In a state of superposition: exploring (in)effective public communication about quantum technology

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CHAPTER 5

Like a Coin Spinning in the Air: The Effect of (Non-) Metaphorical Explanations on Comprehension and Attitudes Towards Quantum Technology

This chapter is based on: Meinsma, A. L., Reijnierse, W. G., & Cramer, J. (2025). Like a coin spinning in the air: The effect of (non-) metaphorical explanations on comprehension and attitudes towards quantum technology. *Manuscript Under Review*.

Abstract

The complexity of the science underlying quantum technology may pose a barrier to its democratization. This study investigated whether metaphors improve comprehension of, and shape attitudes toward, quantum technology. In an online experiment (*n* = 1,167 participants representative of the Dutch population), participants read a news article that included a metaphorical, non-metaphorical, or no explanation of a quantum phenomenon. Both explanation types reduced perceived comprehension of the news article compared to the control group, but increased actual comprehension of the quantum phenomenon. No direct effects were found on affect-based or cognition-based attitudes. Mediation analyses revealed a very small negative indirect effect of explanations on attitudes, through lower perceived comprehension, and a very small positive indirect effect of explanations on attitudes via increased actual comprehension – though the latter was counteracted by a negative direct effect. As metaphors offered no additional benefit over non-metaphorical

explanations, the findings suggest they do not provide a communicative advantage for enhancing understanding or shaping attitudes in this context.

5.1 Introduction

Emergent technologies – defined as quickly growing, scientifically-based innovations whose market potential has not yet fully been exploited (Cozzens et al., 2010) - may feel intangible to the general public. Moreover, public awareness of such technologies is typically limited (Cobb & Macoubrie, 2004; Scheufele & Lewenstein, 2005). Public reactions to previous emergent technologies have shown that public resistance can arise (Kurath & Gisler, 2009). This highlights the importance to take early account of how the general public perceives a new technological development (Mooney, 2010). Engaging the public early in a technology's development can help scientists better understand people's concerns, before a conflict arises (Mooney, 2010).

An example of a current emergent technology is quantum technology. Quantum technology encompasses three domains: quantum computing and simulation, quantum communication, and quantum sensing and metrology (Stichting Quantum Delta NL, 2020). This technology holds the promise of significant societal benefits. For instance, quantum technology promises "a new window into the underground" (p 1), thereby reducing the risk of encountering unexpected ground conditions during the construction of vital energy, transportation, and utility infrastructure (Stray et al., 2022). It may also assist in improving computations that are important for the development of new drugs (Outeiral et al., 2021), and promises to enable fundamentally secure communications globally (Wehner et al., 2018). In contrast, quantum technology raises potential concerns and ethical implications, for instance through the question of who gets access and who falls behind (Ten Holter et al., 2022), and through its potential for criminal use (Vermaas et al., 2019). In addition, the science behind quantum technology is counterintuitive to what we experience in our daily lives, which makes it difficult to grasp.

One way that may make the science behind quantum technology easier to understand is through the use of metaphors. A well-known example is Schrödinger's cat[1] (Van de Merbel et al., 2024), which uses the metaphor of a cat in a box - where the cat is both dead and alive at the same time until the box is opened - to describe the quantum phenomenon of particles existing in two states simultaneously. By comparing an abstract quantum phenomenon (the target domain) to a cat in a box (a more concrete source domain), metaphors are used to bridge the gap between

[1]Schrödinger's cat is a thought experiment devised by Erwin Schrödinger (Die gegenwärtige Situation in der Quantenmechanik, E. Schrödinger, 29 Nov, 1935) to illustrate the paradoxes of quantum mechanics under the Copenhagen interpretation, but it is now more commonly used as a metaphor to explain quantum mechanics in popular culture (Wikipedia contributors, 2025a).

complex quantum phenomena and everyday experiences.

Metaphors are for instance used in newspaper articles about quantum science/technology (Hilkamo & Granqvist, 2022; Wackers et al., 2025), which are important sources for people to get to know about quantum technology (European Commission, Directorate-General for Communication, 2021; Van de Merbel et al., 2024). However, to our knowledge, little is known about the effects of such metaphors on news media recipients.

In this article, we examined the effects of (non-)metaphorical explanations of counterintuitive quantum phenomena in a news article about quantum technology. Specifically, we studied whether (non-)metaphorical explanations influence people's comprehension and attitudes towards the technology.

5.2 Theory

As science and technology are often abstract, complex and unfamiliar, metaphors may make them more concrete, simpler, and easier to understand (Lakoff & Johnson, 1980). According to Lakoff and Johnson (1980) metaphors are a mapping between different domains (note that based on this definition, analogies and similes also fall under the term 'metaphor', which we have therefore also referred to as metaphor throughout this article). Metaphors in communication of science and technology towards a general public generally function to explain a scientific concept in terms of a more familiar one (Beger & Smith, 2020; Smedinga et al., 2023). In this way, metaphors could be helpful in making the complex field of quantum technology more accessible.

5.2.1 Incomprehensible quantum science could limit public engagement

There is a call for making quantum technology more accessible and comprehensible to a general public (Coenen et al., 2022) and engage them early on in its development process (Roberson et al., 2021). One of the reasons for this is that involving a wider group of people in envisioning the impact of quantum technology fits a more democratic process, in which citizens can express their opinions and concerns about developments that may affect them (Van Dam et al., 2020). Moreover, engaging the public in quantum technology may contribute to more public support and less resistance towards it, with previous emergent technologies such as nuclear energy and biotechnology having to deal with public resistance (Druckman & Bolsen, 2011; Kurath & Gisler, 2009).

