Evaluating Art-Based Science Communication of Quantum Physics

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Abstract

This research proposes art-based science communication as an effective approach for the science communication of quantum physics. Metaphors, narratives, and visualizations in art can improve the understanding of abstract scientific concepts (Dahlstrom & Ritland, 2012), elicit emotions, and reach wider audiences (Fraaije et al., 2022). Therefore, art-based engagement could be effective in science communication, especially regarding the complex topic of quantum physics, which has proven challenging to communicate (Van De Merbel et al., 2024). To study the effects of art-based science communication, an art-based intervention representing the quantum phenomenon of wave-particle duality was created based on the guide from Media and Arts Technology (Bryan-Kinns & Reed, 2023). The intervention was exhibited in a public library, and its effects on citizens were evaluated using the framework from research group IMPACTLAB (Land-Zandstra et al., 2023), which measures output (demographics and science capital) and outcome (emotions and direct effects on the participants), leading to long-term impact and thereby effective science communication. The quantitative survey was supplemented with qualitative observations. Participants (n = 55) reported positive changes in knowledge, interest, attitude, and behavioral intention related to quantum physics after experiencing the art-based intervention. Results indicate that the art-based intervention, through eliciting emotions, has mainly positive effects on knowledge and behavioral intention regarding quantum physics. This aligns with the literature; however, in this study, the effects were small. The findings suggest that art-based science communication can be engaging and thereby effective in the science communication of complex and abstract scientific concepts such as quantum physics. The research concludes with a reflection and directions for further research.

Keywords: science communication, art-based public engagement, quantum physics

Evaluating Art-Based Science Communication of Quantum Physics

Quantum mechanics is a part of fundamental physics that describes how particles behave at the subatomic level. In terms of abstract mathematics, quantum theory is well understood. However, it is difficult to imagine how the world at quantum scale works. The properties and behaviors that happen on this small scale are fundamentally different from those in classical physics that we experience. While quantum properties can be clearly mathematically described, they often feel paradoxical, such as quantum particles being both a particle and a wave at the same time (Ismael, n.d.). Additionally, it is impossible to directly observe quantum behavior since quantum particles are too small to reflect light. This leads to descriptions of the quantum world relying on metaphorical constructs such as the spin of electrons, quantum leaps, and wave properties (Schwab, 2018). For these reasons, physicist and Nobel laureate Richard Feynman famously declared that "nobody really understands quantum mechanics" (Feynman, 1965).

After the first quantum revolution during the twentieth century, in which fundamental laws of the quantum world were discovered (Dowling & Milburn, 2003), the current second quantum revolution is bringing the development of quantum-based technologies such as quantum sensors, quantum networks and the proclaimed quantum computer. Quantum technology is expected to have a significant impact on society (Vermaas, 2017). While promising, such innovations can have disruptive effects (Mooney, 2010). Especially regarding quantum and its increasing integration in society, science communication that facilitates early and democratic engagement between scientists and society is essential to ensure responsible research and innovation (Fraaije et al., 2022; Van De Merbel et al., 2023). Besides ethical considerations, engaging citizens leads to more public support (Mooney, 2010) and more socially robust solutions (Roberson et al., 2021).

However, studies reveal that citizens perceive quantum as interesting and globally important but only understand it as related to some "advanced science" (Busby et al., 2018; Van De Merbel et al.,

2023). This suggests that existing efforts have not been effective in communicating quantum physics to citizens, which might not be surprising given its complex and abstract nature. Difficulties in communicating the fundamentals of quantum in an engaging way seem to lead to hyped quantum technologies (Roberson et al., 2021). For example by highlighting potential breakthroughs in new quantum technologies, such as the quantum computer, while substantial technical challenges remain. Consequently, these false expectations can contribute to misinterpretation and mistrust among the public (Achiam et al., 2024).

Art-based public engagement emerges as a promising approach. Art contains metaphors, narratives, and visualizations that can support science communication by making complex and abstract concepts tangible (Dahlstrom & Ritland, 2012). Moreover, by appealing to emotions, an art-based approach can enhance the effects science communication and reach wider audiences (Fraaije et al., 2022).

Despite recognition of the potential of an art-based approach, the evaluation of the specific effects of science communication on the knowledge, interest, attitudes, and behavioral intentions of citizens is lacking (Fraaije et al., 2022; Kappel & Holmen, 2019). Thus, evaluating the potential of art-based science communication can contribute to a better understanding of the effectiveness of science communication efforts.

Research Questions

This study proposes an art-based approach to the science communication of quantum physics. Since quantum technologies are increasingly integrated into society, it is important to involve citizens despite the challenges (Van De Merbel et al., 2023). Given the promising qualities of art in making complex and abstract scientific concepts tangible (Fraaije et al., 2022), evaluating this novel approach can provide valuable insights for more engaging and effective science communication, contributing to both theory and practice. This leads to the main research question:

What are the effects of art-based science communication, through eliciting emotions, on knowledge, interest, attitude, and behavioral intention of citizens regarding quantum?

This main research question is divided into four sub-research questions:

Sub-research question 1: **What is the effect of art-based science communication on emotions?**

Sub-research question 2: **What is the effect of art-based science communication on knowledge, interest, attitude, and behavioral intention regarding quantum?**

Sub-research question 3: **What is the relation between emotions and knowledge, interest, attitude, and behavioral intention regarding quantum?**

Sub-research question 4: **What recommendations can be made for designing effective art-based science communication interventions based on the observed effects?**

In this study we employ a quantitative cross-sectional post-test-only design to capture the immediate effects of a developed art-based intervention on participants, complemented by qualitative observations. This aligns with the exploratory nature of the study.

