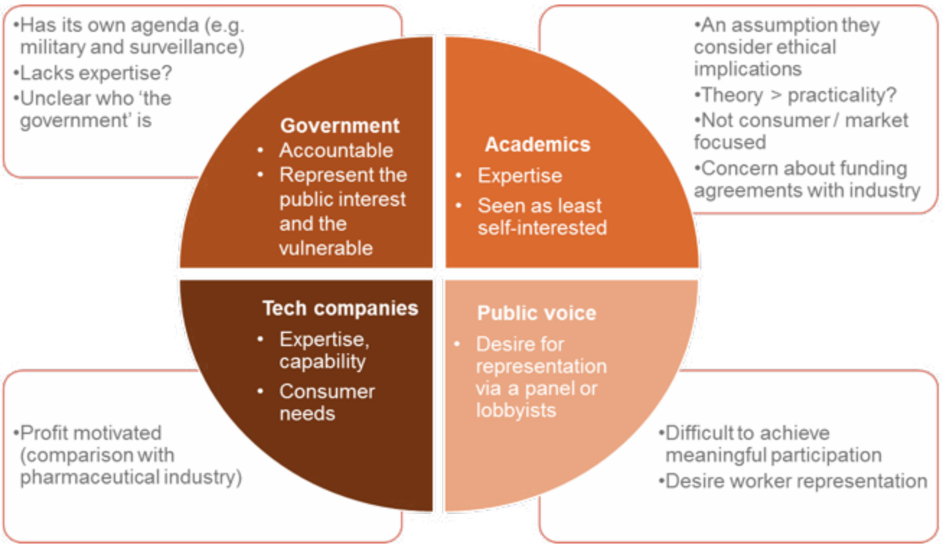
"You need their [the public's] involvement earlier on to stop those [lobby] groups being needed." (Wave 2, York)

"I think they're probably more interconnected, because that's how things work. The technology companies and academic groups must have some relationship with oversight groups…" (Wave 2, Oxford)

A key concern for participants throughout the dialogue was potential job losses following the development of technology including QTs. Various conversations revealed that participants were unsure about whether any organisation would consider this aspect of technological advancement, whether anyone is currently thinking about these implications, and whether anyone was ultimately responsible for these implications. Some participants in York discussed whether universal basic income was an appropriate solution if increasing automation led to job losses; but they were unsure about whether responsibility rested with the technology companies or government. This issue was a priority for participants, and a question remained about who will represent this interest on behalf of the public and how – and what the most appropriate settings are for discussing these issues.

Overall, participants wanted to see a balance of power between different organisations so that a range of voices were considered when funding and development decisions were made. They were satisfied in the main with the range of organisations presented in the governance stimulus; although a few questioned why certain organisation such as the military, the NHS and banks were not included in the diagram as they would probably be the end-users of many of the applications, as well as key investors and developers. Participants across the locations questioned whether and how the military should be involved, but some were sceptical about whether the public would ever be informed about technologies being developed for the military. It was suggested that trade unions should be involved in the oversight body and in decisions particularly in light of potential job losses due to increased automation. It was also suggested that the education sector and the media should be involved in the body because they were seen to have a role to play in teaching the public about QTs.

Figure 8.3. Summary of issues regarding members of the oversight board.



8.3 Governance – use of QTs

Throughout the dialogue, concern was raised about who would have access to QTs and how these could be misused and harm members of the public (through invasion of privacy and the technologies being used as weapons). There was a desire for a range of measures to be in place prior to the commercialisation of technologies to reassure the public about their use in the UK and internationally.

