Like a coin spinning in the air: The effect of (non-)metaphorical explanations on comprehension and attitudes towards quantum technology

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The effect of (non-)metaphorical explanations on comprehension and attitudes towards quantum technology

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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. Specifically, we examined effects on perceived comprehension of a newspaper article about a new quantum computer, actual comprehension of underlying quantum phenomena (superposition and entanglement), and affect- and cognition-based attitudes. 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.

Keywords: science communication, metaphorical explanations, comprehension, attitude, quantum technology, quantum science

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1. Introduction

Emergent technologies — 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 public perceives new technological developments (Mooney, 2010). Engaging the public early can help foster and strengthen meaningful dialogue between scientists and members of the public about its implications, creating connections rather than widening divides (Mooney, 2010).

An example of a current emergent technology is quantum technology. It 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, it 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 its potential for criminal use (Vermaas et al., 2019). Furthermore, the science behind quantum technology is counterintuitive to what we experience in our daily lives, making it difficult to grasp.

One way that may make the science behind quantum technology easier to understand is through 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 complex quantum phenomena and everyday experiences.

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1. Schrödinger's cat is a thought experiment devised by Erwin Schrödinger (1935) to illustrate the paradoxes of quantum mechanics under the Copenhagen interpretation. It is now more commonly used as a metaphor to explain quantum mechanics in popular culture (https://en.wikipedia.org/wiki/Schr%C3%B6dinger%27s_cat).

Metaphors are 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 (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.

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). Since metaphors constitute a mapping between different domains, the term also encompasses analogies and similes, 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). As such, metaphors may help in making the complex field of quantum technology more accessible.

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 reason 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 support and less resistance towards it, which previous emergent technologies such as nuclear energy and biotechnology had to deal with due to public mistrust of science and governments (Druckman & Bolsen, 2011; Kurath & Gisler, 2009).

However, the science that underlies quantum technology is complex and difficult to grasp intuitively even for scientists, potentially drawing a barrier for public engagement. This may be reinforced by experts who emphasize this complexity in their outreach. Using Feynman's well-known remark "I think I can safely say that nobody understands quantum mechanics" (1967, p. 129), experts tend to focus on quantum mechanics as something 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 its development (Van de Merbel et al., 2024), and in the UK participants felt it 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 2.2) and attitudes (Section 2.3), together with the fact that comprehension may influence attitudes (Section 2.4), metaphors are an important tool to study.

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 people feel they have understood from a text (perceived comprehension) and what they actually understood (actual comprehension; Jaeger & Wiley, 2015; Wiley et al., 2018). Specifically, metaphors can cause people to believe their understanding is greater than it actually is (i.e., illusion of comprehension, Jaeger & Wiley, 2015; Wiley et al., 2018). Jaeger & Wiley (2015), for instance, found that students reading a text about the greenhouse effect were generally overconfident in their understanding, with those in the metaphor-enhanced text condition even more so than those in the control group.

For actual comprehension specifically, 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 comprehension differences between metaphor-enhanced texts and control texts (Alexander & Kulikowich, 1991; Braasch & and Goldman, 2010). Metaphors can even have detrimental effects on comprehension when learners map features between source and target domains that cannot be acceptably mapped, leading to misconceptions (Zook & Maier, 1994).

While metaphors in educational texts have been well-studied, it remains unclear whether – and how – metaphors influence comprehension in science communication. Reijnierse et al. (2025) showed that sustainability metaphors increased people's perceived comprehension of the text compared to a control.

However, no significant difference occurred between groups for actual comprehension.

2.3 Effect of metaphor on attitude

Meta-analyses (O'Keefe & Hoeken, 2021; Sopory & Dillard, 2002; Van Stee, 2018) found that metaphors have a small but favourable 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 (Sopory & Dillard, 2002). The effect of metaphors on attitudes, however, appears to be variable as O'Keefe and Hoeken (2021) showed that the 95% prediction interval for the persuasive effect of metaphor includes zero – suggesting that the effect in "the next application (e.g., the next study)" (p.3) may be either positive or negative.

