# Creatively Deliberating on Quantum

## *Art-Based Creative Forms of Public Engagement to Emotional-Moral Deliberation on the Societal Impact of Quantum Technology*

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**Abstract**

The emerging technoscience of quantum technology is expected to have a considerable impact on society. However, a broader public dialogue on its societal impact and possible ethical issues is currently lacking. This may relate to the fact that existing approaches to public engagement often focus upon reasoning and argumentation, and adopt top-down settings. This paper investigates alternative approaches. It presents two pilots on art-based public engagement with quantum technology, designed to create space for people's moral values and emotions in a bottom-up setting. It discusses a small co-creative workshop, in which citizens came up with their own future scenarios and materialised this in pieces of art. With the workshop's outcomes, an artistic video was made and evaluated by workshop participants. These results suggest that art-based engagement that stimulates emotional-moral deliberation could encourage dialogue on quantum technology and should hence be taken seriously as an additional method to societal deliberation on quantum technology.

**Keywords**

quantum technology · art-based engagement · public deliberation · emotions · ethics · responsible innovation

## 1 Introduction

The notion ‘quantum’ no longer merely refers to the theory of quantum mechanics. Quantum technology is an emerging field comprising new, ground-breaking technologies, and first applications towards quantum computing, quantum communication and quantum sensing, are already on their way (Bennett and DiVincenzo 2000; Harrow and Montanaro 2017; Kimble 2008; Ladd et al. 2010; Lloyd 1994; Wehner, Elkouss, and Hanson 2018).

These new quantum technologies are expected to have serious impact on society. Experts themselves speak of a quantum *revolution.* World-leading initiatives and national agendas emphasise its social and moral relevance: quantum development and innovation are ‘not just about the technology; social acceptancy and ethical aspects of quantum technology are important as well’ (Roberson 2021). Therefore, it is high time to openly discuss the impact and possible ethical issues related to imaginable scenarios in the societal implementation of quantum technology (Vermaas 2017).[i] Perhaps even more so because popular science media tend to present either hype or doom scenarios when it comes to quantum technology.[ii]

The pilot project discussed in this paper aims to explore new methods to contribute to such a discussion. For, despite the good intentions on the side of the experts, a broader public discussion on the societal impact and possible ethical issues concerning quantum technology is lacking. With respect to outreach, this may be because most outreach is naturally developed in a top-down setting, while a dialogue can be much more effective for public dialogue (Van der Sanden and Meijnman 2008). We need a dialogue to ‘explore and assess the impacts that quantum technologies will have on science, industry, people and society’ (Vermaas 2017, 241). Those involved in research and development of quantum technologies are almost exclusively scientific, industrial and governmental actors, whereas public engagement is obviously crucial for a societal dialogue.

Present literature recognises that Responsible Research and Innovation (RRI) offers participatory approaches which could stimulate such a dialogue. Coenen and Grunwald already perceive the emergence of a discourse on RRI in the field of quantum technology. They explicitly encourage its goal, which in their words is 'fostering innovation by more closely aligning science and technology development with other social practices and endeavours' (2017, 292).

However, achieving this goal has been challenging. In public engagement efforts quantum technologies are often portrayed as incomprehensible by their enigmatic nature, creating a barrier to the public to genuinely enter dialogue. Furthermore, existing RRI approaches often exclusively focus upon reasoning and argumentation (Fraaije et al. 2022). First, these approaches do not recognise the importance of moral values and emotions in reflection upon emerging and possibly risky technologies (Roeser and Pesch 2016). Obviously, RRI is about *responsible* innovation and aims to take values and concerns of stakeholders into account. Yet emotions are not included, as they are typically considered to conflict with rational and critical reflection. Decision theorists have developed the so-called 'Dual Process Theory' (DPT) (e.g. Kahnemann 2011). According to DPT, humans process information through two distinct systems. System 1 is taken to be based on emotion and intuition, and while it is fast, it is also unreliable. System 2 is taken to be based on rationality and analytical thinking. It is slower but more reliable than system 1. This reason-emotion dichotomy is also prevalent in ethical theory as well as in public discourse.

However, this reason-emotion dichotomy has been challenged by many emotion researchers from psychology and philosophy. So-called cognitive theories of emotions argue for the importance of emotions for practical rationality (Frijda 1986) and moral thinking (e.g. Solomon 1993; Goldie 2000; Nussbaum 2001; Roberts 2003). The neuropsychologist Antonio Damasio (1994) has studied patients who lose their capacity to feel emotions due to damage of

the amygdala, and henceforth lose their capacity to make practical and moral decisions. Hence, emotions are not opposed to rationality but can be an important source of moral insight (Roeser 2011; Furtak 2018). This does not preclude biases (Steinert and Roeser 2020) just as is the case with all sources of insight. That should not mean that we dismiss these sources of insight, rather, that we engage in critical reflection. Such reflection should involve emotions: emotions can help us to critically assess our emotions and those of others, as well as overly rational judgments that may overlook emotional-ethical concerns. In other words, we need emotional deliberation, also in the context of decision making about risky and controversial technologies (Roeser and Pesch 2016). Emotions such as sympathy, compassion, care, and feelings of responsibility can highlight ethical concerns such as justice, fairness, and autonomy; concerns that are often overlooked in quantitative, STEM-based approaches (Roeser 2018). Emotions should play an important role in approaches to responsible innovation (Roeser and Steinert 2020), however, this is not yet the case. A characteristic example of the absence of emotions in the RRI discourse is the recently published 395-page book *Assessment of Responsible Innovation. Methods and Practices* (Yaghmaei and van de Poel 2021). Though edited by RRI experts, the word 'emotion' is not even mentioned once in the book.

Second, this focus upon reasoned argumentation does not consider that artworks such as installations, movies and novels can play a constructive role in facilitating such emotional-moral deliberation (Roeser, Alfano and Nevejan 2018; Roeser and Steinert 2019). Artworks often appeal to non-discursive factors such as embodiment, materiality and affect, which people can use just as much to make sense of emerging technologies (Fraaije et al. 2022, 695). Materiality in the sense of physical interaction with matter, particularly in a creative setting, can play an important role in this context. In the words of Davies, 'reasoned argument, […] is not enough. Good deliberation should incorporate space for emotional, creative – even

disorderly – modes of communication' (Davies 2014, 97) – and we should take this actively into account when designing participatory processes to decision making about technologies.

Again, however, the words 'art' or 'artist', are not mentioned once in the aforementioned book (Yaghmaei and van de Poel 2021). Admittedly, 'creativity' does occur relatively often, but this is mainly about the creation of *knowledge* and creative *reasoning*, rather than something artistic.

The above observations indicate an important research gap and motivate our project. We co-developed, piloted and evaluated a bottom-up outreach project on quantum technology. Our goal was to investigate whether a form of public engagement in which emotional-moral deliberation and creativity play a key role could be an important addition to approaches such as RRI to encourage a public discussion on quantum technology. Our aim was threefold:

1) To develop a better understanding of citizens' perspectives on quantum technology.
2) To examine the value of emotional deliberation in a public dialogue on quantum technology, and particularly ethical and critical reflection on the topic.
3) To explore whether public engagement which has a creative and/or art-embedded format can encourage a public discussion on the possible societal impacts of quantum technology.

Our project consists of two pilots in which we conducted two related, but different forms of creative engagement with quantum technologies.