Across the locations, participants prioritised the role of an independent regulator to enforce standards for use and oversee regulation regarding prosecutions. It was important to participants that any such regulator represented a balance of interests; including the public's. Some communicated the need to establish a robust prosecution process and tough punishments for misuse before QTs were commercialised to pre-empt forms of misuse; particularly regarding privacy evasion (e.g. seeing through walls), criminal activity (e.g. use of encryption technology) and any potential use of the technologies as weapons (e.g. use of unmanned underwater vehicles). This would ensure that the government was not required to retrospectively prosecute people that misused technology after it came out (particularly regarding privacy invasion and hacking). It would also ensure the public's confidence and trust in the governance system. However, there was some reservation about the extent to which the government would bring in effective regulation in all areas, particularly given their potential interest in capitalising on technology for surveillance and military purposes. This would also be difficult given the range of areas QTs cover.

8.3.1 Access to QTs

Participants felt that access to particular QTs should be regulated. Some felt that access to quantum enabled encryption should be restricted for the public, with a few communicating that all public access should be restricted given they thought encryption would only be used if people had something to hide or for criminals and undesirable purposes (e.g. for terrorist use, sharing pornography, or hiding money for tax purposes). Given concerns around encryption, some wanted to see access restricted to government and financial institutions or banks; others wanted to see background checks carried out before people could use quantum enabled encryption and other technologies which were susceptible to misuse. Participants had similar views about other QTs which could be weaponised (e.g. unmanned underwater vehicles).

Some questioned whether the government had considered restricting international access to UK-developed technologies, particularly surveillance technologies which were seen as a threat to national security. Some felt that access to surveillance technology should be limited to government, emergency services and other relevant industries - as again they could not see why the general public would need access to these for non-nefarious purposes. Participants wanted to see surveillance technology use logged (with password and user IDs) to ensure there was a trail of accountability in light of potential misuse by individuals, private companies and even the police. For example, use of cameras to see through walls and potentially into peoples' homes would need to be logged via use of a log in and password, so that if misuse was detected, then the user could be traced and prosecuted later. An accountability trail was crucial for participants who believed that misuse of all technology is 'inevitable', and that rather than stop development all together, robust accountability mechanisms need to be in place.

Despite concluding that in principle regulation and a regulatory body were necessary to tackle the misuse of certain technologies, participants tended to be unsure how this would work in practice. They questioned whether it was possible to regulate QTs in a globalised world in which other countries would likely be developing their own technology and using this for their own ends. This led to discussions around the feasibility of establishing a global regulatory body. Others questioned the feasibility and efficacy of a single regulator, given the diversity of QTs, sectors implicated and the range of ways in which they could be misused. Some assumed there would already be regulatory bodies established to deal with different aspects of potential forms of misuse – e.g. a regulatory body on police misuse of surveillance technology. Additionally, some queried, in the case of military use of technologies, whether regulation was even possible given the nature of this work. However these challenges were difficult to address in more detail within the scope of this exploratory dialogue, particularly given the diverse range of technologies being considered.

8.4 Summary

Whilst a system of regulation and oversight was clearly important to participants, not least as a way of reassuring them in light of some of their concerns, they were also eager to ensure that regulation did not stifle growth or innovation in this area. The latter was particularly important to participants who tended to prioritise the need for the UK to be a leader in this field globally, both to ensure the country was safeguarded against external threats and to ensure the country maintained and built upon its global reputation. Therefore they wanted regulation to also balance this priority.

> ***"They [companies] should be monitored but there should be room for them to innovate. Not to have the pressures on them right from the start so they won't be able to make things, they don't have the freedom to explore." (Wave 2, Oxford)***

> ***"Work with the academics to make sure that regulations don't stop the technology." (Wave 2, Oxford)***

> ***"[I'm concerned about] the Government inhibiting the development of amazing advances." (Wave 2, Glasgow).***

9. Conclusions – key findings and recommendations

9.1 Key findings

9.1.1 Stakeholder perspectives

- As the first substantive piece of research on the public's views on QTs, there was a degree of uncertainty at the start of the project among the research and quantum communities about how the public would respond.
- Stakeholders expected that the public would have low knowledge of and interest in QTs and that they would have a narrow range of associations and many misconceptions of quantum and QTs.
- They assumed the public would have lacked exposure to information about QTs and that they would be put off by scientific language, previous negative experiences of science, and by not seeing QTs as relevant to them – and that they therefore would not actively seek further information. Many of these assumptions played out in the dialogue.
- Stakeholders anticipated that participants would have some associations with quantum, relating to popular culture linking quantum with space or time travel, and stereotypical associations of 'mad scientists' and Einstein. They also thought people might see quantum as something new and revolutionary – and as a 'big step forward'. Stakeholders guessed that if people had heard of any quantum technologies, it would most likely be quantum computing or cryptography.
- There was an assumption that the public would find quantum 'spooky' and 'weird' and that this might prove to be a barrier to engagement.