While these meta-analyses included studies from contexts such as advertising, politics, and health, none 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 with limited information, people can form attitudes towards new technology instantly (Druckman & Bolsen, 2011; Van Giesen et al., 2015). Initially, people tend to rely more on affect – i.e., emotions and feelings towards the technology, whereas this changes over time when cognition – i.e., thoughts and beliefs towards the technology 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.

2.4 Effect of comprehension on attitude

Research suggests that comprehension is important in attitude formation and change (Seel, 2012; Wyer & 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 impact attitudes (Wyer & Shrum, 2015). Within the so-called message-learning approach model, comprehension is regarded as one of the basic processes necessary for achieving attitude change (Seel, 2012).

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.

2.5 Metaphors in communication about quantum technology

Metaphor use has already been recommended in public communication about quantum technology (Grinbaum, 2017; Hilkamo & Granqvist, 2022). Grinbaum (2017), for instance, 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 & Granqvist (2022) 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 about quantum technology. Our research therefore aims to explore whether a (non-)metaphorical explanation of a quantum phenomenon in a news article affects comprehension and shapes attitudes. Specifically, we examine the influence of explanation on perceived comprehension of the news article, actual comprehension of the quantum phenomenon, and affect-based and cognition-based attitudes towards quantum technology. We measured perceived comprehension at the level of the entire text based on Akin et al.'s (2021) finding that people's perceptions of their own knowledge of an emergent technology may be influential for their attitudes towards it. We measured actual comprehension at the level of the quantum phenomenon to directly test Grinbaum's (2017) claim that understanding a quantum phenomenon is important in shaping people's perceptions of quantum technology.

Prior studies worked with metaphor-enhanced texts, where the metaphor was added to the original explanation (e.g., Alexander & Kulikowich, 1991; Braasch & Goldman, 2010; Glynn & Takahashi, 1998; Jaeger & Wiley, 2015). 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 tested three different versions of a news article about a new quantum computer: one with a non-metaphorical quantum phenomenon explanation, one with a metaphorical quantum phenomenon explanation, and one with no quantum phenomenon explanation (i.e., a control). Our research questions (RQs) are as follows (see Figure 1 below):

RQ1 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

RQ2 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?

RQ3 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?

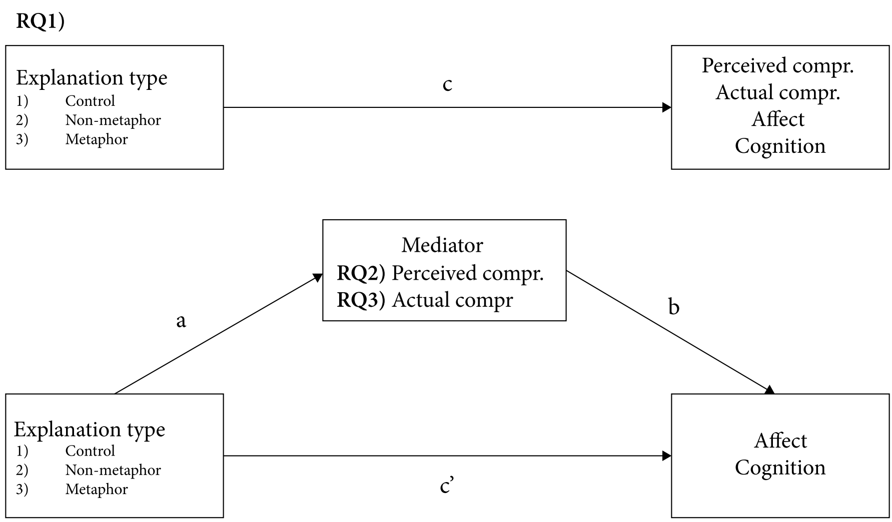

Figure 1. Visual representation of the research questions
Note. The top path diagram illustrates RQ1, examining the direct relationships between the variables. The bottom path diagram shows the two mediation models: RQ2 examines perceived comprehension as a mediator, and RQ3 examines actual comprehension as a mediator.

2. Here we deviated from the preregistration, given that we made the call to examine perceived comprehension of the text as a whole.

