Summary

Quantum technology is an emergent technology of the 21st century that is expected to have significant positive and negative consequences for society. Examples of possible positive consequences include the design of new medicines, the possibility of secure online voting, and the safer construction of energy and transportation infrastructure. However, negative consequences may include the breaking of our encryption, which may enable data breaches, the loss of control over criminal organisations that communicate with each other in a fundamentally secure way via quantum communication, and ethical and privacy issues resulting from large amounts of sensing data. To maximize the positive and minimize the negative impacts of quantum technology, public engagement could be important. Involving societal actors in dialogues about quantum technology could lead to a better understanding of how quantum technology affects different groups of people. Public engagement can also lead to greater public support for, and less resistance to, quantum technology. Furthermore, from a democratic perspective, people should be given the opportunity to participate in dialogues about quantum technology, as this technology could have a significant impact on their lives. **Chapter 1** describes the field of quantum science and technology and the role that science communication can play in such a development in more detail.

This dissertation examines public communication around quantum science and technology that may influence public engagement. Scientific literature points to four potential issues in public communication about quantum science and technology that may hinder its public engagement. These are:

(a) framing quantum science and technology as something enigmatic;

(b) skipping the underlying quantum phenomena when explaining what quantum technology entails;

(c) using a narrow instead of a wider public good frame; and

(d) focusing on the domain of quantum computing at the expense of the other two quantum technology domains (i.e., quantum communication and quantum sensing & metrology).

Chapter 2 and **Chapter 3** describe whether these four potential issues actually occur in public communication about quantum science and technology. To this end,

we conducted a content analysis of 501 English TEDx talks (Chapter 2) and 385 Dutch newspaper articles (Chapter 3) in which information about quantum science and technology was shared.

We found very similar results for both datasets. First, *the spooky and enigmatic frame* appeared in almost a quarter of both datasets, demonstrating that while the frame was present, it did not appear in the majority of talks or articles. Secondly, around half of the analysed material referencing quantum technology contained at least one *explanation for a quantum phenomenon* that we included in our study (superposition, entanglement and contextuality). Thirdly, in both datasets, there were hardly any references to how quantum technology can solve problems or improve people's lives (considered *a wider public good frame*), or to how quantum technology can realise economic development or lead to competition (considered *a narrow public good frame*). However, in an additional analysis of the benefit and risk frames, the wider public good frame – which constitutes a reflection on both the benefits and risks – seemed to be lacking, as the potential benefits of quantum technology were mentioned about six times more often than the potential risks in both datasets. Finally, both datasets showed an emphasis on *the domain of quantum computers and simulation*.

After quantifying the potential issues in Chapters 2 and 3, the study in **Chapter 4** describes their effect on people's engagement with quantum technology using an online experiment. A total of $n = 637$ adults, representative of the Dutch population, participated in the experiment. The participants were randomly assigned to read a text in which the adjective 'enigmatic' was used or not used in the description of quantum mechanics; in which an explanation of a quantum phenomenon was given or not given; and in which one of the following frames was used: benefit, risk, both a benefit and risk, or none of these. The participants' self-reported engagement with quantum technology was then measured using a scale with different variables: 1) the participants' intention to seek additional information about quantum technology (information seeking); 2) their belief in their own ability to understand and engage with information about quantum technology (internal efficacy); 3) their general interest in quantum technology (general interest); and 4) their confidence in their knowledge of quantum technology (perceived knowledge).

Results showed that the enigmatic frame and the risk frame neither increased nor harmed self-reported engagement. However, participants who had read an explanation of a quantum phenomenon scored significantly higher on general interest than those who had not read the explanation, and participants who had been exposed to a benefit frame scored significantly higher on internal efficacy than those who had not. However, participants who had read both a benefit and a risk frame scored significantly lower on perceived knowledge compared to those who had read only about a benefit or only about a risk of quantum technology. This result revealed an interesting tension, as a number of science communication researchers have argued that broad reflection on both the benefits and risks of quantum technology is necessary for the greatest positive societal impact. In Chapter 4, we argue that, in our view, this ethical consideration is more important to consider in public communication about quantum technology than its potential drawbacks.