Literature Review

Defining Science Communication

Science communication, including communication on quantum physics, plays a pivotal role in bridging the gap between science and society, aiming for a positive effect on epistemic and moral trust, social acceptance, and democratic involvement of citizens (Kappel & Holmen, 2019). Burns et al. (2003) define science communication as “The use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science: awareness, enjoyment, interest, opinion-forming, and understanding.”

Science Communication Effects

Knowledge, interest, attitudes, and behavioral intentions are indicators of the effectiveness of science communication (Peeters et al., 2022). Knowledge refers to the understanding of a scientific

topic. Interest refers to the intention to learn more. Attitude encompasses a person's feelings, beliefs, and predispositions. Positive attitudes towards science, including quantum mechanics, can lead to greater acceptance and support (Fishbein & Ajzen, 2009). Behavioral intention reflects the intention to engage in certain behavior in the future and is based on attitude (Fishbein & Ajzen, 2009).

Art-Based Science Communication

Communicating about quantum poses unique challenges due to its complex and abstract nature. Art-based public engagement emerges here as a promising approach due to its strengths in making concepts tangible (Dahlstrom & Ritland, 2012), activating emotions and reaching wider audiences (Fraaije et al., 2022).

Art contains metaphors, narratives, and visualizations, which can be leveraged for engaging and thereby effective science communication. Metaphors map new knowledge to familiar contexts, making abstract scientific concepts more tangible (Dahlstrom & Ritland, 2012). Although never perfectly accurate, metaphors serve as effective introductions for non-experts, sparking interest and providing a basis for deeper understanding (Smedinga et al., 2023). Narratives can apply scientific concepts to personal contexts, making them more familiar and through this personal relevance, appeal to emotions (Dahlstrom & Ritland, 2012; Strick & Helfferich, 2023). Visualizations can make complex scientific concepts more intuitive (Dahlstrom & Ritland, 2012). Additionally, aesthetically pleasing representations in art can attract diverse audiences who might otherwise not easily connect with science (Born & Barry, 2010).

Emotional Engagement

Art evokes strong emotions that can enhance the effectiveness of science communication by making the content more memorable and engaging (Bastiaansen et al., 2019). Emotions play a crucial role in how individuals engage with and retain scientific information (Davies et al., 2019). However, there is limited research on the relation between emotions elicited by art-based science communication

and its effects. Emotions relevant to this study can be broadly categorized into two main dimensions of emotional memory: pleasure (valence) which refers to the positivity or negativity of the emotional experience, and intensity (arousal) which refers to the strength of the emotional experience (Bradley & Lang, 1994). Pleasurable and intense emotional experiences can provide engagement, enhancing memory retention and creating a more favorable attitude towards the scientific content (Peeters et al., 2022).

Case Studies of Art-Based Science Communication

Despite its promising qualities, there have been few cases where art-based public engagement has been employed in science communication efforts. However, these initial results seem promising. Strick & Helfferich (2023) identified active ingredients that drive effective art-based science communication. By making science personally relevant, accessible, and interactive through art, communicators can evoke emotions and have a positive effect on participants' knowledge, interest, attitude, and behavioral intention. Personal relevance is the feeling that science touches participants' personal lives, associated with strong emotions. Accessibility refers to the ease of participating and interactivity to active engagement; these ingredients increase knowledge and familiarity with science. Focusing on quantum physics, Decaroli & Malinowski (2022) reported how art-based engagement could effectively explain complex quantum concepts, provoke questions, and inspire participants. Similarly, Walker & Von Ompteda (2014) found that narrative aspects of art, when closely collaborating with scientists, yielded positive results in public engagement regarding quantum mechanics.

Evaluating Science Communication

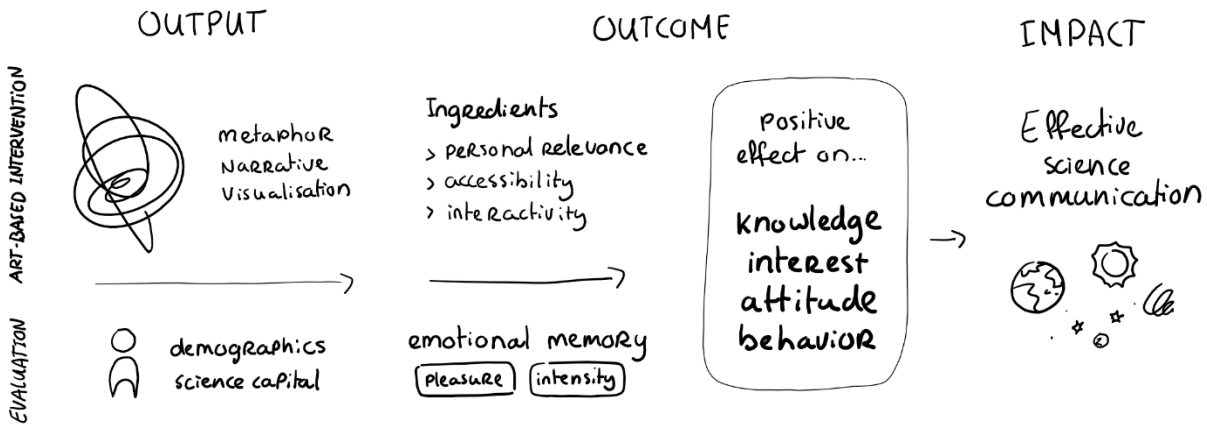
Evaluating effects on knowledge, interest, attitudes, and behavioral intentions can provide insight in the effectiveness of science communication efforts. However, the evaluation of science communication is often lacking (Fraaije et al., 2022; Kappel & Holmen, 2019). An alleged cause is the absence of a reliable evaluation framework (Kappel & Holmen, 2019). In response, the research group

IMPACTLAB developed a framework to evaluate the effects of science communication (Land-Zandstra et al., 2023). The framework considers three major dimensions: output, outcome, and impact. Output measures include participants' demographic information and science capital. Science capital refers to a person's existing knowledge, attitudes, experiences, and skills regarding science. It influences how people engage with and understand science (Archer et al., 2015). Outcome measures include emotional memory and changes in knowledge, attitudes, interest, and behavioral intentions. Impact concerns long-term effects on society (this dimension falls outside the scope of this study).