9.1.2 Spontaneous public perceptions

- There was wide familiarity with the word 'quantum' among the sample – however beyond this there was low knowledge about QTs and low understanding of their potential impacts and implications.
- Participants broadly held a limited set of surface-level associations and generally possessed little information beyond these (except those who had a personal or professional interest in science / technology or family members working in STEM industries). Participants commonly associated QTs with 'advanced' technology (and then often guessed sectors and applications based on this assumption); popular culture references; space travel, and computing. They also held some associations not anticipated by stakeholders, notably gadgets (e.g. phones) and household appliances and products which had used the term in their branding and marketing.
- Despite stakeholders expecting that the public would have a narrow range of associations with QTs, this was found to be more limited than they anticipated. Some of the associations stakeholders anticipated did not emerge, notably quantum being 'spooky' and 'weird'. Participants did not possess enough understanding of quantum to have reached this conclusion.
- There was generally an initial feeling of neutrality towards QTs (although a small number felt excited to be learning about something new and there was some anxiety for a small number regarding discussing a topic they lacked confidence in and saw as for 'clever people' and not them). This neutrality was driven by limited exposure to information about QTs from a narrow range of sources, which meant that participants were yet to develop an emotional response to the topic and were therefore beginning with a blank canvas.

9.1.3 The dialogue journey

- Participants' starting points depended on their level of interest in and confidence regarding science and technology.
- In the first wave, participants generally expressed surprise and excitement about the range and nature of QTs, and were particularly engaged by QTs with health and security benefits. Key concerns focused on access to QTs and who would control development decisions.

- Greater exposure to information about QTs generally saw participants become more engaged and excited by the range of potential benefits associated with the technologies – particularly once they understood how various QTs could impact upon and be relevant to their own lives.
- Individual practical applications were more engaging for participants than the theory behind QTs, as they were more able to understand the implications of the technologies and the potential relevance to their lives.
- Whilst no participants became more negative about QTs, there was a small number for whom the barriers to engagement with science were too high and their engagement remained unchanged (notably in Birmingham).
- Some differences emerged across the four research locations regarding starting points and levels of engagement - with greater overall scepticism being expressed in Birmingham and greatest optimism emerging in York and Glasgow.

9.1.4 Priorities and aspirations

- QTs were seen to have a wide range of benefits for individuals and society. The most engaging QTs were those which participants understood to have the greatest potential impact on individuals and society – notably health technologies. Participants prioritised QTs which had benefits regarding:
    - Improving health (saving or extending lives)
    - Contributing to humanitarian efforts
    - Increasing efficiencies (i.e. generating cost savings, particularly for the NHS)
    - Increasing security
    - Tackling climate change
    - Furthering knowledge
    - Providing faster internet
- Whilst participants appreciated that QTs could be beneficial, they saw the changes and the technologies as incremental and building upon technologies which already exist – and making technology better, faster, and cheaper - rather than QTs as something 'new and revolutionary'.