However, the science that underlies quantum technology is complex, which could draw a barrier for public engagement. This may be reinforced by experts who emphasize this complexity in their outreach. Using Richard Feynman's well-known remark "I think I can safely say that nobody understands quantum mechanics" (Feynman, 1967, p 129), experts tend to focus on quantum mechanics as something that is incomprehensible (Seskir et al., 2023). This focus could be bad for the democratization of quantum technology, as it could hinder comprehension and engagement in discussions on its impact on society (Coenen et al., 2022; Seskir et al., 2023). Research on public engagement with quantum technology found that respondents in the Netherlands felt they had little influence over the development of quantum technology (Van de Merbel et al., 2024), and in the UK participants felt quantum technology was complicated and for experts only (Busby et al., 2017).

An open question in communication about quantum technology is what types of information allow for a good connection between quantum and society. As metaphors may influence comprehension (section 5.2.2) and attitudes (section 5.2.3), together with the fact that comprehension may influence attitudes (section 5.2.4), metaphors are an important tool to study.

5.2.2 Effect of metaphor on comprehension

One of the functions of metaphors in science is to make scientific topics easier to understand (Beger & Smith, 2020). However, metaphors have been found to create differences between what someone feels they have understood from a text (perceived comprehension) and what they actually understood (actual comprehension, see A. J. Jaeger & Wiley, 2015; Wiley et al., 2018). Specifically, metaphors can cause people to believe that their understanding of a text is higher than it actually is (i.e., illusion of comprehension, A. J. Jaeger & Wiley, 2015; Wiley et al., 2018). A. J. Jaeger and Wiley (2015), for instance, found that students who read a text about the greenhouse effect were generally overconfident in their understanding, but those in the metaphor-enhanced text condition were even more overconfident than the ones in the control group.

When looking specifically at actual comprehension, metaphors may not necessarily improve it. While in the field of education some studies have reported positive effects, with metaphor-enhanced texts supporting recall (Glynn & Takahashi, 1998) and reasoning (Yanowitz, 2001), other studies found no significant effects with the metaphor-enhanced texts resulting in similar comprehension results as control texts (Alexander & Kulikowich, 1991; Braasch & Goldman, 2010). Metaphors can even have detrimental effects on comprehension when learners map features between source and target domains that cannot be mapped, leading to misconceptions (Zook & Maier, 1994).

While metaphors in scientific educational texts have been well-studied, it remains unclear whether - and how - metaphors influence comprehension in science communication. A study in environmental communication by Reijnierse et al. (2025) showed that sustainability metaphors increased people's perceived comprehension of the text: people in the metaphor condition rated their comprehension significantly higher than those in the control group. However, there was no significant difference between the groups in terms of actual comprehension.

5.2.3 Effect of metaphor on attitude

Meta-analyses by O'Keefe and Hoeken (2021), Sopory and Dillard (2002) and Van Stee (2018) found that metaphors have a small positive effect on attitudes compared to literal messages. Metaphors with a familiar target domain furthermore led to more positive attitudes than those with an unfamiliar target domain, likely because the latter requires too much cognitive effort to process (O'Keefe & Hoeken, 2021; Sopory & Dillard, 2002; Van Stee, 2018). The effect of metaphors on attitudes, however, appear to be variable, as a next, individual study may also find a negative effect size instead of a positive one (O'Keefe & Hoeken, 2021).

While these meta-analyses included studies from contexts such as advertising, politics, environmental issues and health, none of them included studies focusing on new technology. To our knowledge, the effect of metaphor on attitudes towards new technology remains unclear. Prior research has shown that even when information is very limited, people can form attitudes towards new technology instantly (Druckman & Bolsen, 2011; Van Giesen et al., 2015). These attitudes may be based more on affect – i.e., emotions and feelings towards the technology, or cognition – i.e., thoughts and beliefs towards the technology. For unfamiliar technologies, people tend to rely more on affect, whereas this changes over time when cognition starts to play a bigger role (van Giesen et al., 2018). Examining both affective and cognitive responses to an emergent technology can therefore form a good image of people's attitudes.

5.2.4 Effect of comprehension on attitude

Research suggests that comprehension is important in attitude formation and change (Wyer Jr & Shrum, 2015). For example, comprehension of information that creates a visual image in one's mind, as well as information that is presented in the form of a story, can have a stronger effect on one's attitude. Even when the features that make a text more vivid and therefore easier to remember are completely irrelevant to the attitude in question - as in determining one's guilt in a court case after a delay in viewing the evidence - they can still influence attitude formation (Wyer Jr & Shrum, 2015).

For emergent technology specifically, people's beliefs of having enough information to form a judgment may influence their attitudes more than what they actually know (Akin et al., 2021). In an online survey in the US, Akin et al. (2021) found that people's perceptions of their own knowledge significantly predicted their positive attitudes towards three emergent technologies (nuclear energy, nanotechnology and synthetic biology). In contrast, people's actual knowledge only predicted two of those technologies – for the newest of the three technologies, synthetic biology, actual knowledge did not significantly predict attitudes. This provides reasons to investigate the relationship between comprehension and attitudes in the context of emergent quantum technology.

5.2.5 Metaphors in communication about quantum technology

Metaphor use has already been specifically recommended in public communication about quantum technology (Grinbaum, 2017; Hilkamo & Granqvist, 2022). Grinbaum (2017), for instance, has emphasized from a philosophical viewpoint the importance of effectively explaining counterintuitive quantum phenomena to ensure the public can grasp the basics of what quantum physicists work with daily. Without this comprehension, people's perception of quantum technology may become more negative. To address this, Grinbaum (2017) suggests metaphors to explain the science and at the same time convey the beauty of quantum science. Hilkamo and Granqvist (2022) have also emphasized the importance of metaphors in the quantum technology domain, as they can appeal to emotions.