This research adopts the framework of Land-Zandstra et al. (2023). In Figure 1 an illustrated overview of the literature, based on the IMPACTLAB framework is presented (Land-Zandstra et al., 2023).

Figure 1

Overview of the Literature Based on the IMPACTLAB Framework (Land-Zandstra et al., 2023)



Method

This section describes the approach used to evaluate the art-based science communication intervention regarding quantum physics. The methodology received ethical approval within the Media Technology framework for research ethics at Leiden University (register code FWN2022-008).

Research Design

This study employs a quantitative cross-sectional post-test-only design, capturing data at one moment in time to assess the immediate effects of the art-based intervention. To enrich the quantitative findings, qualitative observations were made during the intervention. These observations were not systematically analyzed but provided contextual insights. The cross-sectional design was chosen for its efficiency in collecting data, its convenience for the participants, and its ability to capture participants' initial responses immediately after experiencing the installation. This design fits the exploratory nature of this study since existing research evaluating art-based science communication is limited.

Participants

The target population comprised citizens of the Netherlands aged 18 and above. This adult group is valuable for science communication, as quantum technology will likely influence their lives, making it important that they are informed and able to exert influence, for example by voting. Participants were sampled using non-probability self-selection sampling. Participants voluntarily participated with informed consent, ensuring genuine interest in the art installation and research.

Art-Based Intervention

The art-based intervention took the form of an interactive art installation, created based on the guide from Media and Arts Technology (Bryan-Kinns & Reed, 2023). Through metaphor, narrative, and visualization (Dahlstrom & Ritland, 2012), the fundamental quantum phenomenon of wave-particle duality was represented in the artwork. The ingredients driving effective science communication were

incorporated into the installation (Strick & Helfferich, 2023). Personal relevance was featured through a recognizable book metaphor, accessibility in its simplicity, and an interactive element based on movement illustrating the collapse of the wave-function. The installation was designed to be engaging and thought-provoking, encouraging curiosity, and exploration. See Appendix A for details on the design of the art-based intervention. In Figure 2 the final art-based intervention is presented. The following video gives an impression: https://youtu.be/-A6pF1pIHiE.

Figure 2

The Final Art-Based Intervention

Setting

The art-based intervention was presented in an exhibition format, as an artwork, in a public space. This context is where citizens are likely to encounter such an intervention, giving the study more ecological validity (Keyson & Bruns, 2009). The exhibition of the art-based intervention was held in a local library in the neighborhood Ypenburg in The Hague, The Netherlands. This library is part of the The Hague Library network. The exhibition took place during the library's opening hours over five weekdays

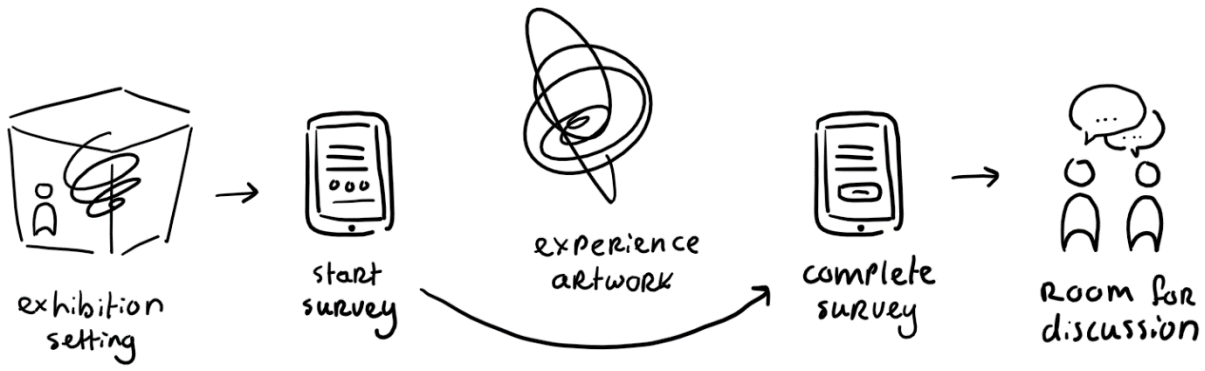
in May 2024. A description explaining the artwork was provided in both Dutch and English, documented in Appendix B. The researcher was approachable for questions or comments during the exhibition.

Data Collection

Data was collected using an adapted questionnaire from the IMPACTLAB toolkit (Land-Zandstra et al., 2023). The questionnaire was recreated digitally to facilitate answering, analyzing, and managing the data, using the platform Qualtrics. Participants could scan a QR code near the artwork and complete the questionnaire on their smartphones. Both English and Dutch versions were available depending on the participant's language preference. It took no longer than 15 minutes for participants to complete the survey. An illustrated overview of the described steps is presented in Figure 3.