The first pilot is presented in Section 2 and discusses a creative workshop on quantum technology in which citizens came up with their own future scenarios and materialised these in collaborative pieces of art. This section describes the workshop and analyses the research data that were gathered. This analysis is directed at all three aims mentioned above.

Using the workshop's outcomes as input, a 3-minute artistic video was created in co-operation with a video artist. This is the second pilot. Section 3 discusses the video, as well as opinions of workshop participants on the video and its potential to stimulate discussion. In this pilot, the second and third aims are central. The results of this pilot underscore the importance of emotional-moral deliberation and suggest that the creative and open format of both the workshop and video may indeed stimulate ethical and critical reflection and public deliberation. Our findings indicate that such a process can help people make sense of the pre-eminently intangible implications of quantum technology and enable them to participate in a fruitful discussion on the topic.

Obviously, further empirical studies are needed to further corroborate the findings from these pilots. Hopefully our study can inspire more research into the contribution of creative and art-based engagement for a broader societal discussion on quantum technology.

## 2 Pilot 1: the creative workshop

Pilot 1 concerns the creative workshop. First, we describe the design, method, and workshop structure, and then provide an analysis of the research data. This analysis is directed at 1) the development of a citizen perspective on quantum technology based upon the 'bottom-up' information we gathered about the existent values and emotions regarding the possible societal impacts of quantum technology; 2) investigating the value of emotional deliberation in a public dialogue on quantum technology, and particularly ethical and critical reflection on the topic; 3) investigating the potential of this interactive workshop as a creative form that could encourage a public discussion on the possible societal impacts of quantum technology.

## *2.1 Method*

### *2.1.1 Design*

Our interdisciplinary team consisted of three philosophers, one of which with a physics background (Trijsje Franssen, Sabine Roeser and Pieter Vermaas ((TU Delft, The Netherlands)), two physicists (Julia Cramer and Sense Jan van der Molen (Leiden University, The Netherlands)); and one video artist (Hannie van den Bergh (Studio HB)). In our design of the workshop, each team member provided input from their own field of expertise. With respect to its structure, we were inspired by literature on value sensitive co-design (Yoo et al. 2013), research and design of creative exercises in engineering ethics education (Van Grunsven, Franssen, Gammon and Marin 2024), literature on co-creation (Jansma, Dijkstra and de Jong 2022) and co-creative workshops on nanotechnologies and health (Schuurbiers et al. 2022).[iii] Drawing on this combination of literature and experience we decided to roughly structure the workshop programme according to four of the characteristic phases of design: *Exploration, Ideation, Prototyping*, and *Reflection* (see Subsection 2.1.4 for more detail).

### *2.1.2 Data analysis*

The raw data gathered from the workshop consist of recordings of group discussions; video-recordings of creation presentations; pictures; post its; and written notes of team members. Philosopher T transcribed the audio– and video recordings and analysed the data using qualitative as well as quantitative methods. This analysis was checked with the whole team for cross-validation.

Data on emotions were categorised according to the three-dimensional 'Wheel of Emotions' created by psychologist Robert Plutchik (2001, 349). The wheel is a circumplex model in which primary emotions are conceptualised analogous to the colours on a colour wheel. Its primary emotions are *joy*, *trust*, *fear*, *surprise*, *sadness*, *disgust*, *anger* and

*anticipation*, which are all bipolar: *joy* versus *sadness*, *trust* versus *disgust*, etc. The model has a third dimension, so that the total structural model is shaped like a cone. The colours on the cone's vertical dimension represent the different intensities of the same primary emotions. An emotion's intensity increases as you move towards the wheel's centre and decreases as you move outward. *Rage*, for instance, as the most intense version of *anger*, is a dark red. *Annoyance*, as its least intense version, is a light red. Moreover, just as some colours are made by mixing primary colours, primary emotions can combine and form other emotions. *Optimism*, for instance, is a combination of *joy* and *anticipation*. *Disapproval* is a combination of *sadness* and *surprise*.

### *2.1.3 Participants*

Recruitment of participants was done in two ways: physically, through the distribution of flyers and posters at a high school in Leiden; as well as digitally, through e-mails and social media, thereby using both professional and private networks of the research team. This resulted in a group of 10 citizens of various ages (between 17-55 years old); gender (8 women and 2 men); levels of education (from secondary school to PhD); and professions (amongst which were a physiotherapist, software engineer and sociologist) (see Table 1). Eight participants were Dutch, and two had a different nationality. All participated voluntarily.[iv]

We are aware that due to the small number of participants the group cannot be considered as a solid representation of society. There might be a self-selection bias given the topic of the workshop, for almost all participants followed university or pre-university training. However, it was still a quite diverse group.

[Table 1]

### *2.1.4 Structure*

The workshop lasted approximately 4 hours and took place in the evening at Leiden University, The Netherlands. Except for one member the entire team was present. The workshop was supported by an MSc student and a PhD student in science communication of quantum technology.

As mentioned, the workshop's structure followed four of the general phases of design, i.e. *Exploration, Ideation, Prototyping*, and *Reflection*. It started with an introduction (Exploration), followed by a discussion (Ideation), creation session (Prototyping) and participant presentations (Reflection) respectively. For the participants that were interested there was a lab tour through the physics lab at the end (see Table 2 for the programme).

[Table 2]

Given that the workshop was a pilot and our approach was explorative, we used the design phases 'roughly' and did not demand – nor expect – them to remain strictly separated. While creating an artefact, the boundaries between ideation and prototyping, for instance, may easily be blurred. This is, however, not considered to be problematic. On the contrary, because our assumption is that the very embodied character of creative exercises contributes to sense making, deliberation and hence ideation, in a way that a purely discursive setting may not.

That said, the exploration phase consisted of an introductory presentation, an introduction round, and group formation. The workshop started with a short presentation by the philosopher T, who gave basic information on quantum mechanics and technology. The narrative was shaped in collaboration with the physicists J1 and S2. We consciously chose to assign this presentation to a philosopher rather than a physicist because we assumed that a presentation by a lay person in the field of quantum technology would contribute to an informal atmosphere and stimulate identification of participants with the team. Furthermore, the team

agreed beforehand that they would not dress too formally, again to prevent a formal or hierarchical atmosphere.

After the introductory presentation there was an introduction round. Participants and team members were seated in a semi-circle and all persons, including team members, shortly introduced themselves. Before the workshop, participants were asked to bring with them an object that they somehow associated with quantum technology. They also introduced this object. One of the team members wrote key words on a whiteboard, i.e. salient notions mentioned by the participants. The initial idea was that these notions would help to guide which participants would be divided over three groups on a particular quantum technology each of which was first shortly explained: quantum computing, quantum communication and quantum sensing. These quantum technologies were chosen by the research team because they are the technologies that are currently developing at the highest speed.

As said, the process of group formation was meant to be according to the themes of the participants' objects. However, we found out that these themes were often not relatable to one of the three quantum technologies. In addition, participants who knew each other and had come to visit the workshop together, preferred to be in the same group. Therefore, grouping was based rather on familiarity than common themes. We did, however, stick to focusing on one quantum technology per group.