3. Methodology

Following our research questions, we performed an online experiment. The study information, design plan, sampling plan, variables and analysis plan were pre-registered on the Open Science Framework before data collection started (https://osf.io/qmryu). The study was approved by the Ethics Review Committee of the Faculty of Science, Leiden University (reference number 2023-021).

3.1 Materials

We designed a newspaper article, based on a real event (NOS, 2024), about the European Commission's decision to build a new quantum computer in the Netherlands. The text contained 162 words in the control conditions, with an additional paragraph of 73–80 words in the explanation conditions (see Figure 2 for the English translation).

We chose to explain the quantum phenomena *superposition* or *entanglement* in the explanation conditions, as these underlie quantum technology, are counterintuitive from the perspective of everyday experiences and are often explained in popular communication (Meinsma et al., 2023, 2025). To identify which metaphors for superposition and entanglement were deemed most accurate for communicating with non-experts, we conducted a small study among Dutch-speaking quantum experts.

3.1.1 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. After providing consent, confirming 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 (presented in random order) about one of two quantum phenomena (superposition/entanglement). The metaphors were generated by ChatGPT 3.5, as this tool is widely used and known for its accessibility, and as science communication research encourages investigating the accuracy of AI-generated content (Schäfer, 2023).

After reading each metaphor, participants rated its accuracy and validity on a 7-point Likert scale. They also indicated how likely they were to use a metaphor when talking to non-expert audiences about superposition or entanglement (7-point scale). Next, participants ranked the metaphors from most to least likely for use in a conversation with non-expert audiences and justified their ranking.

Universiteit Leiden

NEW QUANTUM COMPUTER FOR THE NETHERLANDS

The Netherlands will receive one of eight new quantum computers that the European Commission is having built. They hope that this will give Europe a better competitive position in the field of quantum technology.

23 October 2024

The Dutch quantum computer costs 20 million euros. It will be located at the Amsterdam Science Park and is expected to be built in the summer of 2026. Quantum computers work differently than the computers we use now. They use the principles of quantum physics, a domain within physics that deals with the smallest particles. An important characteristic of this is *superposition/entanglement*. Quantum computers use *superposition/entanglement*, among other things, as a result of which, in the future, they may be able to solve certain problems faster than our current computers can.

	Item: Superposition	Item: Entanglement
Control	*No text*	*No text*
Non-metaphorical	Superposition is a quantum phenomenon. A particle in superposition is not just in one state. As long as the particle is in superposition, it is in a combination of different states at the same time. This situation continues until we measure the particle. Only when we perform a measurement on the particle does the particle enter a single state. Particles in the quantum world can therefore exist in multiple states at the same time until they are measured or observed. This is how the quantum world works.	Entanglement is a quantum phenomenon. When two particles are entangled, it means that their states are somehow connected. If you measure the state of one particle, you immediately know what the state of the other particle is. Even if those particles are on opposite sides of the universe. So the state of one particle ensures that the state of the particle it is entangled with is fixed. This is how the quantum world works.
Metaphorical	Superposition is a quantum phenomenon. A particle in superposition can be compared to a coin spinning in the air. As long as the coin is spinning, it appears to be heads and tails at the same time. This situation continues until we slap the coin on the table. Only when we slap the coin on the table does the coin land on either heads or tails. The coin therefore appears to be heads and tails at the same time until it is measured or observed. That is how it works in the quantum world.	Entanglement is a quantum phenomenon. Entangled particles can be compared to a pair of dice where the outcomes are always the same. When one die is thrown, the outcome of the other die is immediately determined. Even if it is thrown on the other side of the gaming table. The outcome of one die therefore ensures that the outcome of the die it is connected to is fixed. That is how it works in the quantum world.

The arrival of a quantum computer is an important moment for the competitive position of the Netherlands in quantum technology. But what the technology will mean exactly for you and me is still unclear. The researchers involved hope to find out more about this with this project.

Figure 2. Translated English version of the news article

Finally, we asked if they knew of an alternative metaphor for superposition or entanglement. Those who answered "yes" were prompted to shortly describe it, and rate its accuracy and validity.