Figure 3

Overview of the Method



The survey included questions about the output (demographics and science capital) and questions about the outcomes of the art-based intervention (emotional memory, interest, attitude, knowledge, and behavioral intention). In this research, the third evaluation dimension, impact, was not directly measured. Impact refers to the long-term effects of science communication efforts on society and requires long-term data collection, which falls outside the timeframe of this research. The

questionnaire was adapted to the art-based intervention and included quantum-specific questions. The full questionnaire is provided in Appendix C.

The choice of using a survey was driven by its efficiency in collecting data from a large number of participants in a structured manner. Surveys are effective in quantifying variables and capturing self-reported data on knowledge, attitudes, and behaviors, which are essential for understanding the impact of the intervention (Peeters et al., 2022).

In addition, qualitative observations were made by the researcher during the intervention. These observations included noting participants' questions, comments, and interaction with the artwork. Although not systematically analyzed, these observations provided contextual insights that complement the survey data.

Measures

Measures were derived and adapted from the IMPACTLAB toolkit (Land-Zandstra et al., 2023), created to evaluate the effectiveness of a science communication effort. The reliability and validity of these measures have been previously established by IMPACTLAB.

Output Measures

Output consisted of seven questions, including three on demographic information and four related to science capital (see Table 1). Reliability analysis was conducted on the four items of science capital. The scale demonstrated high internal consistency (Cronbach's alpha = .850). Therefore, a science capital scale was constructed and computed as the mean of the four items.

Table 1

Description of Output Measures

Measure	Description	Response format
Age	Age in years	Open-ended response
Gender	Gender	Man, woman, other
Education	Highest completed educational level	Multiple choice
Science capital	Composite measure of familiarity with science concepts, based on responses to four items	Scale (1-5)

Outcome Measures

Outcome included 12 questions. There were eight questions on emotional memory, divided in pleasure and intensity. These measures capture the subjective emotional responses evoked by the art-based intervention. The decision was made to analyze the emotions separately. As an exploratory study, this approach allows for a detailed and nuanced understanding of the emotions elicited by the intervention and their associations with knowledge, attitude, interest, and behavioral intention.

There were four questions on the effects of the art-based intervention (changes in knowledge, attitude, interest, and behavioral intention related to quantum) (see Table 2). The effect variables were also analyzed separately, because they represent different aspects of the participants' responses to the intervention, such as cognitive changes (knowledge), affective changes (attitude), motivational changes (interest), and behavioral changes (behavioral intention).

Table 2

Description of Outcome Measures

Measure		Description	Response format
Emotion			
	Pleasure	"How do you feel after experiencing the artwork?" Four items: Happy-Sad, Pleased-Annoyed, Hopeful-Despairing, Satisfied-Unsatisfied	Bipolar scale (1-10)
	Intensity	"Which words describe your feelings about the artwork best?" Four items: Relaxed-Thrilled, Dull-Full of Energy, Calm-Excited, Not Interesting-Interesting	Bipolar scale (1-10)
Effect variables			
	Knowledge	"Because of the artwork I now know more about quantum."	Likert scale (1-5)
	Interest	"After experiencing the artwork I want to know more about quantum."	Likert scale (1-5)
	Attitude	"Has your opinion of quantum changed after experiencing the artwork?"	5-point scale (1-5)
	Behavioral Intention	"After experiencing the artwork I would like to attend similar activities in the future."	Likert scale (1-5)

Data Analysis

The quantitative data was cleaned and analyzed using descriptive statistics and inferential statistical methods in SPSS 29. The main analysis focused on identifying correlations between emotional responses and effect variables to determine the effects of the art-based intervention. To examine these relationships, Spearman's rho (ρ) was used. Spearman's rho was chosen because it is suitable for ordinal data. Cronbach's alpha for reliability analysis was calculated to assess the internal consistency of the science capital scale. A value above 0.70 is considered acceptable for reliability. Notably, the question about attitude was recoded and reversed for the analysis to align with the scale of the other items.

Qualitative observations were used to provide additional context to the quantitative findings. These observations were not systematically analyzed but were considered to enrich the understanding of participants' interactions and responses to the intervention.

Results

The results include a descriptive analysis of the data followed by the inferential statistics. In addition, qualitative observations from the researcher are noted.

After excluding six participants who did not complete the whole survey, one participant who was 17 years old, and two participants who pretested the survey, 55 participants were included in the study. Seven participants completed the English version of the survey. All data was anonymized.

Descriptive Statistics

The descriptive statistics are given for output (demographics and science capital) and outcome (emotional memory and effects).