The group discussions were the most important part of the ideation phase. Each group consisted of 3-4 participants and two team members, which were one expert (one physicist) and one moderator (a philosopher or the artist). Paper, pens, post its and cards with emojis were available.[v] The moderator explained the discussion format, after which the expert gave a short introduction to the quantum technology in question. Then, the following two questions were discussed:

a) *What will your life be like in 30 years? Do you think quantum technology will influence it, and if so, how?*

b) *What would you want your life to be like in 30 years?*

   i. *Why would this be desirable/good?*

   ii. *For whom/what?*

*Discuss several themes and choose 1 or 2 emojis and explain your choice.*

To make sure that factual expectations as well as moral values would be discussed, the questions were emphatically chosen to be a descriptive / predictive (*a*) and normative one (*b*) respectively. Further, to enable participants to discuss emotions in a playful way, when starting the discussion of a question each time they were asked to pick one or two cards with emojis that represented their 'gut feeling' or first reaction to the question and explain their choice. The available emojis included at least six of Plutchik's primary emotions (joy, fear, surprise, sadness, disgust, anger) as well as other ones frequently used in social media. A blank card was also available, to provide participants with the possibility to draw their own emoji – or whatever else they wanted to draw. The discussion lasted for about 90 minutes. The discussions of all three groups were recorded and team members made notes. After the discussions the prototyping phase started. Each group made a creation that represented a future scenario, building upon the outcomes of the discussions. This lasted about 45 minutes in total. The tinkering material consisted of A5 paper, coloured paper, coloured pens, foam forms, clay, tape, scissors, and laces. Pictures were taken of the results.

Next, one participant of each group presented their common creation. They explained its elements, the underlying questions and themes. Participants of the other groups were given the opportunity to react, ask questions and reflect upon the result.

Finally, participants were offered a tour through the physics lab where they could, amongst other things, have a look at actual experimental measurement setups. Here the group

was introduced to several research projects related to quantum physics, specifically in quantum sensing and in quantum materials. Furthermore, experimental research on the fundamental boundaries of quantum mechanics were explained to the participants at the relevant set-ups.

## *2.2 Analysis*

In the following, we present our data analysis in a holistic way, yet still mainly chronologically: the introduction round (subsection 2.2.1), and then the emotions and values (2.2.2 and 2.2.3 respectively) that came up during the group discussions, which we also relate to the final presentations. We present the most significant outcomes, zoom in on specific examples in more detail to illustrate their relevance, and at the end of this section zoom out again to discuss the findings in the light of our research aims (2.3).

### *2.2.1 Introduction round*

During the introduction round, all persons shortly introduced themselves, presented their object/theme and explained their association with quantum technology. Five out of ten participants brought an object, the others presented a theme. Table 3 shows the full list of objects/themes and the participants' explanations.

[Table 3]

Two general observations worth mentioning are the following: first, more objects and themes represented aspects of quantum *theory* (6) than technology (4); second, all had a clear association with emotion.

Three specific examples we would like to discuss are a) the stairs as pictured in artwork such as *Relativity* by the Dutch graphic artist M. C. Escher ('Escher's stairs', from now on); b) the slinky; and c) the raincoat. We identify the related emotions as *amazement* (Escher and slinky) and *fear* (raincoat) respectively.

Escher's stairs were said to symbolise the incomprehensibility of quantum mechanics. This particularly concerns the transportation of particles: as difficult as it is to follow a path along Escher's stairs it is to grasp quantum teleportation. Both evoke amazement as well as certain sense of uncanniness due to not being graspable.

The participant who brought the slinky explained that it represented a particle and a wave simultaneously and the participant related this to the double-slit experiment. Moreover, just like a quantum particle the slinky would keep on moving unless you touched it, analogous to measuring quantum spin. This respondent also expressed amazement about the nature of the quantum particle and its infinite movement. This time, however, without the former participant's uncanny feeling, maybe because in this case the object was as a child's toy.

The raincoat association is less obvious. The participant mentioned that it contained water-resistant material, and therefore it needed to be cleaned with a specific kind of laundry soap. She said she would always wash her hands several times afterwards, because she felt a certain disgust toward the material and even found it frightening somehow. Apparently, what links the raincoat to quantum physics is an emotional rather than a purely rational or scientific association.

### *2.2.2 Emotions*

To identify emotions our researchers read the audio transcriptions searching for explicitly mentioned emotions, as well as implicit ones. The latter were identified based upon interpretations of words or expressions that referred to an emotional state. To ensure the analysis to be as objective as possible, several team members read and interpreted the texts individually, to finally agree upon the outcome presented. As said, the data were categorised according to Plutchik's three-dimensional 'Wheel of Emotions' (see section 2.1).

[Table 4]

[Chart 1]

The outcome of our analysis is shown in Table 4 and Chart 1. Table 4 shows how often emotions occurred during the group discussions separately. As the sum of occurrences in numbers were not equal for each individual group, percentages were calculated per group as well as overall. Chart 1 presents the results of the group percentages. Given the small sample outcomes need to be interpreted with caution. Nevertheless, as a pilot they shed light on some interesting features that could be further explored in a larger study.

The emotion occurring most often during the group discussions is *anticipation* (32%), followed by *fear* (25%). The in-between category of *optimism* (*anticipation and joy*) is third on average (12%). The emotions that follow optimism, from *joy* (6%) to *disgust* (2%), all have a significantly lower frequency than the first three.

The fact that anticipation has the highest frequency, is not hard to explain since the discussion focused upon the future: participants were asked to imagine and reflect upon future possibilities, opportunities and threats. Words such as 'possible', 'perhaps', 'could' and 'will' were most frequent. Although at first, anticipation may appear to be a relatively neutral emotion, without exception anticipation was accompanied by another emotion. In line with the negative or positive character of the anticipated development, these emotions were often fear and optimism respectively, and, they were second and third in frequency. A typical example of such a combination is this quote from the Quantum Internet group (Q1), which has the highest score (27%) on *fear*:

> *'I am really **afraid** that this kind of technologies **will be** used to control people. It is by means of internet that persons like Putin or Xi are watching us even more.'*
>
> -------Quantum Internet group

Here, fear [*afraid*] and anticipation [*will be*] come together.

The Quantum Computing (QC) group expressed a combination of *anticipation* and *optimism*:

> *'I think one **could** be doing research much more **easily**, into, for instance, health care. That one could code DNA-cells oneself, for example.'*
>
> -------Quantum Computing group

The Quantum Sensing (QS) group has the highest score on *anticipation* (43%). The quote below expresses a feeling of *disapproval* of endlessly developing measurement techniques:

> *'The way I **feel** about sensing, making things more and more precise, **maybe** it becomes an obsession knowing everything in detail, and we're losing the picture of why we are doing it in the first place.'*
>
> --------Quantum Sensing group

A few results of the individual groups are particularly worth noting.

To start with the QI group, this was the only group that expressed *boredom*, which, according to Plutchik, is the least intense version of *disgust*. The participants are informed that experts speak of a 'quantum revolution'. One participant reacts as follows:

> *'...revolutionary – that is said so often. Then I wonder: will it really have that much impact? […] In my study, communication and multimedia design, there is one hype after another. Five*

*years ago the world was also supposed to change completely, whereas nothing much has changed actually.'*

-------Quantum Internet group

This reaction is particularly interesting because it concerns hype in technology. In this group, as well as in the QS group, the discussion and artwork do not represent a clear hype or doom scenario. In fact, the QI artwork presents a 50-50 divide of positive and negative emotions (see Image 1): both morally good people (the angels) and people with bad intentions (wearing balaclavas) will be able to use quantum to communicate safely. Purposes can be both good and evil, and hence the outcomes as well. Positive anticipation and anxiety are, accordingly, in a very precise balance. Safety and danger, good and bad, are literally two sides of the same coin.