9.1.5 Concerns about the development and use of QTs

- Some concerns were raised throughout the dialogue about the development and use of QTs, some of which related to the development of technology in general:
    - Who controls the development of QTs – and how far decisions would be driven by company profit, potentially at the expense of the public interest;
    - Who would have access to QTs - there was an assumption that QTs would be expensive and that therefore large companies and wealthier people would have greater and earlier access to them. Participants were concerned that QTs could drive a greater gap in society between those who do and do not have access to them (particularly regarding access to health benefits) and that this gap may be more persistent and less surmountable than the current technology gap.
    - Automation and job losses – was an emotive and salient issue and job losses in driving, analytical and logistical roles were seen as an immediate and relevant risk. They wanted to see a co-ordinated response to this societal implication.
    - Environmental damage – participants questioned QTs overall contribution to climate change; whilst some QTs were seen to contribute positively (e.g. sensors helping to monitor climate change), others were seen as potentially regressive (e.g. helping to find oil) and participants wanted to see progressive QTs prioritised.

- Other concerns raised were more specific to the QTs discussed, and included:
  - Whether QTs would spark a defensive international arms race – where nations felt compelled to invest in quantum computers defensively to ensure their security. While the development of this technology was thus perceived to be inevitable - not a matter of choice - participants were keen that the UK was at the forefront of quantum computing, and so supported investment;
  - Misuse of QTs for the purposes of hacking and cyber warfare – there were wide concerns about theft of money and data and risks to personal, commercial, financial and government systems – and this was a key, salient concern. There was a desire for encryption to be prioritised in response to this, as well as greater public education about cybercrime.
  - Misuse of encryption technology to hide criminal activity – there was wide concern about use of encryption to hide illicit communications, particularly regarding terrorism, organised crime, paedophilia, and tax evasion. However QTs were seen as a new tool to hide these crimes, rather than as creating a new form of crime. Participants were generally prepared to accept a 'backdoor' to communication encryption to help tackle what they saw as 'worse' crimes.
  - Misuse of imaging technologies by criminals, companies and the state – to see through walls and clothes by criminals, voyeurs, security companies and the state was a low level concern. Whilst there was some anxiety about these issues, participants were generally accepting of surveillance technologies and saw QTs as an incremental change in this area.
- Whilst concerns were raised, overall participants were not overly concerned about the development and use of QTs and the risks associated with them. They saw the benefits associated with QTs as worthwhile and as positive progress for society and were keen to see the UK investing in and leading on QTs in the international arena, and did not want the UK to be 'left behind'.

"Society always wants to improve, progress needs to be made, whether it's in medicine or security. At the end of the day humanity is looking for a better world and quantum technologies are going to play a big part in it." (Wave 1, York)

- The following considerations also alleviated concerns:
  - The risks associated with QTs were not necessarily seen to be new but to build on already existing risks with which participants were familiar (the quantum computer was seen to be the exception to this rule as it was seen to present the greatest step change and a new type of risk to society due to the scale of the potential threat)
  - The risks were not necessarily specific to QTs – and were seen to be relevant to technological advancement more widely (notably automation and job losses)
  - Misuse of technology was seen to be inevitable
  - Some risks were seen to be less tangible, immediate and relevant – and therefore invoked lower levels of anxiety.

9.1.6 Governance of the development and use of QTs

- Outstanding concern about control in the development and use of QTs could be mitigated through the establishment of governance mechanisms to reassure participants that:
  - The public interest would be considered in the development of QTs as well as company profit (notably regarding health technologies);
  - Access to the benefits associated with QTs and societal impacts related to this would be actively considered;

- o Misuse which poses a threat to individuals and society would be deterred and punished.

- Participants wanted to see governance mechanisms in place prior to commercialisation which were strong and independent (and therefore able to hold government and public body to account if they misused these technologies)
- Restricting public access to some QTs was seen as appropriate when participants felt the risks of public access outweighed potential benefits (e.g. to encryption, surveillance technologies, and those which could be misused to physically harm individuals)
- Whilst good governance was important to participants, they did not want to see regulation stifle innovation in and advancement of this area or disadvantage the UK in the international area – as long as the public interest was actively considered and uneven access to the benefits of these technologies was addressed in light of public funding of the development of these technologies.