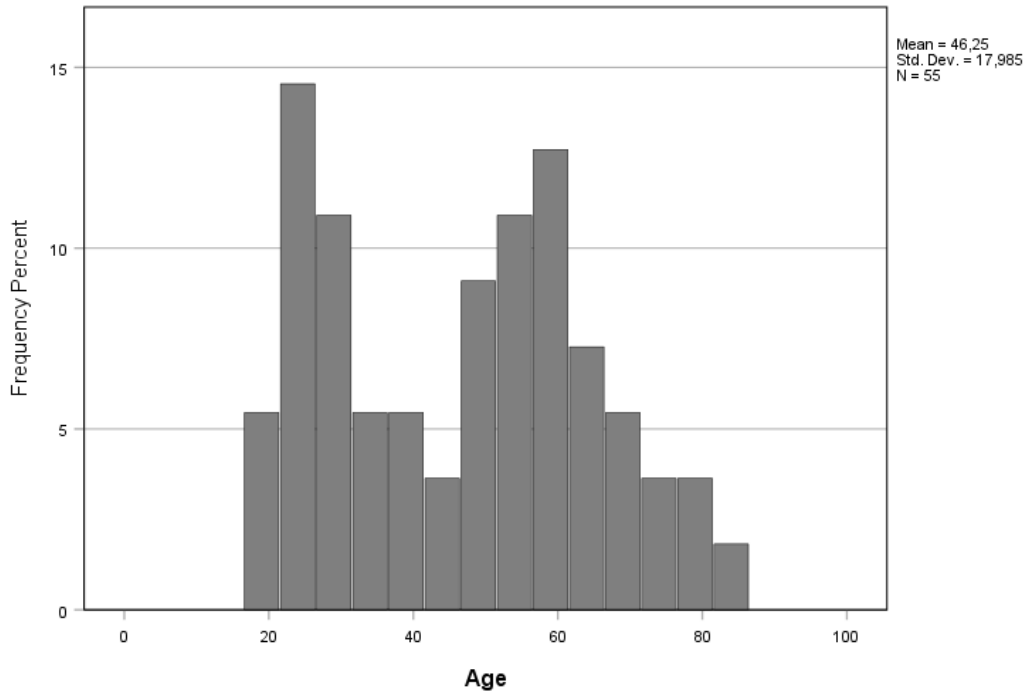
Output

Demographics

The age of the participants ranged from 19 to 82 years. The histogram (see Figure 4) shows a distribution with peaks around ranges 20-30 and 50-60. The mean age is 46.25 years (SD = 17.99).

Figure 4

Distribution of Age



Regarding gender, 32.7% identified as male, 65.5% as female, and 1.8% as other. The highest level of education obtained by the participants is detailed in Table 3. The participants' level of education was notably high, with 71% having completed higher education (HBO or university), compared to 37% in the Ypenburg neighborhood (Den Haag in Cijfers, 2021).

Table 3

Education of Participants

Education	*n*	*%*
Primary school	1	1.8
LBO	0	0
MAVO	3	5.5
VMBO	1	1.8
MBO	7	12.7
HAVO	0	0
VWO	2	3.6
HBO	20	36.4
University	19	34.5
Other	2	3.6

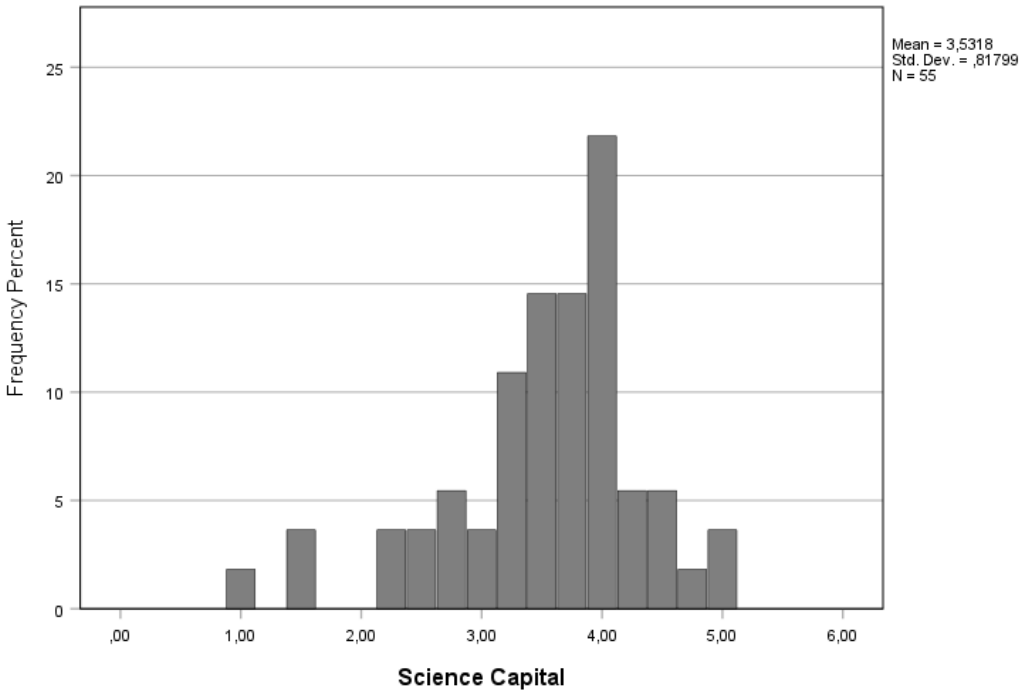
Note. N = 55.

Science Capital

Science capital was measured using four items. The composite science capital score, which ranges from 1 to 5, was computed as the mean of these four items. The mean composite science capital score was 3.35 (SD = 0.82). The distribution of science capital scores (see Figure 5) indicates that most participants scored between 3 and 4, suggesting that the majority of respondents have a moderate level of science capital, with fewer participants scoring very low or very high.

Figure 5

Distribution of Science Capital



Outcome

Emotional memory: Pleasure and Intensity

The pleasure aspect of emotion was measured using four items on a 10-point bipolar scale. The means and standard deviations of the pleasure items are presented in Table 4.