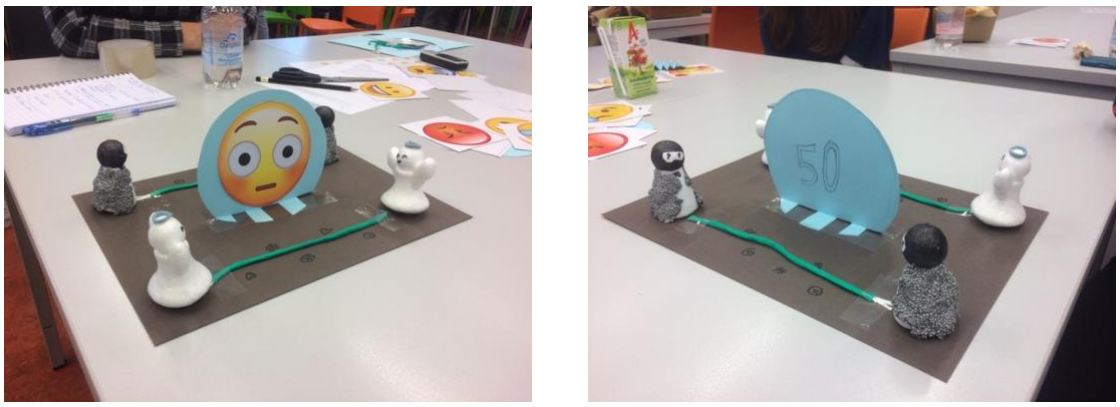



Image 1. Artwork Quantum Internet group. Angels are communicating safely through quantum internet. On the other side of the same coin, so do criminals.[vi]

If the QI and QS scenario (see below) are representative for a larger public, there might be less hype and doom thinking about quantum technology amongst citizens than is suggested by the media. However, although the QC group was the most enthousiastic at first, they *did* end up

with an extreme doom scenario. In their story (depicted on Image 2), Bob, representing the average human being, has a brain implant – developed and owned by Elon Musk using quantum computers. Like many others, Bob voluntarily chose the implant, because it made humans smarter in a variety of ways. This obviously reflects a certain optimism with respect to quantum possibilities. Yet again by means of quantum computing, Musk found out there are aliens on their way to attack the earth. 'And then, Musk decided to mobilise everyone with a brain chip for his personal army to protect the earth.' In other words, in this scenario people's brains were taken over by Musk and thereby forced to defend the earth. As the image shows, the aliens are about to drop a nuclear bomb, so the story is not likely to have a happy ending.

Image 2. Artwork Quantum Computing group. Human Bob lives on a green and peaceful earth and has a brain implant that makes him smarter. Yet when aliens start to invade the earth – we see one of them and the mothership, which is about to drop a nuclear bomb – Bob is forced to defend the earth.

Image 3. Artwork Quantum Sensing group. A human on an isolated island in a metaphorical sea of data. The dots on its body are the many sources of information from which big data are gathered and lead through cables to unknown locations. She asks: 'So what?' The two other figures represent quantum entanglement.

Particularly interesting is the process of development of the QC group's scenario. As said, this group has the highest score on optimism, and apart from *fear* none of the other negative emotions – *sadness*, *anger*, *disgust* – occur even once during the discussion. On the contrary, the participants are fascinated by the potentialities of quantum technology, particularly for purposes of scientific research, health care and the environment. However, as soon as they start with the hands-on tinkering exercise, their focus shifts to the dangerous side of quantum technology and emotions of fear and even terror become dominant. Though other factors may not be excluded, it seems that the creative exercise somehow caused a change of direction as to which emotions prevailed. The question as to how and why exactly remains to be answered. In any case, after discussing the values in the next section, we come back to the role of creativity in fostering a dialogue on quantum technology.

The QS group did not only have the highest score on *anticipation* of all three, but also on *disapproval* and *pensiveness*?.[vii] Related to this may be that they score lowest on fear. Rather than *fearing* the potential impact of quantum technology, they *disapprove* of some of the possible consequences. Rather than feeling anxiety, they are *questioning* its usefulness and feel an urge to critically reflect upon its possible impact. The quote above from the Quantum Sensing group is an example of disapproval: the measuring potential of quantum sensing could lead to obsession. A typical example of pensiveness is summarized in one element of their piece of art: the figure representing the future human is being measured and says: 'So what?' (see Image 3). During their presentation, one of the participants explains:

> *'So much is possible, you can see so much can be measured. But the question is: So what? What do [all the data] actually bring? Do you really want to know everything? Did the actual goal play a central role during the development [of the technology]?'*
>
> --------Quantum Sensing group

By asking these critical questions the participants express a need to carefully reflect upon the purpose and possible impact of quantum technology. Interestingly, explicitly mentioning the process of development, this perfectly aligns with the purpose of our workshop and our research as such. Their *pensive* attitude confirms there is a need for an approach to innovation that takes values such as responsibility, critical reflection and citizen participation seriously. Which brings us to the next section, which is on values.

### *2.2.3 Values*

Table 5 and Chart 2 show a list of values and their frequency during the group discussions. The list emerged from the discussions and, with a few exceptions, consists of *moral* values. A

separate category was created for ‘good’ and ‘bad’, when participants referred to something that was not related to a particular value, but inherently good or bad in a moral sense. After having a closer look at these figures, we elaborate upon the relation between emotions and values and present its worth as a method for our analysis.

[Table 5]

[Chart 2]

Unsurprisingly, the workshop’s theme being inherently related to scientific knowledge, *Knowledge* appeared most frequently on average (18%). The next three values that appeared most frequently are moral values: *Sustainability* (14%), *Health* (13%) and *Safety* (9%) respectively. All three groups expressed a strong hope for quantum technology to somehow bring possibilities to contribute to *sustainability* or fight climate change. The QS group, for instance, had a specific idea about using quantum sensing for wind energy. The technology could make more precise measurements and provide more data. This could be used for weather predictions, which in turn could contribute to sustainable energy.

With respect to *health* there was a general positive feeling, especially towards potential improvements in health care.

> *‘I think that so much is possible. Personalised medication [would be] wonderful, because at this point all research is based upon white men.’*
>
> -----Quantum Internet group

*Safety* was a topic of conversation in different ways. Since one of the main goals of quantum internet is safe communication, the theme of safety within the QI group was mentioned in a communication context, almost without exception. On the other hand, when discussed in the

QC group, it concerned (physical) safety of humans in the context of possible conflicts and war. The QS group did not mention safety very often (3%).

With only 1% difference, the next most important value is *privacy* (8%). This is particularly worth mentioning because it is the only value – again a *moral* value – that ended up in all three artworks. Safe communication through quantum internet (QI group) would improve privacy. Yet if the immense amounts of personal data that could be collected about each individual would be accessible to, e.g. an insurance company (as in case of the QS group's scenario), this could seriously harm your privacy. Or worse, if your brain activity could directly be accessed by commercial companies through a micro-chip (QC scenario), would any privacy be left at all?

### *2.3 Discussion*

In the following we reflect on observations from pilot 1 in the light of our research aims presented in the Introduction and Section 1.