It is not yet known exactly how metaphors influence comprehension and attitudes in public communication such as news articles about quantum technology. Our research therefore aims to explore whether a (non-)metaphorical explanation of a quantum phenomenon in a news article affect comprehension (both perceived and actual) and shape attitudes (both cognition- and affect-based).

Prior studies worked with metaphor-enhanced texts, where the metaphor was added to the original explanation (see e.g., Alexander & Kulikowich, 1991; Braasch & Goldman, 2010; Glynn & Takahashi, 1998; A. J. Jaeger & Wiley, 2015; Yanowitz, 2001). However, this results in a double explanation of the phenomenon – once non-metaphorically and once metaphorically. Because we are interested in whether a metaphorical explanation in itself provides benefits, we work with three different conditions. Our research questions are as follows (see Figure 5.1 below):

Research Question 1: To what extent does the use of a non-metaphorical quantum phenomenon explanation vs a metaphorical quantum phenomenon explanation vs a control in a news article influence:

(a) perceived comprehension of the news article[2]

(b) actual comprehension of a quantum phenomenon

(c) affect-based attitudes towards quantum technology

(d) cognition-based attitudes towards quantum technology

Research Question 2: To what extent does perceived comprehension of the news article mediate the possible effects of explanation type (non-metaphorical quantum explanation, metaphorical quantum explanation, no explanation) on affect- and cognition-based attitudes?

Research Question 3: To what extent does actual comprehension of the quantum phenomenon mediate the possible effects of explanation type (non-metaphorical quantum explanation, metaphorical quantum explanation, no explanation) on affect- and cognition-based attitudes?

5.3 Methodology

Following our research questions, we performed an online experiment. The study information, design plan, sampling plan, variables and analysis plan were preregistered on the Open Science Framework before the data collection started (https://tinyurl.com/mr3hp4w9). The Ethics Review Committee of the Faculty of Science, Leiden University gave ethical approval to conduct the study (reference number 2023-021). The following section gives an overview of the materials used, the design and procedure, the participants and the variables of the study.

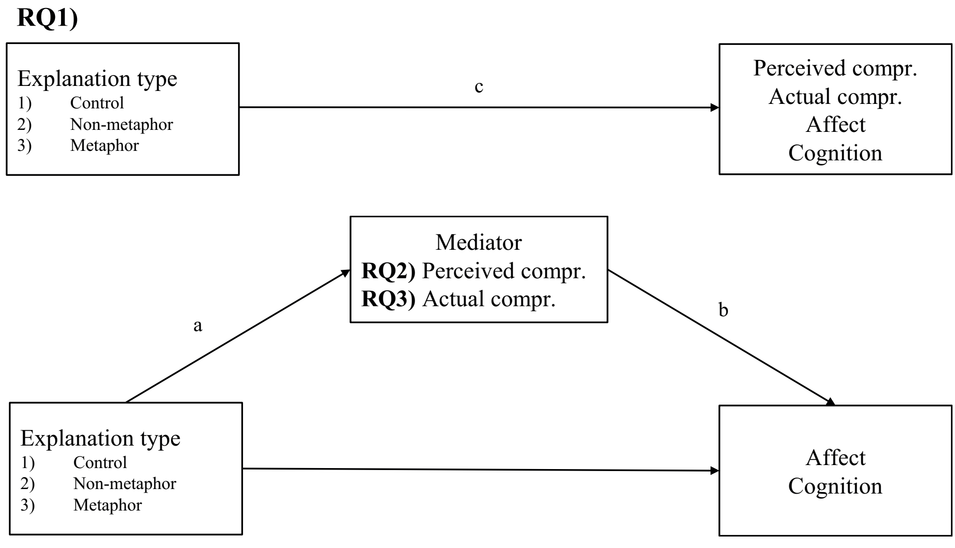
5.3.1 Materials

We designed a newspaper article about a new quantum computer that the European Commission has decided to build in the Netherlands as stimulus material. The article was based on an actual event (see NOS, 2024). The text contained 162 words

[2]Here we deviated from the preregistration, given that we made the call to examine perceived comprehension of the text as a whole, informed by previous studies that measured perceived comprehension at the level of the entire text.

Figure 5.1

Visual representation of the research questions. The top path diagram illustrates RQ1, examining the direct relationships between the variables. The bottom path diagram shows the two mediation models: RQ2 examines perceived comprehension as a mediator, and RQ3 examines actual comprehension as a mediator.



in the control conditions, with an additional paragraph of 73 to 80 words included in the explanation conditions. The text of the news article and different conditions can be found in Appendix A4.1.

We chose to explain the quantum phenomena *superposition* or *entanglement* in the explanation conditions. These phenomena are relevant to study as they underlie quantum technology, are counterintuitive from the perspective of everyday experiences and are often explained to general audiences in popular communication (Chapters 2 and 3). To identify which metaphor for superposition and entanglement were deemed most accurate for communicating with non-experts, we conducted a small study among Dutch-speaking quantum experts.

Expert insights: method

We emailed an online survey to 67 researchers from Dutch universities, who were selected based on their university profiles. Only those working in a field where quantum physics plays a role and with Dutch as a native language could participate. First, we asked participants to provide consent. Then, after indicating that Dutch was (one of) their native language(s) and indicating the quantum-related field in which they worked (based on Fox et al., 2020), participants were randomly assigned to read five metaphors about a quantum phenomenon (superposition or entanglement) that were displayed in a random order. The metaphors were generated by ChatGPT 3.5, as this AI tool is widely used and known for its accessibility and as science communication research encourages investigating the accuracy of AI-generated content (Schäfer, 2023). The precise wordings per metaphor can be found in Table A17 in the Appendix.