Table 4

Means and Standard Deviations of Pleasure

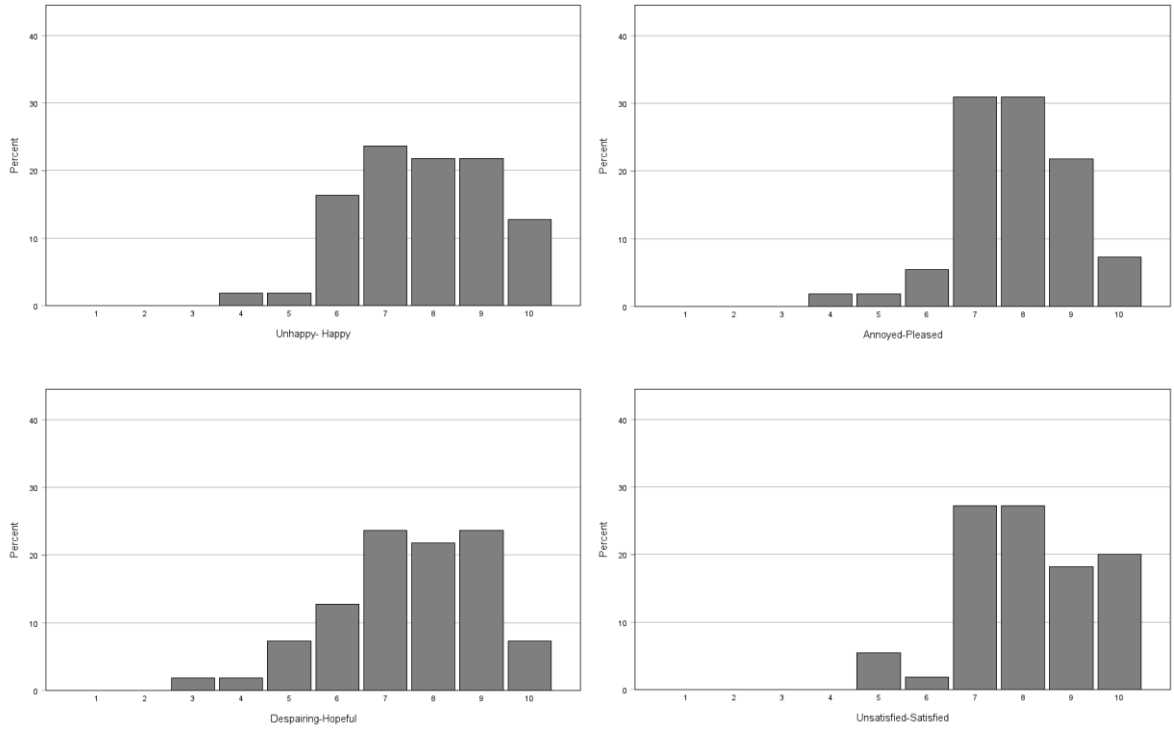
Item	*M*	*SD*
Unhappy - Happy	7.78	1.44
Annoyed - Pleased	7.82	1.22
Despairing - Hopeful	7.51	1.57
Unsatisfied - Satisfied	8.11	1.36

Note. N = 55.

The distributions of the scores are presented in four bar charts in Figure 6.

Figure 6

The Distribution of Pleasure



Participants felt mostly happy after experiencing the artwork (*M* = 7.78, *SD* = 1.43) and pleased (*M* = 7.82, *SD* = 1.22). Participants also felt hopeful (*M* = 7.51, *SD* =1.57), though with more variability. The highest mean score was for satisfaction (*M* = 8.11, *SD* = 1.36).

The high mean scores and the consistency in the scores across the pleasure items suggest that the art-based intervention received positive emotional responses from the participants.

The intensity aspect of emotion was measured using another set of four items on a 10-point bipolar scale. Their means and standard deviations are presented in Table 5.

Table 5

Means and Standard Deviations of Intensity

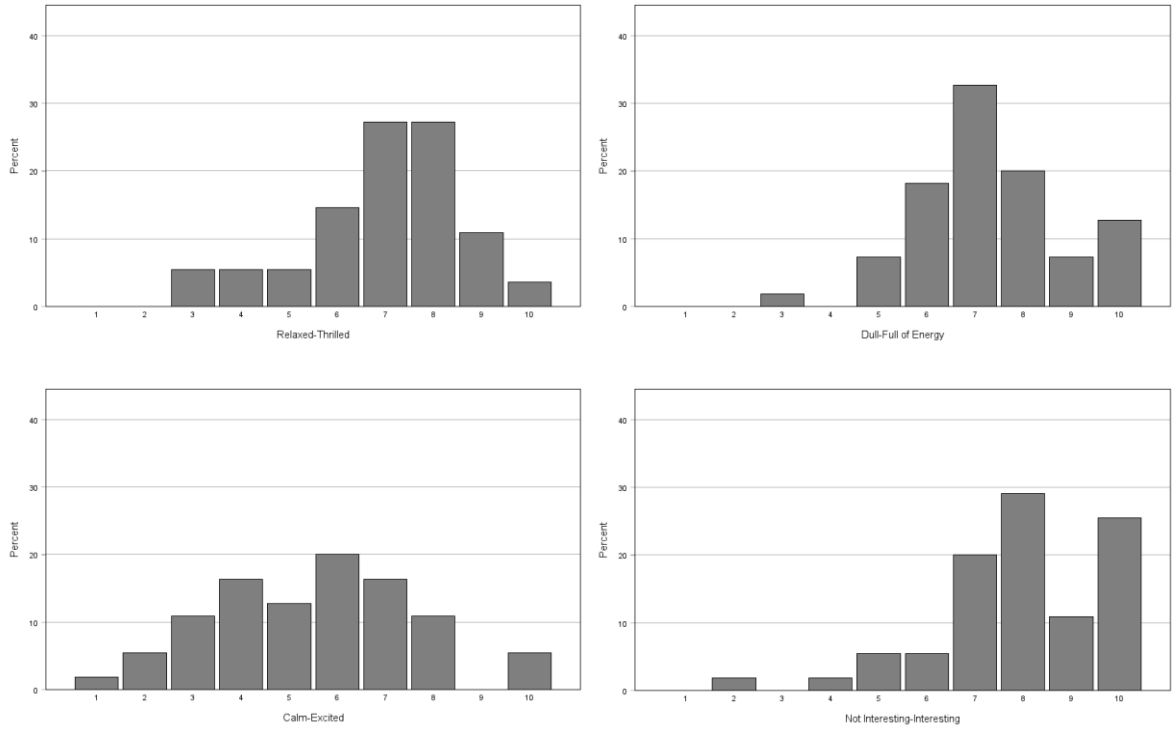
Item	*M*	*SD*
Relaxed - Thrilled	6.96	1.68
Dull - Full of energy	7.33	1.52
Calm - Excited	5.51	2.10
Not interesting - Interesting	7.96	1.74