We found that our study and analysis of the emotions facilitated an interpretation and analysis of values that were often not explicated during the discussions. A good example is *fear*. As we saw, fear is the second most frequent emotion, yet it is likely that a traditional Responsible Innovation approach would not have considered this to be relevant in a discussion that is supposed to be a critical reflection upon an emerging technology. The quote by the Quantum Internet group about Putin and Xi watching us (see Subsection 2.2.2) could have easily been dismissed as an uninformed, emotional-hence-irrational statement. No value is mentioned explicitly, but paying thoughtful attention to the fact that fear plays a central role enables us to identify significant underlying values. In this case, fear of control and being watched reveals key moral values such as autonomy, privacy and safety.

Similarly, brain chips that would make you smarter are not very likely to be taken seriously in a discussion on quantum technology – let alone aliens. The QC group's scenario however, as extreme as it may be, does imply some core values that are at stake when it comes to an emerging technology such as quantum. The brain chip, for instance, is simultaneously felt to be desirable and frightening. It is desirable as it would enhance a person's cognitive capacities: thinking, learning, calculating, etc. It points at relevant values such as autonomy, independence, and knowledge. However, when Elon Musk takes control of the brain chip, it becomes frightening: privacy, safety and autonomy of the human (represented by Bob)– are in danger. In fact, the human *as such* is in danger – and not just physically:

— *'What is the impact on Bob, mentally. Is Bob still alive? Is he still Bob?*
— *That is a good question. Do you remain yourself if it's still your body, or your thoughts? Because Bob's thoughts are being changed by the micro-chips'.*

--------*Quantum Computing group*

In other words, our personal identity, our very *nature* is put at risk. Despite the bizarre futuristic context, fundamental questions are asked about the impact of technology on human nature, the mind-body relationship and personal identity.

We believe that the above two examples suggest that taking emotions seriously is valuable since it brings to light important underlying values as well as fundamental questions about the possible societal impact of technological developments. Dismissing the quoted statements as emotional *and therefore irrelevant* could have led to missing out on these values and questions. This is in line with our theoretical framework, which emphasizes the important contribution of emotional-moral deliberation to a public dialogue on technologies such as quantum technology (Roeser 2006). This pilot has thereby helped shed light on the first two of

our research aims: understanding of citizen perspectives and examining emotional-moral deliberation.

Regarding our third research aim we do not have explicit data. However, we made observations that raise relevant questions if we wish to learn more about the question whether the creative format of the workshop has encouraged the participants' discussion and ethical and critical reflection.

A first theme that we observed is the embodied character of the hands-on exercises. The participants from the QC group created an alien mothership, which they attached to the ceiling with a string. The work thereby expanded about 100 centimetres vertically. The participants were standing and moving while they created and presented their work. A question to investigate would be how embodiment and interaction contributed to emotional-moral deliberation upon quantum technology.

A second theme is the hands-on material we supplied. We consciously chose relatively simple tinkering material such as paper, pens and foam puppets. In what way did this specific material contribute to emotional-moral deliberation upon the topic? Would other tinkering material have stimulated the discussion more, less or in a different way? For instance, each group work included a foam figure representing a human being. These figures seemed to help participants to identify with future humans and to come up with concrete scenarios. However, the foam figures probably encouraged a human-centered perspective, and perhaps left less space to discuss other morally relevant subjects, such as e.g. animal wellbeing.

Related to the above two themes is a third theme of informality and comfort. We aimed for an informal atmosphere, assuming this would stimulate creativity and discussion. Given the regular sounds of laughter participants seemed to be at ease. Especially the QC group whose work presented 'Bob's' situation were clearly having fun. Would a 'merely' rational discussion have provided an equal sense of playfulness and comfort?

We believe that further investigation into the above questions could provide important information on the subject of aim 3, i.e. art-embedded public engagement and discussion on quantum technology (p.5). Perhaps in a follow-up research project one could add a participant survey after the workshop to ask questions on these aspects of the creative format.
In the next section we dive deeper into aim 3, where we discuss pilot 2.

## 3 Pilot 2: the artistic video

In the second phase of our research we translated the information we gathered during the workshop into an artistic video, and subsequently we tested the video's potential to stimulate discussion on quantum technology. This test consisted of a survey in which workshop participants were asked to judge the video and its possibilities to encourage a public discussion on quantum technology.

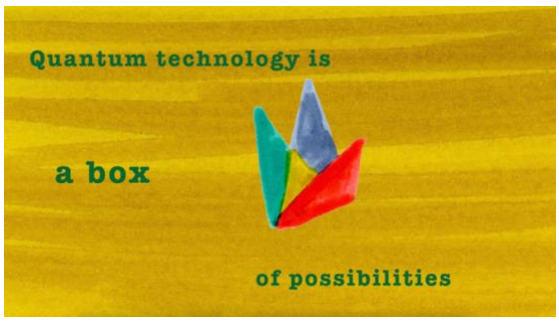
### *3.1 Creation of the video*

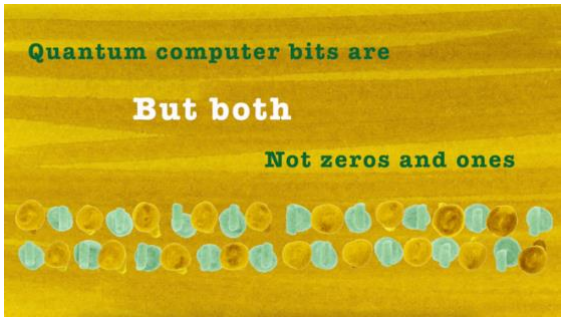
Inspired by the concept of co-creation, our aim was to make the video together with the participants of the workshop. It was not co-created in the sense that the participants directly created the video's images as such. Yet indirectly, they did: the input for the video concept consisted exclusively of material from participants, i.e. the audio transcriptions, video recordings of their presentations, the objects they brought and the works of art they made. We consciously chose to use only bottom-up gathered data for the video, to test whether an artistic video, inspired by citizens' ideas and feelings, may for this reason be useful to engage people, particularly as alternative to standard informative videos in which quantum theory and technology are explained by experts in a top-down format and appeal primarily to rational argumentation.

The artist of our team (H1) and philosopher T collaborated to develop the concept of the video. Its two main aims were formulated as follows:

a. *to visualise the variety of values, emotions, thoughts, perspectives and images of citizens regarding (the future of) quantum technology;*
b. *to stimulate reflection, especially moral-emotional reflection, on (future scenarios of) quantum technology, by providing those watching with a rich palette of thoughts/possibilities to independently take a view upon the topic.*

Together with an illustrator and musician, H1 created a 3-minute animation entitled *Quantum Impressions*. This resulted in a colourful video which shows a variety of figures and shapes in continuous movement, accompanied by electronic sounds. Philosopher T added a few lines of animated text in order to provide some context and make a more explicit connection with elements from the workshop's output. The lines of text are not intended to be explanatory or informative, but expressive and poetic, in order to appeal to feelings and imagination. Images 4-5 show screenshots of the video's opening lines.[viii]




Images 4-5. Screenshots from artistic video *Quantum Impressions* (https://vimeo.com/790054806)

It starts with a triangular, metaphoric box of possibilities, which comes back several times in different shapes and sizes. Then dots change into stripes and into dots again which symbolises the superposition state of quantum bits. Next, we see blue waves, inspired by the sea of data from the Quantum Sensing group's artwork, while the text poses questions about morally relevant topics discussed during the workshop, such as health, climate and privacy. A dark circle symbolises the Quantum Computing groups theme of the earth and the universe. Then hands with large nails appear, with the text *Who will be in control?*; a hole turning into a large eye, with the text *Who is watching you and me?*, referring to a Big Brother-like watching creature that the Quantum Internet group spoke of. The video ends with a somewhat chaotic assemblage of rapidly spinning colourful figures and shapes, and a last few lines of animated text (Image 6).