After reading each metaphor, participants rated its accuracy and validity on a 7-point Likert scale. They also indicated how likely it would be for them to use a metaphor when talking to a non-quantum expert about superposition or entanglement (7-point scale). Next, participants ranked which metaphor they would use if they were to use a metaphor in a conversation with non-quantum experts from most likely to least likely and justified their ranking. Finally, we asked participants if they knew of an alternative metaphor about quantum superposition or entanglement. If they answered “yes”, they were prompted to shortly describe the alternative metaphor, and rate it on accuracy and validity.

Expert insights: results

The survey ran between January 15th and March 15th, 2024 resulting in a total of n = 22 completed surveys. The majority of the participants were scientists

Table 5.1

Mean total scores (and SDs between brackets) for superposition and entanglement answered on a 7-point Likert scale. The total scores are an average of the scores on accuracy and validity, and are ordered from highest to lowest. The precise wordings per metaphor can be found in Table A17 in the Appendix.

Superposition		
#	Metaphor	Total (SD)
1	A coin spinning in the air	4.13 (1.86)
2	A radio producing a jumble of sounds	4.04 (2.94)
3	A cat, a vial of poison and a radioactive atom in a locked box	3.21 (2.59)
4	An artist dabbing his brush in multiple colours	3.04 (2.31)
5	A musician composing a music piece	2.25 (2.01)
Entanglement		
#	Metaphor	Total (SD)
1	A pair of dice	5.30 (1.89)
2	Two dancers performing a perfectly synchronized dance routine	3.80 (2.55)
3	A telepathic twin	3.35 (2.06)
4	Two compass needles that always point in opposite directions	3.15 (2.46)
5	Two clocks with perfectly synchronized second hands	2.90 (2.53)

working in a field involving quantum physics (n = 21), and one participant is an engineer. In total, 12 participants evaluated five metaphors about superposition, and 10 participants evaluated five metaphors about entanglement. The median completion time was 14 minutes 50 seconds. Experts indicated it was very likely (M = 5.68, SD = 1.36) that they would use a metaphor in a conversation with non-quantum experts to explain superposition or entanglement.

Table 5.1 shows that the coin metaphor scored highest for superposition (M = 4.13, SD = 1.86) and the dice metaphor for entanglement (M = 5.30, SD = 1.89). A complete overview of the experts' feedback per metaphor can be found in Table A18 in the Appendix. Based on these results, the metaphorical explanation condition thus included the coin metaphor for superposition and the dice metaphor for entanglement.

5.3.2 Design and procedure

The main study made use of an experimental design with 6 conditions: 1 factor with 3 levels (explanation type: metaphorical, non-metaphorical, no explanation) and 2 items (quantum phenomena: superposition and entanglement). Participants provided consent and then declared to not use any external sources, as we wanted to explicitly discourage the use of search engines and AI (see Meem et al., 2024). General information (age, gender, education) and control variables were asked, after which participants were randomly assigned to one of the 6 conditions. After reading the news article, participants were asked to answer questions on their perceived comprehension, actual comprehension, affect-based and cognition-based attitudes.

5.3.3 Participants

The experiment ran between January 29th and February 3rd, 2025 and resulted in a total sample of n = 1,176 participants. Participants were recruited by PanelClix (https://www.panelclix.nl/), an external panel service in the Netherlands. For each completed questionnaire in PanelClix, participants receive points ('clix') which they can exchange for money amongst others. The median time to complete the survey was 5 minutes and 50 seconds.

A total of n = 9 participants were excluded from the full analyses because they a) finished the survey within 90 seconds (n = 4); b) answered both the attention check question and the actual comprehension question incorrectly (n = 3); or c) reported being under the age of 18 (n = 2). As 36 participants failed to answer the actual comprehension question by mainly typing a letter or a non-existing word, they were excluded from only that part of the analysis. This resulted in a final sample of n = 1,131 participants for the analyses involving the actual comprehension variable and 1,167 participants for the remaining analyses.

The sample characteristics of the 1,167 participants closely matched the population statistics of the Netherlands (CBS, 2024). In terms of gender, n = 596 (51.1%) identified as male, n = 568 (48.7%) as female and n = 3 (0.3%) as other. Participants were between 18 and 88 years old ($M = 47.7$, $SD = 16.8$). In terms of education level, n = 236 participants (20.2%) reported having completed a low level of education, n = 591 (50.6%) reported an average level, and n = 340 (29.1%) reported a high level of education.

5.3.4 Dependent variables

Perceived comprehension. Perceived comprehension of the newspaper article was measured with 3 items (Miele & Molden, 2010). These are: *"How well do you feel you understand the news article?"* [1 = very poorly, 7 = very well], *"How certain are you that you will answer questions correctly about the news article?"* [1 = very uncertain, 7 = very certain], and *"How confused about the news article do you feel?"* [1 = not at all confused, 7 = very confused] (reverse coded). The three items were averaged into an index ($M = 4.38$, $SD = 1.20$, Cronbach's $\alpha = 0.73$).

Actual comprehension. To check whether participants remembered which quantum phenomenon was mentioned in the news article, we asked a control question. Participants were asked to select the phenomenon they had just read from a multiple-choice question (answer options: superposition, entanglement, tunnelling, decoherence, I don't know), and based on their answer, were asked to write in their own words what the selected phenomenon meant. If 'I don't know' was selected, the question was formulated as: *"Describe in your own words how particles behave at the smallest scale"*. We calculated the index on a scale from 0 to 4 based on the text provided by the participants (*M* $= 0.43$, *SD* $= 0.78$). A point was given for each of the following elements:

- For superposition:

  (a) mention the connection with quantum;

  (b) something can be A and B at the same time;

  (c) a measurement has influence;

  (d) after which a single state is left.