Note. N = 55.

The distributions of the scores are presented in four bar charts in Figure 7.

Figure 7

The Distribution of Intensity



Participants felt moderately thrilled (*M* = 6.96) with some variability (*SD* = 1.68). They generally felt full of energy (*M* = 7.33, *SD* =1.52). Responses were more diverse for the calm-excited emotion *(M* =

5.51, *SD* = 2.10), indicating a greater variability in how participants felt about this aspect. The highest scoring emotion was feeling interested (*M* = 7.96, *SD* = 1.74).

The varied mean scores for intensity suggest that while the artwork made participants feel moderately thrilled and highly energetic and interested, the level of intensity had slightly lower and less consistent responses compared to the emotional memory aspect of pleasure, especially visible in the item Calm-Excited.

Effect

The effects of the art-based intervention were measured using four items on 5-point scales. The results are summarized in Table 6, including mean, standard deviation, median, and mode for each item.

Table 6

Means, Standard Deviations, Medians, Modes, and Ranges of Effect Variables

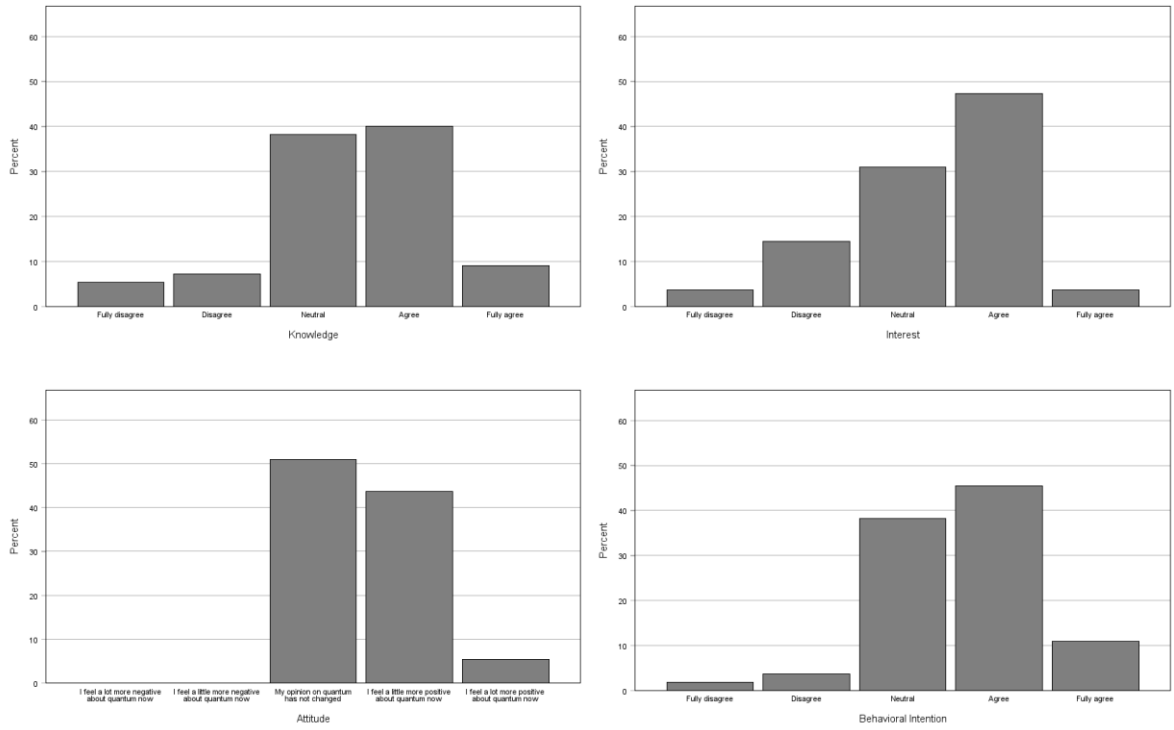
Item	*M*	*SD*	Median	Mode	Range
Knowledge	3.40	0.96	3	4	4
Interest	3.33	0.90	4	4	4
Attitude	3.55	0.60	3	3	2
Behavioral intention	3.60	0.81	4	4	4

Note. N = 55.

The distributions of the scores are presented in four bar charts in Figure 8.

Figure 8

The Distribution of the Effect Variables



Participants reported a moderate increase in their knowledge about quantum topics (*M* = 3.40, *SD* = 0.96), with 49% agreeing or fully agreeing that they knew more after the artwork, and 38% being neutral. There was a moderate desire to learn more about quantum (*M* = 3.33, *SD* = 0.90), with 51% indicating an increase in interest. Behavioral intention to attend similar future activities had the highest mean score (*M* = 3.60, *SD* =0.81), with 56.4% agreeing or fully agreeing. Attitudes towards quantum showed a positive shift (*M* = 3.55, SD = 0.60), with 44% feeling a little more positive and 6% a lot more positive, while 51% reported no change. No participants felt more negative.