In **Chapter 5**, we present whether metaphors make important quantum phenomena (superposition and entanglement) more comprehensible and whether this, in turn, influences people's attitudes towards quantum technology. We used an online experiment in which a total of n = 1,167 adults, representative of the Dutch population, participated. They read a fictional news article that contained either a metaphorical explanation, a non-metaphorical explanation, or no explanation at all about superposition or entanglement. Afterwards, four variables were measured: 1) the participants' beliefs about their understanding of the news article (perceived comprehension); 2) their actual understanding of the quantum phenomenon (actual comprehension); 3) their emotions and feelings towards quantum technology (affect-based attitude); and 4) their thoughts and beliefs about quantum technology (cognition-based attitude).

The metaphorical explanation of superposition and entanglement in the news article came from a small-scale study we conducted among n = 22 Dutch quantum experts prior to the experiment. In response to calls from the science communication community to evaluate the accuracy of AI-generated scientific explanations, we had ChatGPT 3.5 generate five metaphors for superposition and five metaphors for entanglement, which the Dutch quantum experts then evaluated for accuracy. The most accurate metaphor for superposition compared the phenomenon to a coin spinning in the air, which is heads and tails at the same time until the coin hits the table. The most accurate metaphor for entanglement compared it to rolling a pair of dice, where if one die is rolled, the outcome of the other die is predetermined, even if it is on the other side of the gambling table.

The results of our experiment showed that participants who had read an explanation of a quantum phenomenon, regardless of whether that explanation was metaphorical or non-metaphorical, scored their perceived comprehension of the news article significantly lower than those who had not read an explanation of a quantum phenomenon. However, the actual comprehension of the quantum phenomenon among the explanation-condition groups was significantly higher than among the no-explanation-condition groups. We found no significant differences between the groups in terms of their attitude towards quantum technology.

Since previous research suggests a relationship between comprehension and attitude, we also investigated this relationship in the context of our study. The effects we observed were significant but very small, and did not differ between metaphorical and non-metaphorical explanations. We found that providing an explanation of a quantum phenomenon in the news article significantly reduced participants' feelings of understanding the news article, which in turn led to less positive attitudes towards quantum technology. However, we also found that providing an explanation of a quantum phenomenon increased participants' actual understanding of the quantum phenomenon, which in turn led to more positive attitudes towards quantum technology, but that this positive effect was counteracted by a direct negative effect.

Finally, **Chapter 6** reflects on the studies in this dissertation. We present the limitations of the work and the possible follow-up research that arises from it, and conclude with four recommendations for science communication researchers and four recommendations for science communicators.

Recommendations for science communication researchers. The first recommendation for science communication researcher is that, as demonstrated in this dissertation, claims about potential issues should be empirically examined to gain true insight into their occurrence and effects. Second, the content-analytical studies in this dissertation showed very similar results between English TEDx talks and Dutch newspaper articles. Future research should investigate whether these patterns are a general trend in public communication about quantum technology. Third, the experimental studies in this dissertation showed that the type of information provided can already shape people's views of quantum technology. Therefore, investigations into how certain communication decisions about largely unfamiliar topics shape outcomes should be continued. And finally, this dissertation demonstrated that measuring the effects of frames on variables that are not directly about public support can provide important insights into engagement. This therefore warrants further investigation.

Recommendations for science communicators. First, it is up to science communicators themselves to decide whether or not to present quantum science as something spooky or enigmatic, as a brief, single mention seems to have no advantage or disadvantage to public engagement. Second, the studies in this dissertation showed that whether or not to include explanations of counterintuitive quantum phenomena in public communication depends on the goal of the communication. If the goal is to increase interest in quantum technology, and engagement with quantum technology in general, or if the goal is to (slightly) increase people's understanding of the quantum phenomenon, explanations may help. However, if the goal is to make your audience feel that they have understood the communication itself, explanations

are better omitted. Third, metaphors seemed to offer no additional advantage over non-metaphors in explaining quantum phenomena. It is therefore up to science communicators themselves to decide whether to use metaphors. However, they should be cautious about using metaphors that are too complex or mysterious to convey, to avoid resistance from experts. And finally, science communicators should pay attention to a broader range of quantum technologies than only quantum computers and emphasize their potential benefits and risks, to present a balanced perspective.