- For entanglement:

  (a) mention the connection with quantum;

  (b) there is a connection/correlation between parts;

  (c) measurement of one part influences the other part;

  (d) which is not dependent on the distance.

In addition to assigning points, participants' reuse of the metaphor was analysed. Both the index and the metaphor reuse were coded reliably, as intercoder agreement between two coders was perfect to near-perfect for almost all cases (see section A4.2 in the Appendix for full details on the intercoder reliability analysis).

Affect-based attitude. Affect-based attitude was measured with 7 items (van Giesen et al., 2018). These are: *"How do you feel about quantum technology after having read the news article? I feel..." ...joy, ...desire, ...fascination, ...satisfaction, ...fear* (reverse-coded), *...sadness* (reverse-coded), *...disgust* (reverse-coded) [1 = not at all, 7 = very much]. The seven items were averaged into an index (*M* $= 4.34$, *SD* $= 0.92$, Cronbach's $\alpha = 0.71$).

Cognition-based attitude. Cognition-based attitude was measured with 7 items (van Giesen et al., 2018). These are: *"What is your view on quantum technology after having read the news article? Quantum technology is...." ...useful, ...functional, ...beneficial, ...useless* (reverse-coded), *...harmful* (reverse-coded), *...disadvantageous* (reverse-coded), *...unusable* (reverse-coded) [1 = not at all, 7 = very much]. The seven items were averaged into an index (*M* $= 4.67$, *SD* $= 0.99$, Cronbach's $\alpha = 0.81$).

5.3.5 Control variables

We further measured five control variables, since we expected these to potentially influence our dependent variables. These were: *awareness of quantum, science news use, interest in new technology, faith in intuition* and *need for cognition*. All information regarding these variables is available in the Appendix A4.3.

5.3.6 Analysis and statistical procedures

Data were analysed with jamovi 2.3.28. Results of the two items (superposition and entanglement) were collapsed for the analysis to make generalizable claims on the effectiveness of (non-)metaphorical explanations across quantum phenomena. Randomization checks were performed to make sure that the participants were evenly distributed across the three conditions.[3] Participants were found to be evenly distributed across the three conditions for gender ($\chi^2(2) = 1.79$, $p = 0.408$), age ($\chi^2(6) = 3.98$, $p = 0.679$), level of education ($\chi^2(4) = 2.86$, $p = 0.581$), quantum technology awareness ($F(2, 1164) = 0.360$, $p = 0.698$), science news use ($\chi^2(2) = 0.608$, $p = 0.738$), interest in new technology ($F(2, 1164) = 0.808$, $p = 0.446$), faith in intuition ($F(2, 1164) = 1.04$, $p = 0.353$) and need for cognition ($F(2, 1164) = 0.110$, $p = 0.896$). Therefore, we did not include any of these variables as a covariate in the analyses.

[3]Note that for gender, the 'other' category was too small to meet the assumptions of the chi-square test of independence, which we therefore excluded.

To answer RQ1, four separate ANOVAs were performed using the explanation condition as independent variable and perceived comprehension, actual comprehension, affect-based attitudes, and cognition-based attitudes as dependent variables.

To answer RQ2 and RQ3, four separate mediation analyses were conducted using the jAMM module. We used the explanation type condition as the independent variable, perceived comprehension (for RQ2) and actual comprehension (for RQ3) as the mediator, and affect-based attitudes and cognition-based attitudes as the dependent variable. Confidence intervals were computed with the Bootstrap percentiles method using 5000 bootstraps.

5.4 Results

5.4.1 Main effects on the dependent variables

Statistically significant differences between the conditions were found for perceived comprehension ($F(2, 1164) = 8.49$, $p < .001$, $\eta^2 = 0.014$) and actual comprehension ($F(2, 1131) = 32.6$, $p < .001$, $\eta^2 = 0.055$). We found no statistically significant differences between the conditions for affect-based attitudes ($F(2, 1164) = 1.48$, $p = 0.23$) or cognition-based attitudes ($F(2, 1164) = 1.81$, $p = 0.16$).

Results of the pairwise comparisons with a Bonferroni correction showed that for perceived comprehension, the control group scored significantly higher than both the non-metaphorical group (mean difference = 0.32, $SE = 0.09$, $p < .001$) and the metaphorical group (mean difference = 0.29, $SE = 0.08$, $p = 0.002$). There was no significant difference between the metaphorical and non-metaphorical group (mean difference = -0.028, $SE = 0.09$, $p = 1.000$). For actual comprehension, the control group scored significantly lower than the non-metaphorical group (mean difference = -0.43, $SE = 0.06$, $p < .001$) and the metaphorical group (mean difference = -0.31, $SE = 0.05$, $p =< .001$). The difference between the non-metaphorical group and the metaphorical group was not significant (mean difference = 0.13, $SE = 0.06$, $p = 0.069$).

5.4.2 Mediation effects

Although no significant differences were found between the conditions on affect-based and cognition-based attitudes, mediation can still exist in the absence of a main effect (O'Rourke & MacKinnon, 2018). In performing the mediation analyses, we chose the control group as a reference group given the outcomes of the main effect analyses.

Table 5.3

Means (and SDs between brackets) by condition, based on the estimated marginal means estimated from the statistical model. Perceived comprehension, affect and cognition were measured on a 7-point Likert scale. Actual comprehension was measured on a scale from 0 to 4.