3.1.2 Expert insights: Results

The survey ran between January 15th and March 15th, 2024, resulting in $n=22$ completed surveys. Most participants were scientists working in a quantum-related field ($n=21$), and one indicated to be an engineer. 12 participants evaluated the superposition metaphors, and 10 the entanglement metaphors. The median completion time was 14:50 minutes. Experts indicated it was very likely ($M=5.68$, $SD=1.36$) that they would use a metaphor in conversations with non-expert audiences to explain superposition or entanglement.

The coin metaphor scored highest for superposition ($M=4.13$, $SD=1.86$) and the dice metaphor for entanglement ($M=5.30$, $SD=1.89$; Table 1). In addition to being preferred by experts, these metaphors are also commonly used in popular-scientific communication about quantum (e.g., Bornman, 2021; Servifyspheresolutions, 2025). Consequently, we selected these two metaphors for the main experiment.

At this point, it is important to acknowledge the partial nature of metaphorical mappings as there is never a one-to-one alignment between source and target (Lakoff & Johnson, 1980). This partiality is particularly true for metaphors for superposition and entanglement because neither has a counterpart in classical physics. In everyday life, things like a bike, a coin or a person can only be in one state (e.g., one place) at a time, never in two. Similarly, two bikes, dice or people are never connected in such a strong way that one of them determines the state of the thing it is entangled with. However, quantum particles in superposition can *genuinely* exist in multiple states at the same time, and entangled quantum particles are *genuinely* connected in such strong ways. Consequently, the metaphors say something true about these phenomena. And although coins are never simultaneously heads and tails and dice outcomes are not dependent on one another, people can probably imagine such scenarios — thus providing sufficient justification for using these (inherently flawed) metaphors in our main experiment.

3.2 Design and procedure

The main study used 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 they would not use any external sources, as we wanted to explicitly discourage the use of search engines and AI (Meem

Table 1. Mean total scores (and SDs between brackets) for superposition (top) and entanglement (bottom)

	Superposition	
	Metaphor	**Total**
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**
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)

Note. The total scores are an average of the scores on accuracy and validity, and are ordered from highest to lowest. Answers were provided on a 7-point Likert scale (1=less accurate/valid – 7=more accurate/valid). The precise wordings per metaphor can be found in Table A.3 in the Appendix

et al., 2024). General information (age, gender, education) and five control variables were asked, after which participants were randomly assigned to one of the conditions. After reading the news article, participants answered questions about their perceived comprehension, actual comprehension, affect-based and cognition-based attitudes.

3.3 Participants

The experiment ran between January 29th and February 3rd, 2025 and resulted in $n = 1{,}176$ 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 which they can exchange for money amongst other rewards. The median survey completion time was 5:50 minutes.

$N = 9$ participants were excluded from the full analyses because they finished the survey within 90 seconds ($n = 4$); answered both the attention check and the actual comprehension question incorrectly ($n = 3$); or reported being younger than 18 ($n=2$). As 36 participants failed to answer the actual comprehension question by providing bogus responses, 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 $n=1{,}167$ participants for the remaining analyses.

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

3.4 Dependent variables

Perceived comprehension. Perceived comprehension of the newspaper article was measured with 3 items (Miele & Molden, 2010) "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). Because the three items showed good internal consistency (Cronbach's alpha=0.73), meaning they correlate well and effectively measure the same underlying construct (Tsang et al., 2017), items were averaged into an index ($M=4.38$, $SD=1.20$).

Actual comprehension. To verify recall of the quantum phenomenon mentioned in the news article, participants answered a multiple-choice question (answer options: superposition, entanglement, tunnelling, decoherence, I don't know), and 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 0–4 based on the text provided by participants ($M=0.43$, $SD=0.78$). A point was given for each of the following elements:

– Superposition: (1) mention the connection with quantum; (2) something can be A and B at the same time; (3) a measurement has influence, (4) after which a single state is left
– Entanglement: (1) mention the connection with quantum; (2) there is a connection/correlation between parts; (3) measurement of one part influences the other part; (4) this influence is not dependent on the distance

The index was coded reliably, as intercoder agreement between two coders with knowledge of quantum physics (ALM and a PhD student of JC) was perfect to near-perfect for almost all cases.

Affect-based attitude. Affect-based attitude was measured with 7 items (Van Giesen et al., 2018): "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 suggesting adequate internal consistency).