Image 6. Screenshot from artistic video *Quantum Impressions*

### *3.2 Online survey and discussion*

In order to explore the above-mentioned research aims, in an online survey[ix] the workshop participants were asked to judge the video. Half of them, i.e. five persons, responded. Despite the small scale, their answers are informative.

Overall, the respondents' reactions were diverse. Some clearly enjoyed watching the video more than others. All of them picked at least two emotions from a list of emotions we meant to visualise in the video, such as joy, fear and interest. Remarkably 'fear', one of the main emotions from the group discussion analysis, was not ticked. Yet respondents independently added the characterisations of 'unique', 'strange' and 'mysterious', which do carry a sense of discomfort, that might best be characterised as 'uncanniness'. This could be an effect of the video, which may have emphasised an emotion of such kind.

Moral values were recognised as well, amongst which sustainability, privacy and safety. Further, we included symbolic images referring to topics of discussion, such as of zeros and ones, entanglement and global communication. These aspects were also noted and appreciated, for when asked what they liked best about the video several respondents referred to their recognition of these elements. This suggests that the video was effective in light of our aim a) *to visualise the variety of values, emotions, thoughts, perspectives and images of citizens regarding (the future of) quantum technology*.

When it comes to our aim (b) '*to stimulate reflection […]*', the results are less straightforward. One of the respondents did state that what they liked best about the video was 'it makes you think'. Overall, however, there was a significant difference between the respondents' answers to the video's possible influence on their *personal* discussion on the one hand, and their idea of its potential to encourage a broader, *societal* discussion on the other hand. To our question '*If you would have seen the video during the workshop, do you think it would have influenced the discussion within your group?'* three respondents answered 'yes', one of them 'I don't know', and one of them 'no'.

- *Yes, on its content, because it would have opened the discussion more easily;*

*- Yes, on its form, we would have entered [the discussion] more creatively and would have tried to answer more questions;*

*- No, because the video did not provide much content. It was rather just fun to look at.*

The results were very divergent regarding the question to what extent they agreed with the following statement: *'This video could help people to openly discuss the topic of quantum technology in society with one another.'* Each of the five optional answers with a degree from 'totally agree' to 'totally disagree' was given once. It is not entirely clear why, as the answers did not include a motivation. Yet several reasons as to why the video would not have a discussion encouraging effect can be found in comments to other questions. Answers as to what they liked least about the video were 'vagueness', 'a lot of repetition', 'questions are being asked, but I don't get answers'. One respondent commented 'I think the video is too abstract and uninformative, text could help'. We emphatically chose not to create an informative video, but some of our respondents missed this aspect. Apparently, the video was expected to 'inform' to stimulate a societal discussion. An interesting question would be in what way the video format influenced participants' expectations. One can imagine that expectations of an enigmatic painting would have been different. Further, the participants' feedback invokes interesting questions on a broader level. What does it tell us about what art as such is 'meant' to do in scientific settings? Stimulate critical reflection, or inform? Given that our intention was the former, maybe more context should be given to participants to make that more explicit.

Another remarkable difference is that between the potential impact of the video on their *discussion* during the workshop, and their *creation*. The participants' answers to the latter are opposite to the former question. To '*If you would have seen the video during the workshop, do you think it would have influenced the piece of art you made with your group?*' the majority

answered negatively. Only one participant answered ‘yes’; one ‘I don’t know’, and the three others ‘no’:

> *- Yes, on its content, perhaps we would have gone in a more philosophical direction, something that matched with the video’s vibe;*
> *- No, because the piece of art did not have much to do with this video I think;*
> *- No, because the discussion already gave us plenty of material to tinker;*
> *- No, because here we were already thinking in a creative way.*

The first ‘no’ is interesting as the video was building on material from the workshop. Furthermore, the motivations of the last two answers are interesting in the light of our project. As it turns out, the video was not ‘needed’ to foster creativity, because the workshop itself had already stimulated creativity as such. This does, however, support our research hypothesis on the value of creative formatting of public engagement. The video was not seen as adding to that, but that could be overcome by providing more context on the possible role of the video.

## 4 Conclusion

Currently, a broader public dialogue on the possible societal impacts of quantum technology is missing. This may relate to the fact that existing approaches such as RRI to public engagement often focus upon reasoning and argumentation, and that outreach is usually developed in a top-down setting. Therefore, in the two pilots discussed in this paper, we investigated whether other, *creative* forms of public engagement, could be a valid addition to RRI approaches to encourage a public discussion on the societal impacts of quantum technology.

We think that the two pilots are promising. First, the workshop, specifically designed to create space for people’s (moral) values and emotions and developed in a bottom-up setting,

resulted in vivid discussions on possible societal impacts of quantum technology. Several survey respondents explicitly mentioned that the discussion as such had already encouraged creative thinking before they started with the hands-on exercise, which not only confirms the usefulness of emotional-moral deliberation, but also its stimulative effect on creativity. Reversely, the encouraging potential of the workshop's creative format calls for further investigation. Themes such as embodiment, tinkering material and atmosphere raise interesting questions about art-embedded public engagement.

The translation of the moral-emotional, imaginative output of the citizen workshop into our artistic video also provided for interesting insights. The survey was too small and its results too diffuse to draw conclusions as to whether it would stimulate reflection on quantum technology. The survey's results do suggest it could have encouraged the group discussions during the workshop, but not a broad, societal one. Criticism was mainly directed at the video's 'vagueness' and lack of information. Of course, keeping in mind the small-scale nature of our research, and the uniqueness of this one video, we cannot draw strong conclusions. However, the feedback can still be useful input when considering the development of an artistic video to stimulate a societal discussion. As several respondents indicated, they would have appreciated it to include basic information on quantum technology. This also invokes interesting questions on a broader level. If the participants expected the video to 'inform' rather than encourage discussion, maybe this is due to the scientific setting, in which people are used to expect videos to be informative? That could mean that more context needs to be given in order to make clearer that the video was meant as an artistic work that was primarily meant to stimulate discussion and critical ethical reflection.

Finally, the aim of this paper was not to draw hard empirical conclusions, but rather to explore a novel theoretical framework and a concrete research method to conduct public deliberation through co-creation and art-based emotional deliberation. Our findings are meant

to inspire other researchers to further explore this artistic form of public engagement (and possibly others, as numerous setups can be considered) to encourage a public discussion on new technologies such as quantum technology. Further research could be conducted on a larger scale and compare this approach to other approaches. If the results would be encouraging, this would support including artistic approaches in public deliberation to contribute to responsible innovation of technologies.