Comprehension				
Condition	Perceived	95% CI	Actual	95% CI
Control	4.58 (0.06)	[4.46, 4.69]	0.19 (0.04)	[0.11, 0.26]
Non-metaphorical explanation	4.26 (0.06)	[4.14, 4.38]	0.62 (0.04)	[0.54, 0.70]
Metaphorical explanation	4.29 (0.06)	[4.17, 4.40]	0.49 (0.04)	[0.42, 0.57]
Attitude				
Condition	Affect	95% CI	Cognition	95% CI
Control	4.39 (0.05)	[4.30, 4.48]	4.74 (0.05)	[4.64, 4.84]
Non-metaphorical explanation	4.36 (0.05)	[4.26, 4.45]	4.66 (0.05)	[4.56, 4.76]
Metaphorical explanation	4.28 (0.05)	[4.19, 4.37]	4.61 (0.05)	[4.51, 4.71]

Perceived comprehension of the news article as mediator

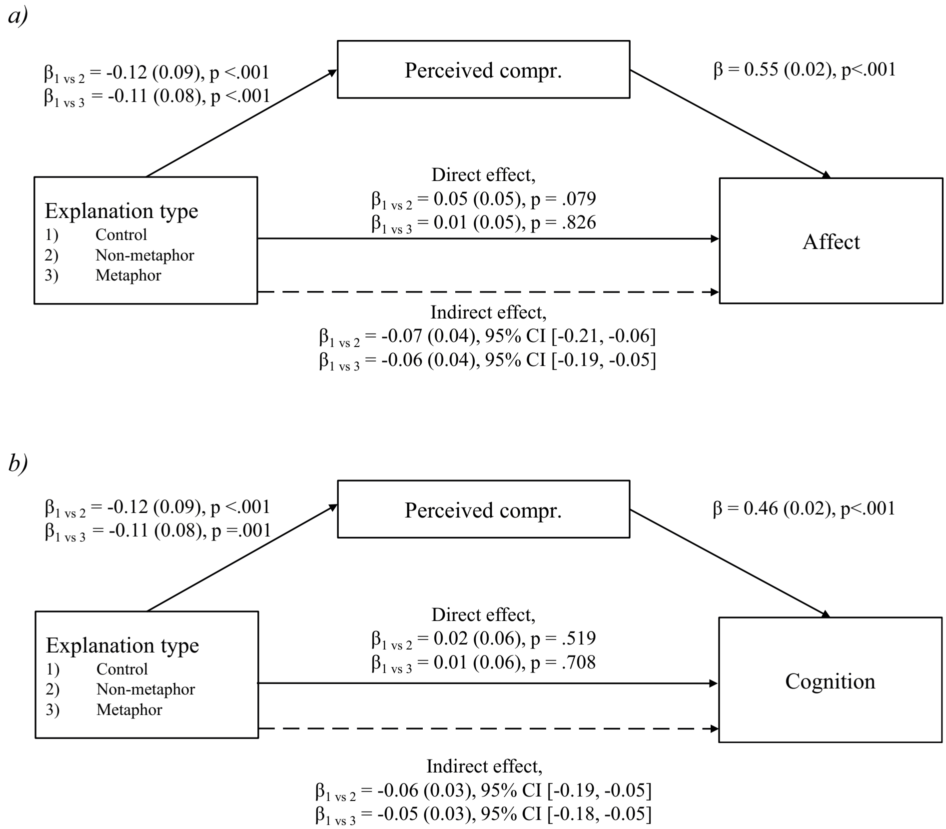
We found some evidence that perceived comprehension acts as a mediator between explanation type and both affect-based attitudes and cognition-based attitudes, as none of the confidence intervals for the tested indirect effects contained zero. Figure 5.2 shows the results (see Table A19 in the Appendix for the complete table).

As shown in Figure 5.2, we found a small but statistically significant decrease in perceived comprehension when participants received the non-metaphorical ($\beta = -0.12$, $p < .001$) or metaphorical explanations ($\beta = -0.11$, $p < .001$), compared to the control group. This indicates that both types of explanations lowered participants' feeling of understanding the news article. We furthermore found a strong statistically significant increase in both affect ($\beta = 0.55$, $p < .001$) and cognition ($\beta = 0.46$, $p < .001$) when participants scored higher on perceived comprehension. This indicates that there is a relationship between a higher perceived comprehension of the news article and feeling and viewing quantum technology more positively.

Given these two findings, the indirect effects found between explanation type and affect or cognition, with perceived comprehension as the mediator, were statistically

Figure 5.2

Visual representation of the results, depicting perceived comprehension as a mediator, with a) affect and b) cognition as dependent variables. Note that β_{1vs2} (β_{1vs3}) denotes the effect size of the non-metaphorical group (metaphorical group) with control as reference.



significant ($p < .001$) but very small (β's ranged between -0.07 and -0.05). The direct effects, i.e. the effect of explanation type on affect or cognition when accounting for perceived comprehension, and the total effects were non-significant in all cases. This suggests that the effect of explanations on people's affect-based and cognition-based attitudes towards quantum technology is entirely dependent on how well they feel they understood a news article on the topic. Without a change in perceived comprehension, there would be no effect.