Cognition-based attitude. Cognition-based attitude was measured with 7 items (Van Giesen et al., 2018): "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 suggesting adequate internal consistency).

3.5 Control variables

We further measured five control variables, since we expected these to potentially influence our dependent variables: awareness of quantum, science news use, interest in new technology, faith in intuition and need for cognition.

3.6 Data analysis and randomization checks

Data were analysed with jamovi 2.3.28. Results of the two items (superposition and entanglement) were collapsed to make generalizable claims on the effectiveness of (non-)metaphorical explanations across quantum phenomena.

Randomization checks confirmed even distributions of participants across the three conditions for gender[3] ($\chi^2(2) = 1.79$, $p = 0.408$), age ($\chi^2(6) = 3.98$, $p = 0.679$), education level ($\chi^2(4) = 2.86$, $p = 0.581$), 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 covariates in the analyses.

3. The 'other' category was too small to meet the assumptions of the chi-square test of independence, which we therefore excluded.

4. Results

4.1 Main effects (RQ1)

To answer RQ1a-d, four separate ANOVAs were performed using explanation type as the independent variable and perceived comprehension, actual comprehension, affect-based attitudes, and cognition-based attitudes as dependent variables. Statistically significant differences between conditions were found for perceived comprehension of the news article ($F(2,1164) = 8.49$, $p < .001$, $\eta^2 = .014$) and actual comprehension of the quantum phenomenon ($F(2,1131) = 32.6$, $p < .001$, $\eta^2 = .055$), but not for affect-based ($F(2,1164) = 1.48$, $p = .23$) or cognition-based attitudes ($F(2,1164) = 1.81$, $p = .16$).

Table 2. Means (and SDs between brackets) for comprehension (top) and attitude (bottom)

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				
	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]

Note. Scores based on the estimated marginal means estimated from the statistical model. Perceived comprehension and affect- and cognition-based attitudes were measured on a 7-point Likert scale (1 = lower scores – 7 = higher scores). Actual comprehension was measured on a scale from 0 to 4 (0 = low/no comprehension – 4 = high comprehension of the phenomenon).

Pairwise comparisons with a Bonferroni correction showed that for perceived comprehension of the news article, the control group scored significantly higher than both the non-metaphorical (mean difference = 0.32, SE = 0.09, p < .001) and the metaphorical group (mean difference = 0.29, SE = 0.08, p = .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 of the quantum phenomenon, the control group scored significantly lower than the non-metaphorical (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 and the metaphorical group was not significant (mean difference = 0.13, SE = 0.06, p = 0.069).

These results suggest that adding a quantum phenomenon explanation (irrespective of whether it is metaphorical or non-metaphorical) to a news article about quantum technology is beneficial for increasing people's actual comprehension of the phenomenon. By contrast, it makes them feel they have understood the news article as a whole less well.

4.2 Mediation effects (RQ2-3)

Although no significant differences were found between conditions on affect-based and cognition-based attitudes (Section 4.1), mediation can still exist in the absence of a main effect (O'Rourke & MacKinnon, 2018). To answer RQ2 and RQ3, four separate mediation analyses were therefore conducted using the jAMM module in jamovi, with explanation type as the independent variable, perceived comprehension (for RQ2; Section 4.2.1) and actual comprehension (for RQ3; section 4.2.2) 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 5,000 bootstraps. In performing the mediation analyses, we chose the control group as a reference group given the outcomes of the main effect analyses (Section 4.1).

4.2.1 Perceived comprehension of the news article as mediator (RQ2)

We found some evidence that perceived comprehension of the news article acts as a mediator between explanation type and both types of attitudes, as none of the confidence intervals for the indirect effects contained zero (See Figure 3 below).