## Acknowledgements

We would like to thank Hannie van den Bergh, Aletta Meinsma, Jasper Peer and the workshop participants for their valuable contributions and support.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## Tables

Table 1. Participants of the workshop; all members of the research team were present except for P[x]

| | **Estim. Age Range** | **Gender M/F/X** | **Education / Profession** |
|---|---|---|---|
| **Members Research Team** | | | |
| H1 | 30+ | F | Artist |
| J1 | 30+ | F | Assistant Professor Quantum and Society |
| P | 30+ | M | Associate Professor Philosophy of Technology; Dr. Quantum Physics |
| S1 | 30+ | F | Full Professor Philosophy of Technology |
| S2 | 30+ | M | Full Professor Condensed Matter Physics |
| T | 30+ | F | Lecturer/Researcher Philosophy of Technology |
| **Team Support** | | | |
| A1 | 18-30 | F | PhD-student Quantum Physics |
| J2 | 18-30 | M | Student-assistant Quantum Physics |
| **Citizens** | | | |
| A2 | 18-30 | F | 4th year college student Media Communication |
| C | 18-30 | F | One to last year of pre-university education |
| G | 30+ | M | Teacher Mechatronics and ICT vocational college Leiden |
| H2 | 18-30 | F | PhD-student Wageningen Wind Energy |
| I1 | 30+ | F | Holds an MA in Sociology of Education |
| I2 | 18-30 | F | PhD-student Wageningen Wind Energy |
| L | 30+ | F | Holds an MA in Innovation in Medical Care |
| M1 | 18-30 | F | One to last year of pre-university education |
| M2 | 18-30 | M | One to last year of pre-university education |
| M3 | 18-30 | F | Physiotherapist |

Table 2. Workshop programme

| |
|---|
| 17.00 – 17.20 Introductory presentation (Exploration) |
| 17.20 – 17.40 Plenary introduction round (Exploration) |
| 17.40 – 17.50 Explanation 3 different quantum technologies |
| 17.50 – 18.00 Break |
| 18.00 – 19.00 Group discussions (Ideation) |
| 19.00 – 19.30 Break and Dinner |
| 19.30 – 20.00 Creation (Prototyping) |
| 20.00 – 20.30 Presentation participants of results (Reflection) |
| 20.30 – 21.00 Labtour |

Table 3. Objects or themes chosen by the participants

| Participant | Object/theme | Explanation/association |
|---|---|---|
| A2 | Smartphone | Contains a lot of information – will we have a quantum phone in the future? |
| C | Double-slit experiment | Fascinated by double-slit experiment. |
| G | Transistor | Electrons, nuclear model. |
| H2 | Role of scientist in the future | Recently TU Delft physicist Sophie Hermans made it to the '30 under 30' list of *Forbes* magazine because of a successful experiment on teleportation of information through a quantum network. This demonstrates the importance of quantum technology and the (quantum) scientist in the future.[xi] |
| I1 | Raincoat | Contains water-resistant material which needs to be cleaned with a specific kind of laundry soap, which evokes a certain disgust or fear. Both quantum and raincoat concern material that follows scientific laws on a microscopic level, yet both are also somehow intangible and therefore frightening. |
| I2 | Black holes and movie Matrix | Black holes are ungraspable. Movie *The Matrix*, which depicts a parallel reality consisting of numbers. |
| L | M. C. Escher's stairs | The stairs in work by the artist M. C. Escher (e.g. *Relativity*), playing with gravity and perspective, represent transport of particles in ungraspable ways – quantum teleportation is incomprehensible. |
| M1 | Slinky (helical spring toy) | Simultaneously a particle and a wave. Continuous movement unless you 'measure'. Reference to double-slit experiment. |
| M2 | Large, closed black backpack | Schrödingers cat: the backpack contains a cat simultaneously dead and alive. |
| M3 | Telescope | Webb telescope represents the many possibilities of technology |

Table 4. Number of times emotions occurred per discussion group and overall. Those marked yellow became central in the group's artwork

| Emotion | Q Internet Group | Percentage QI Group | Q Sensing Group | Percentage QS Group | Q Computing Group | Percentage QC Group | Total | Percentage Total |
|---|---|---|---|---|---|---|---|---|
| **Anticipation** | 19 | 30% | 19 | 43% | 14 | 26% | 52 | 32% |
| **Fear** | 17 | 27% | 8 | 18% | 16 | 30% | 41 | 25% |
| **Optimism** | 4 | 6% | 3 | 7% | 13 | 25% | 20 | 12% |
| **Joy** | 7 | 11% | 0 | 0% | 3 | 6% | 10 | 6% |
| **Surprise** | 3 | 5% | 1 | 2% | 6 | 11% | 10 | 6% |
| **Sadness** | 2 | 3% | 7 | 16% | 0 | 0% | 9 | 6% |
| **Trust** | 4 | 6% | 1 | 2% | 1 | 2% | 6 | 4% |
| **Disapproval** | 1 | 2% | 5 | 11% | 0 | 0% | 6 | 4% |
| **Anger** | 4 | 6% | 0 | 0 | 0 | 0% | 4 | 2% |
| **Disgust** | 3 | 5% | 0 | 0% | 0 | 0% | 3 | 2% |

Table 5. Number of times values occurred per discussion group. Those marked yellow are the values that became central in the group's artwork

| | Q Internet Group | QI percentage | Q Sensing Group | QS percentage | Q Computing Group | QC percentage | Total | Total percentage |
|---|---|---|---|---|---|---|---|---|
| **Knowledge** | 11 | 13% | 19 | 27% | 10 | 17% | 40 | 18% |
| **Sustainability** | 11 | 13% | 11 | 15% | 8 | 13% | 30 | 14% |
| **Health** | 7 | 8% | 10 | 14% | 11 | 18% | 28 | 13% |
| **Safety** | 7 | 8% | 2 | 3% | 10 | 17% | 19 | 9% |
| **Privacy** | 7 | 8% | 7 | 10% | 3 | 5% | 17 | 8% |
| **Naturalness** | 13 | 15% | 0 | 0% | 3 | 5% | 16 | 7% |
| **Autonomy** | 5 | 6% | 2 | 3% | 2 | 3% | 9 | 4% |
| **Justice** | 3 | 3% | 1 | 1% | 1 | 2% | 5 | 2% |
| **Efficiency** | 0 | 0% | 5 | 7% | 0 | 0% | 5 | 2% |
| **Participation** | 0 | 0% | 4 | 6% | 0 | 0% | 4 | 2% |
| **Entertainment** | 1 | 1% | 0 | 0% | 2 | 3% | 3 | 1% |
| **Responsibility** | 0 | 0% | 2 | 3% | 0 | 0% | 2 | 1% |
| **Affordability** | 0 | 0% | 0 | 0% | 1 | 2% | 1 | 0% |
| **Social Contact** | 1 | 1% | 0 | 0% | 0 | 0% | 1 | 0% |
| | | | | | | | | |
| **Good** | 8 | 9% | 6 | 8% | 3 | 5% | 17 | 8% |
| **Bad** | 14 | 16% | 2 | 3% | 6 | 10% | 22 | 10% |