Actual comprehension of the quantum phenomenon as mediator

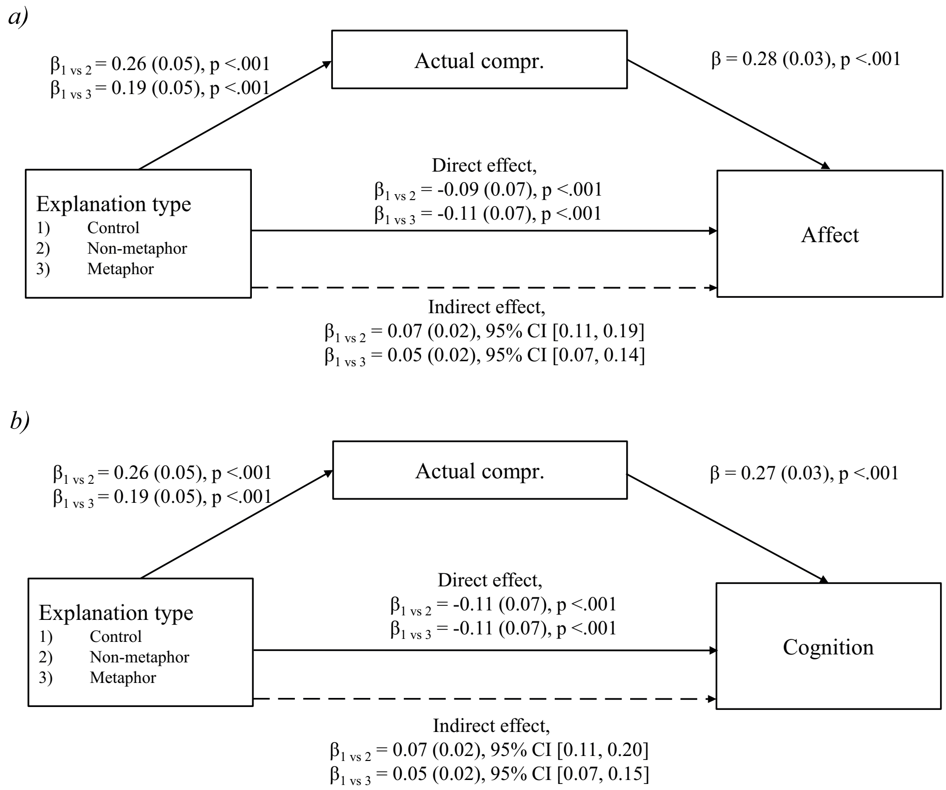
We also found some evidence that actual comprehension acts as a mediator between explanation type and both affect-based attitudes and cognition-based attitudes, as again none of the confidence intervals for the tested indirect effects contained zero. Figure 5.3 shows the results (see Table A20 in the Appendix for the complete table).

We found a small but statistically significant increase in actual comprehension when participants received the non-metaphorical ($\beta = 0.26$, $p < .001$) or metaphorical explanations ($\beta = 0.19$, $p < .001$), compared to the control group. We furthermore found a small statistically significant increase in both affect-based attitudes ($\beta = 0.28$, $p < .001$) and cognition-based attitudes ($\beta = 0.27$, $p < .001$) from actual comprehension. This indicates that there is a relationship between a higher actual comprehension of the quantum phenomenon and feeling and viewing quantum technology more positively.

Given these two findings, the indirect effects between explanation type and affect or cognition, with actual comprehension as the mediator, were statistically significant ($p < .001$) but very small (β's ranged between 0.05 and 0.07). The direct effect, which is the remaining effect after accounting for actual comprehension as a mediator, revealed a small negative effect (β's between -0.11 and -0.09). The total effects were non-significant. Since the indirect and direct effects have opposing signs, finding a mediating effect in this case while the total effect is non-significant is called inconsistent mediation (O'Rourke & MacKinnon, 2018). This suggests that while explanations may increase people's affect-based and cognition-based attitudes towards quantum technology by improving their understanding of quantum phenomena (i.e., actual comprehension), this positive effect is counteracted by a direct negative effect of explanation type on affect-based and cognition-based attitudes. There may be other mechanisms at play that result in such a counteracting effect.

Figure 5.3

Visual representation of the results, depicting actual comprehension as a mediator, with (a) affect and (b) cognition as dependent variables. Note that β_{1vs2} (β_{1vs3}) denotes the effect size of the non-metaphorical group (metaphorical group) with control as reference.



5.5 Discussion

This study examined, through a large-scale experiment, how (non-)metaphorical explanations of a quantum phenomenon influenced people's perceived comprehension of a news article about quantum technology, their actual comprehension of a quantum phenomenon, and their attitudes towards this emergent technology.

5.5.1 Effects of explanation type on comprehension

We found that including an explanation of a quantum phenomenon – regardless of whether it was metaphorical or non-metaphorical – led to lower perceived comprehension scores of the text, while actual comprehension scores of the quantum phenomenon were higher. The findings that metaphors can lead to higher perceived comprehension (Reijnierse et al., 2025) or enhance people's overconfidence (A. J. Jaeger & Wiley, 2015; Wiley et al., 2018) was thus not apparent in our study. The opposite even emerged, where (non-)metaphorical explanations had a detrimental effect on participants' perceived comprehension of the text, but improved their actual comprehension of the quantum phenomenon, compared to a control condition. It should be noted that actual comprehension scores were low in all conditions (≤ 0.62), suggesting that people did not grasp the phenomenon well.

It is important to note that we measured perceived comprehension for the text as a whole, but actual comprehension specifically for the quantum phenomenon. Perhaps the fact that explanations reduce perceived comprehension of the text indicates an information overload, where the length and amount of information make a text seem more complex. In contrast, we found that explanations contribute to an improved actual comprehension of a quantum phenomenon. This makes sense, because without an explanation it is conceivable that people do not know what superposition or entanglement entails (also note the low awareness for quantum technology, see Figure A8), and therefore cannot answer a question about it correctly.