As shown in Figure 3, we found a small but statistically significant decrease in perceived comprehension when participants received the non-metaphorical (β = −0.12, p < .001) or metaphorical explanations (β = −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

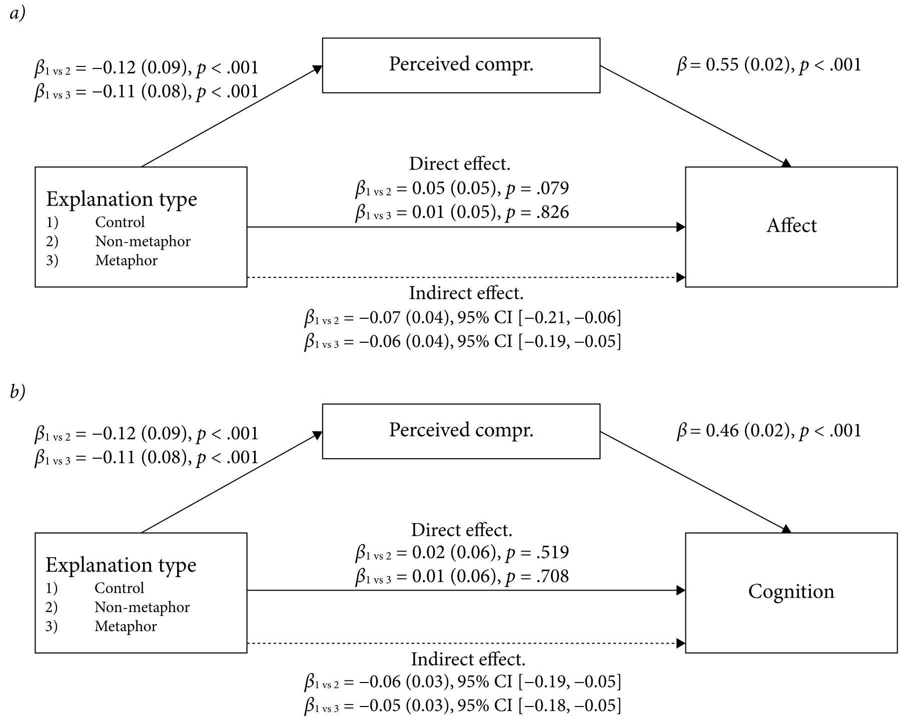

Figure 3. Visual representation of the results for RQ2
Note. The top top path diagram displays results for affect as dependent variable. The bottom path diagram displays results for cognition as dependent variable. Note that $\beta_{1\text{ vs }2}$ ($\beta_{1\text{ vs }3}$) denotes the effect size for the non-metaphorical explanation (metaphorical explanation) with control as reference.

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, indicating a relationship between higher perceived comprehension of the news article and feeling and viewing quantum technology more positively.

Given these findings, the indirect effects found between explanation type and affect or cognition, with perceived comprehension as the mediator, were statistically significant ($p < .001$) but very small (β's 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 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.

4.2.2 Actual comprehension of the quantum phenomenon as mediator (RQ3)

We found some evidence that actual comprehension of the quantum phenomenon acts as a mediator between explanation type and both types of attitudes, as again none of the confidence intervals for the tested indirect effects contained zero (See Figure 4 below).

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 ($\beta = 0.28$, $p < .001$) and cognition-based attitudes ($\beta = 0.27$, $p < .001$) from actual comprehension. This indicates that there is a relationship between higher actual comprehension of the quantum phenomenon and feeling and viewing quantum technology more positively.

Given these 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 between 0.05 and 0.07). The direct effect, i.e., 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. This is called inconsistent mediation, as the indirect and direct effects have opposing signs, resulting in a significant mediating effect while the total effect is non-significant (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 attitudes.

5. Discussion

5.1 Key findings and relation to previous research

This study examined, through a large-scale experiment, how (non-)metaphorical explanations of a quantum phenomenon influenced comprehension and attitudes. RQ1 asked to what extent the use of a non-metaphorical vs a metaphorical vs no explanation of a quantum phenomenon in a news article influences the (a) perceived comprehension of the news article and (b) actual comprehension of the