## Charts

Chart 1. Number of times emotions occurred in percentages

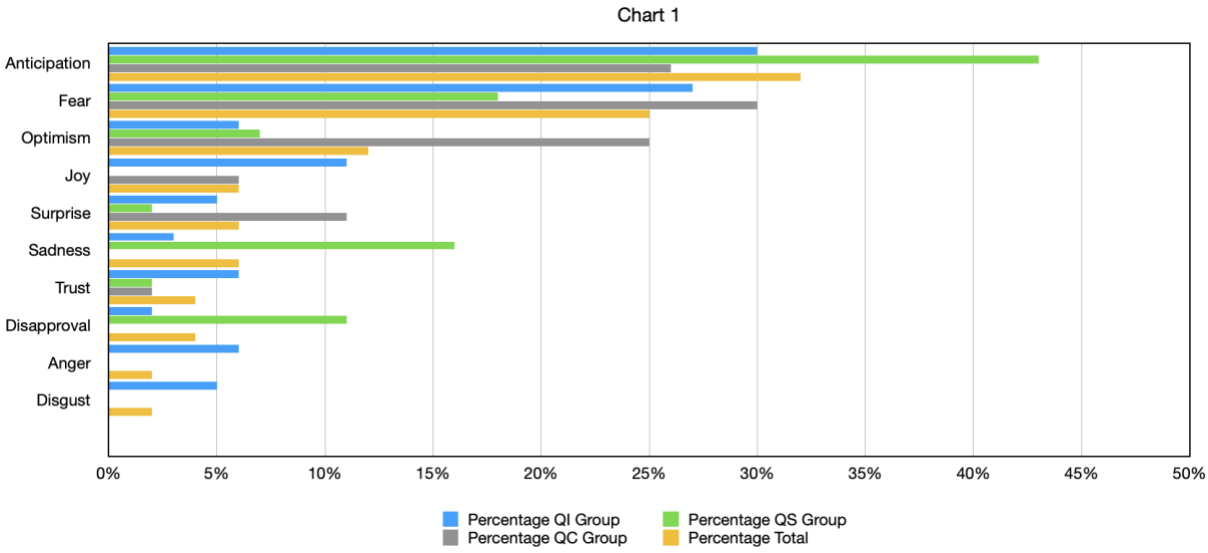
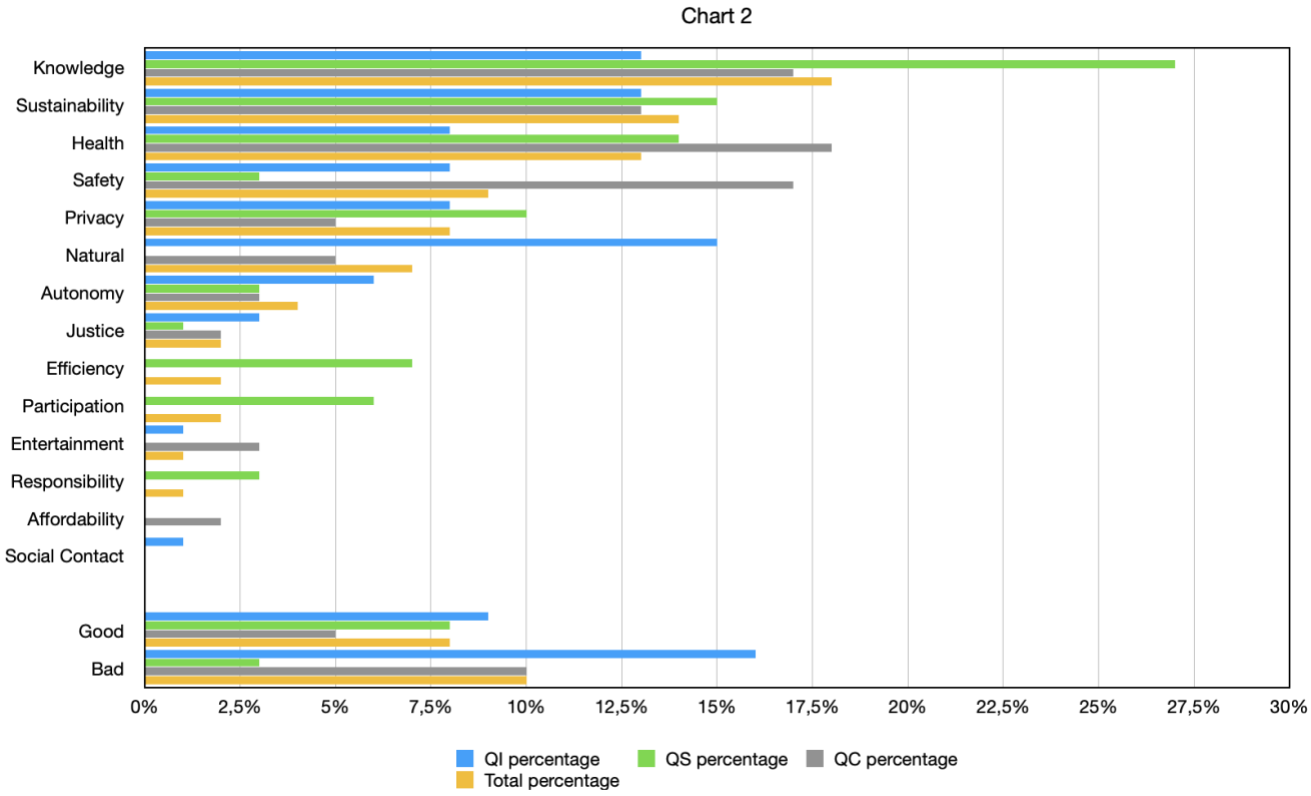



Chart 2. Number of times values occurred in percentages



## Endnotes

[i] TU Delft has had two 'Vision Teams' for this purpose: interdisciplinary teams of TU Delft scientists and engineers with which the university aims to participate in public discussions on technologies and their possible societal impacts. Both Vision Teams published magazines to make quantum technology and their impact more accessible to citizens (Vermaas et al. 2019; 2022).

[ii] For instance, according to *The Quantum Insider* (2020) quantum technology would revolutionise machine learning, and *The Telegraph* headlined "China's quantum leap plunges West into a race to protect its secrets" (2021).

[iii] Our artist team member Hannie van den Bergh contributed to the development and execution of these co-creative workshops on nanotechnologies and health. They were participatory (citizen and stakeholder) workshops, and were organised in The Netherlands as part of the European GoNano-project (http://gonano-project.eu/). Exceptionally, this project combined an explicit co-creative approach with RRI objectives (Jansma, Dijkstra and de Jong 2022).

[iv] We followed the research ethics procedure of TU Delft's Human Research Ethics Committee, HREC, which provided approval for conducting this study.

[v] With emojis we refer to picture characters or pictographs that display a facial representation. They are used to convey emotions in a digital medium, particularly (but not exclusively) used in an online and smartphone environment. Obviously, the emotion represented by an emoji or the way it is interpreted depends on many factors and may differ from time, place, individual, etc.

[vi] The fact that the coin was a 50 cent one and its head a 'flushed face' emoji (supposedly symbolising embarrassment, confusion, or shame) was not of any particular significance according to the group.

[vii] According to Plutchik's wheel of emotions 'pensiveness' falls under the umbrella of *sadness*. It should, however, not be understood as a light form of grief. We define pensiveness as a critical attitude that expresses a need for careful reflection upon the issues at stake.

[viii] For the complete text: see Appendix. You can find the video at https://vimeo.com/870687995?fl=pl&fe=sh.

[ix] See Appendix.

[x] To keep the anonymity of the participants, their names remain hidden.

[xi] The American business magazine *Forbes* is well known for its lists and rankings, including the '30 under 30' video series of young entrepreneurs and innovators: https://www.forbes.com. News from TU Delft on

experiment in question: https://qutech.nl/2022/05/25/teleport-quantum-information-across-network/ Accessed 14-02-'25.

## Appendix

### *A. Flyer workshop*

### *B. Video text*

### *C. Online survey*