We found no differences between metaphorical and non-metaphorical explanations on actual comprehension, consistent with Alexander and Kulikowich (1991) and Braasch and Goldman (2010), but contrasting others (Glynn & Takahashi, 1998; A. J. Jaeger & Wiley, 2015; Yanowitz, 2001). A main difference is that we ensured the phenomenon was explained only once in the metaphor condition, while previous work often used metaphor-enhanced texts that lead to double explanations of a phenomenon. Furthermore, our actual comprehension question focused specifically on the quantum phenomenon, whereas other studies also tested comprehension of parts unrelated to the metaphor (see e.g., Alexander & Kulikowich, 1991; A. J. Jaeger

& Wiley, 2015). Finally, different ways to measure actual comprehension exist, for instance through closed multiple-choice questions (Alexander & Kulikowich, 1991), open recall questions (Glynn & Takahashi, 1998), inference questions (questions about 'what happens if something in the system changes'; Yanowitz, 2001) and prompting to write a full essay (Braasch & Goldman, 2010; A. J. Jaeger & Wiley, 2015). These different ways probably also lead to different comprehension scores, with some tapping into more shallow levels of comprehension and others into deeper ones (see also Bernholt et al., 2023).

A closer look at the actual comprehension answers furthermore provides an interesting insight about the terms 'superposition' and 'entanglement'. Some participants wrote that superposition is about a competitive (market) position ($n = 46$, 8.0%) and entanglement about intertwining things, such as weaving, mixing or melting ($n = 39$, 6.6%). While the technical terms 'superposition' and 'entanglement' might not be considered metaphorical to quantum scientists (Beger & Smith, 2020), they may be processed differently by people outside the quantum field. Furthermore, only 13.1% of the participants in the metaphor condition reused the provided metaphors (a coin spinning in the air: $n = 33$, 16.6%; rolling a pair of dice: $n = 19$, 9.6%). Perhaps the metaphorical explanation remained too abstract or was too brief to fully understand the quantum phenomenon.

5.5.2 Effects of explanation type on attitude

We found no differences between the three conditions for affect-based attitudes and cognition-based attitudes. This differs from the small persuasive effect of metaphors compared to literal messages as found in meta-analyses (O'Keefe & Hoeken, 2021; Sopory & Dillard, 2002; Van Stee, 2018). The target domain was likely too unfamiliar with low quantum technology awareness scores (see Figure A8), making the cognitive effort required to process the metaphor too great (Sopory & Dillard, 2002; Van Stee, 2018).

Previous research suggests that using metaphors to explain quantum phenomena, such as superposition and entanglement, might improve attitudes towards quantum technology (Grinbaum, 2017). However, in our study, attitudes towards quantum technology were positive across conditions, regardless of whether a quantum phenomenon was explained. This suggests that resistance, found with other emergent technologies (Druckman & Bolsen, 2011; Kurath & Gisler, 2009), may currently not apply for quantum technology. Given the low awareness of quantum technology, it is plausible these positive attitudes formed during the survey (see also Druckman & Bolsen, 2011; van Giesen et al., 2018). Apparently, reading a neutral-toslightly-positive article about quantum technology is enough to form these attitudes, regardless of an additional explanation about underlying phenomena.

5.5.3 Comprehension as a mediator between explanation type and attitudes

Results of the mediation analyses suggest that explanations have a very small negative indirect effect on people's attitudes towards quantum technology, due to the fact that people feel they understood the news article less. This is consistent with Akin et al. (2021), who found that people's beliefs about their own knowledge of a technology were more influential in shaping their attitudes than their actual knowledge. While we also found a very small positive indirect effect of explanations on attitudes mediated by actual comprehension, this was counteracted by a direct negative effect. Apparently, improving people's actual comprehension of the underlying quantum phenomena does not necessarily result in more positive views towards quantum technology, as there could be other mechanisms at play that counteract the positive effect on comprehension.

In addition, and in contrast with what Grinbaum (2017) advocated, the type of explanation, metaphorical or non-metaphorical, did not lead to different outcomes on comprehension and therefore on attitudes. One possible explanation for this is that the metaphors used in our study, although deemed most accurate and valid, did not evoke a sufficiently vivid image in people's minds (Wyer Jr & Shrum, 2015). It could well be that with a different metaphor attitudes would have been affected more, for example with the famous metaphor of Schrödinger's cat. While experts in preparation of the experiment acknowledged that the metaphor is very well-known (see also Van de Merbel et al., 2024) and therefore may resonate better, some experts pointed out that the metaphor is incorrect and too complicated to bring across.

5.5.4 Resistance to metaphor

Finally, we want to point out an interesting additional finding: some experts in preparation of the experiment indicated that the metaphors made the quantum phenomena unnecessarily complicated and mysterious, creating only more confusion. One expert even emailed us afterwards saying that their "strong feeling is that it is dangerous to use a metaphor for such a profound phenomenon". This aligns with the body of research that metaphors can cause resistance. Such a comment also ties in with Feynman's quote that quantum phenomena are too complex to explain (Feynman, 1967), which could be bad for the democratization of quantum technology (Seskir et al., 2023).

5.5.5 Practical implications

In this study, we have shown that explanations of quantum phenomena in a news article affect people's comprehension, which subsequently mediates attitudes towards quantum technology. We recommend that, if the goal of a news article is to increase people's feeling that they have understood the text, journalists better skip the explanation of counterintuitive quantum phenomena. De Jong (2025) has taken this a step further by arguing that quantum phenomena should not be explained to a general public, but there should be an increased focus on the functional capacities of quantum technology to lower the barrier to engage in ethical discussions about quantum.

Our recommendation changes if the goal is to increase people's actual understanding of the underlying quantum phenomena of quantum technology. Explanations help to increase actual comprehension of quantum phenomena, but our findings suggest that there is no additional benefit of using metaphors to explain counterintuitive quantum phenomena.