9.2 Recommendations

The following recommendations for the quantum community emerged from the dialogue:

- **Participants generally wanted to see the UK investing in QTs** and leading on this topic in the international context – as they saw the benefits as providing progress for individuals and society and to ensure the security of the nation if other countries were developing the technologies.
- **There is an opportunity and growing need for the quantum community to tell its own story –** participants had not yet developed an emotional response to quantum and QTs and this neutrality represents an opportunity to develop positive associations with QTs before sensationalist media coverage fills this gap. Participants recognised that they usually received information on emerging technologies from the mass media and were concerned reporting would be sensationalist. As such, there was a sense of urgency for the quantum community to seize the moment by providing accurate and balanced information. Participants were open to hearing more from scientists and researchers and believed that the quantum community would be best placed as experts and had a duty to educate and engage the public.

"Scientists have more knowledge and less spin, than...the media." (Wave 2, Glasgow)

- **Researchers should take responsible research and innovation more seriously.**
- **Excitement about the potential benefits associated with QTs could act as effective engagement hooks –** participants expressed clear aspirations about QTs which could save or extend life, improve wellbeing, increase security, or had humanitarian applications - and these could be used to encourage engagement. They were particularly excited by health related technologies and those which could result in efficiency savings for the NHS.
- **Address concerns about quantum computing and encryption as these are seen to present the greatest step change and potential threat to society and therefore induce public fear –** participants expressed the greatest levels of concern about hacking that could be made possible by the quantum computer. They wanted to see defensive investment in quantum computing (so the UK stays ahead of other countries) and quantum enabled encryption prioritised as a potential solution to this threat. However, they also wanted to see greater public education regarding cyber threats so people could better protect themselves. There is a need for clarity regarding what protection quantum enabled encryption can provide and the limitations of this approach.
- **Engage with wider debates regarding concerns associated with technological advancement –** there was a desire expressed for the quantum community to participate in wider debates about societal impacts of QTs as QTs may touch on these issues in the future:
  - o Automation - participants were concerned about the threat of automation (notably to

driving, analytical and logistical roles). They were unclear whose responsibility it was to address these issues, but wanted to see a co-ordinated response to the threat which they saw as widely relevant and imminent.

  - Privacy and surveillance – interesting findings emerged from the dialogue around privacy trade-offs and what types of crimes the public considered to be 'worse' than invasion of privacy.
  - Environmental damage – participants wanted to see QTs prioritised which they saw to be progressive by benefitting the environment rather than those which were seen as regressive and contributing to climate change and environmental damage (e.g. improving oil detection).
- **Create governance mechanisms which consider the public interest** – participants wanted to see governance mechanisms with the following features:
  - An oversight body which is comprised of multiple voices (including government, academia and tech companies) – to balance private interest, and ensure active consideration of the public interest and wider societal and ethical implications as these technologies are developed;
  - Active consideration of wider societal impacts associated with the development of QTs within academic ethics processes - this was important to maintain the high level of trust participants had in academics, who they saw to be the least self-interested players in the field (although this trust was predicated on the assumption wider societal implications were routinely considered);
  - Active consideration of threats of harm to individuals and society – to ensure adequate regulation and enforcement are in place prior to commercialisation, to deter criminals and punish those who might misuse the technology;
  - A strong and independent oversight body - so that government, public body (including police) and military misuse can be prosecuted (particularly regarding surveillance).

In addition to these recommendations, a number of lessons regarding how to communicate effectively with the public about QTs and how participants wanted to be involved with decision-making regarding QTs in the future were drawn from the dialogue – and these can found in Appendix 1 which is available on request from EPSRC.

Oversight board for this project

Chair

Professor Richard A.L. Jones FRS

Department of Physics and Astronomy, University of Sheffield

Members

Hilary Sutcliffe

Director SocietyInside

Kai Bongs

Director of the UK National Quantum Technology Hub in Sensors and Metrology, University of Birmingham

James Wilsdon

University of Sheffield

Professor Marina Jirotka

Department of Computer Science. University of Oxford

Derwen Hinds FIET

This project was carried out in compliance with our certification to ISO 9001 and ISO 20252 (International Service Standard for Market, Opinion and Social Research).