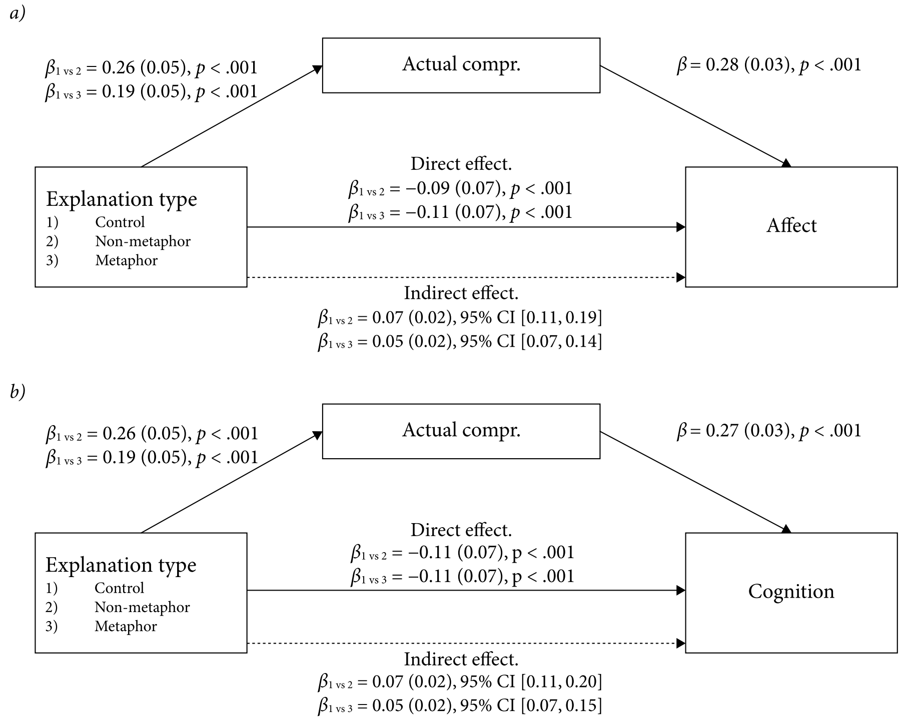

Figure 4. Visual representation of the results for RQ3
Note. The top top path diagram displays results for affect as dependent variable. The bottom path diagram displays results for cognition as dependent variable. Note that $\beta_{1\ \mathrm{vs}\ 2}$ ($\beta_{1\ \mathrm{vs}\ 3}$) denotes the effect size for the non-metaphorical explanation (metaphorical explanation) with control as reference.

quantum phenomenon, as well as (c) affect-based and (d) cognition-based attitudes towards quantum technology.

In contrast to previous research, metaphors did not lead to higher levels of perceived comprehension (Reijnierse et al., 2025) or enhance people's 'illusion of comprehension' (Jaeger & Wiley, 2015; Wiley et al., 2018) of a text. The opposite even emerged, where explanations – either metaphorical or non-metaphorical – had a detrimental effect on participants' perceived comprehension of the text, but improved their actual comprehension of the quantum phenomenon described, compared to the condition without explanation.

The extra information (i.e., explanation of a quantum phenomenon) may have caused information overload where the length and amount of information can make a text seem more complex, resulting in lower perceived comprehension. At the same time, participants were likely unaware of what superposition and entanglement mean due to limited familiarity with the target domain of quantum science and technology. Consequently, providing an explanation may have logically contributed to their comprehension of the quantum phenomenon.

It should be noted, however, that actual comprehension scores were low across conditions (≤ 0.62), suggesting that people did not grasp the quantum phenomena well. Some first insights into this matter can be found in participants' answers to the open question tapping their actual comprehension. These show that on average only 13.1% of the participants in the metaphor conditions reused the provided metaphors, possibly suggesting that the metaphors we used did not evoke a sufficiently vivid image in people's minds (Wyer & Shrum, 2015), preventing a metaphor effect from occurring.

As for the effects on affect-based and cognition-based attitudes, we found no differences between the three conditions. Despite meta-analyses finding a small persuasive effect of metaphors over literal messages on attitudes (O'Keefe & Hoeken, 2021; Sopory & Dillard, 2002; Van Stee, 2018), and previous research suggesting that using metaphors to explain quantum phenomena might improve attitudes towards quantum technology (Grinbaum, 2017), we thus did not find such effects in our study. One possible explanation for this is that the lack of familiarity with the target domain may have made the cognitive effort required to process the metaphor too great (Sopory & Dillard, 2002; Van Stee, 2018).

At the same time, however, attitudes towards quantum technology were relatively positive across conditions. This suggests that resistance, found with other emergent technologies (Druckman & Bolsen, 2011; Kurath & Gisler, 2009), may currently not apply for quantum technology. Apparently, reading a neutral-to-slightly-positive article about quantum technology sufficed to form positive attitudes, regardless of the presence of additional (metaphorical) explanation about underlying phenomena.

Our second research question asked to what extent perceived comprehension of the news article mediates the effects of explanation type on attitudes. Results of the mediation analysis 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. These results are in line with Akin et al. (2021), who suggested that people's *beliefs* about their own knowledge of a technology were more influential in shaping their attitudes than their *actual* knowledge.

The final research question asked to what extent actual comprehension of the quantum phenomenon mediates the effects of explanation type on attitudes. While we found a very small positive indirect effect of explanations on attitudes mediated by actual comprehension, this was counteracted by a direct negative effect. Contrary to what Grinbaum (2017) proposed, improving people's actual comprehension of the underlying quantum phenomena thus does not necessarily result in more positive views towards quantum technology.

5.2 Limitations and suggestions for future research

While our study provides novel insights into the role of (metaphorical) explanations in communication about quantum technology, it also has some limitations. First, while we carefully selected the metaphors by consulting quantum experts first (Section 3.1), it could well be that comprehension and attitudes would have been affected more or differently with a different metaphor, for example the famous metaphor of Schrödinger's cat.

In light of the discussion about metaphor selection, it is also important to reconsider the question whether metaphors should be used at all when communicating about quantum to non-expert audiences. Some experts in our study indicated that Schrödinger's cat is incorrect and too complicated to bring across. Experts also commented on metaphor more generally, arguing that they make 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 about resistance and ties in with Feynman's (1967) quote that quantum phenomena are too complex to explain, which could be bad for the democratization of quantum technology (Seskir et al., 2023).

In terms of text manipulations, our two explanation conditions contained more words than the control condition. While this design reflects a realistic consequence of Grinbaum's (2017) argument, as including an explanation of quantum phenomena when communicating about quantum technology inevitably increases text length, it may have introduced a potential confound. To address this limitation, future research could compare our explanation conditions with a control text containing equally long, but unrelated, extra content. To limit the effect of a single message, different types of unrelated content should be designed, and the results should be collapsed (see Slater et al., 2015).

Finally, the way in which we measured our dependent variables also raises questions for future research. Although our decision to measure comprehension at different levels (text and quantum phenomenon) was most consistent with the questions raised in the literature (Akin et al., 2021; Grinbaum, 2017), we recommend further research to examine perceived comprehension at the quantum phenomenon level and/or actual comprehension at the text level, as well.

Such further research may also consider different ways to measure actual comprehension, for instance through closed multiple-choice questions (Alexander & Kulikowich, 1991), open recall questions (Glynn & Takashi, 1998), inference questions (Yanowitz, 2001) and prompting to write a full essay (Braasch & and Goldman, 2010; Jaeger & Wiley, 2015). These different operationalizations probably yield different comprehension scores, with some tapping into more shallow levels of comprehension and others into deeper ones (see also Bernholt et al., 2023). Qualitative research, such as interviews, could reveal how people actually understand these metaphors and where potential misunderstandings and resistance arise.

5.3 Conclusion

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 *feelings* of having understood the text, journalists would be better off skipping the explanation of counterintuitive quantum phenomena. De Jong (2025) even argues that quantum phenomena should not be explained to non-expert audiences at all, but rather that there should be an increased focus on the functional capacities of quantum technology to lower the barrier to engage in ethical discussions about quantum.

If, however, a journalist's goal is to increase people's *actual* understanding of phenomena underlying quantum technology, providing an explanation of the phenomenon is recommended. Given that we found no differences between metaphorical and non-metaphorical explanations, our findings suggest that metaphors do not provide a communicative advantage for enhancing understanding or shaping attitudes in this context. Consequently, using non-metaphorical explanations in communication about quantum phenomena might be the preferred option.

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Data availability statement

Supplemental data supporting this study's findings are openly available on the Open Science Framework at https://osf.io/qmryu.

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