The moderate to high mean scores, along with the distributions skewed towards agreement, suggest that participants generally experienced slightly positive effects.

Inferential Statistics

The effect of the art-based installation can be understood by analyzing the correlation between the emotions evoked by the installation and the effect variables such as knowledge, attitude, and behavioral intention. Positive effects on these variables indicate effective science communication. The Spearman's rho correlations are presented in Table 7.

Table 7

Spearman's Rho Correlations Between Emotions and Effect Variables

	Knowledge	Interest	Attitude	Behavioral intention
Emotion				
Pleasure				
Unhappy-Happy	.306*	.239	.051	.507**
Annoyed-Pleased	.027	.122	-.035	.199
Despairing-Hopeful	.169	.084	-.027	.236
Unsatisfied-Satisfied	.110	.107	-.134	.407**
Intensity				
Relaxed-Thrilled	.211	.053	.060	.390**
Dull-Full of Energy	.400**	.211	.157	.375**
Calm-Excited	.059	.226	.184	.175
Not Interesting-Interesting	.362**	.178	.066	.524**

Note. N = 55.

*$p < .05$. **$p < .01$. (2-tailed)

Dull-Full of Energy (ρ = .400, $p < .01$) and Not Interesting-Interesting (ρ = .362, $p < .01$) from intensity show significant positive correlations with knowledge indicating that these emotions are associated with knowing more about quantum after experiencing the art intervention. Unhappy-Happy (ρ = .306, $p < .05$) from the pleasure shows a less strong but still significant positive correlation with interest.

Significant positive correlations with behavioral intention are observed across multiple emotions, particularly those related to intensity . Not Interesting-Interesting (ρ = .524, $p < .01$), Relaxed-

Thrilled (ρ = .390, $p < .01$), and Dull-Full of Energy (ρ = .375, $p < .01$) all indicate strong significant correlations. Unhappy-Happy (ρ = .507, $p < .01$) and Unsatisfied-Satisfied (ρ = .407, $p < .01$) from pleasure also show significant positive correlations, suggesting that these emotions are linked to a higher likelihood of attending similar activities.

Generally, there are weak and non-significant correlations between the emotions and attitude and interest. This suggests that the art installation's effect on changing opinions and wanting to know more about quantum is not strongly linked to the specific emotions measured in this study.

The results indicate that certain emotions, particularly those related to intensity, have a significant impact on knowledge and behavioral intention. Emotions such as Dull-Full of Energy and Not Interesting-Interesting show strong positive correlations with these effect variables. In contrast, emotions related to pleasure show more varied and generally weaker correlations, with Unhappy-Happy showing some significant correlations, especially with behavioral intention.

Observations from the Researcher

In addition to the quantitative data, qualitative observations were made by the researcher during the intervention. These observations, although not systematically analyzed, provide valuable contextual insights into the participants' interactions with the artwork.

Interest in the Artwork: Participants seemed to enjoy the artwork, commenting on aesthetic aspects and how it fitted in its environment, as it represented a book while exhibited in the library. When the artwork caught their interest, they often made an effort to walk around and observe it from different angles or playfully experiment with the interactive element. Curiosity was apparent in conversation, participants asked questions about quantum and its connection to the artwork or reflected on their personal experiences with quantum. They were also curious about the mechanism that provided the movement in the artwork and wanted to know how the artwork was made.

Accuracy of Questionnaire Items on Emotions: Some participants mentioned that they thought the questions on emotional memory were a bit extreme considering the presented artwork. For example, they did not feel intense excitement after their brief interaction with the artwork. Sometimes, participants' answers appeared to be largely influenced by their personal circumstances. One person mentioned reporting being "not happy" on the questionnaire because they had a bad day rather than it being caused by the art-based intervention.

Characteristics of Library Visitors: It seemed that the library visitors were often in a rush, only expecting to return their books or borrow new ones. In these cases, they were not prepared to stay for long or interact much. Other visitors lingered longer in the library to read, study, or look at the newly arrived books. Especially this last category of visitors was most inclined to participate in the survey. It also seems that library visitors in general, could be more active in gaining new knowledge and interested in new developments compared to the general population.

Promising Collaboration with the Library: The collaboration with the library was very accommodating. They specifically expressed interest in involving more exact sciences in the future, for example, in their regularly organized activities.

Discussion

This research evaluated the effects of art-based science communication regarding quantum physics. The main question was answered through several sub-questions.

Sub-research question 1: What is the effect of art-based science communication on emotions?

The study demonstrated that the art-based intervention elicited positive emotions, characterized by high levels of pleasure. While the intervention elicited a comparatively lower intensity of emotions, the level was still high, with participants feeling especially energetic and interested after engaging with the intervention. Participants mentioned enjoying the aesthetics of the artwork. They also

showed fascination with the interactive moving mechanism and how the movement relates to quantum mechanics.

These findings indicate that an art-based intervention promotes a positive science communication experience by eliciting positive and intense emotions, thus encouraging curiosity. This aligns with the literature (Fraaije et al., 2022).

Sub research question 2: What is the effect of art-based science communication on knowledge, interest, attitude, and behavioral intention regarding quantum?

The study demonstrated that art-based science communication can have positive effects on knowledge, interest, attitude, and behavioral intention. Participants generally reported slightly positive effect across these variables, with behavioral intention exhibiting the most effect. Approximately half of the participants either agreed or fully agreed that the art-based intervention had positive effects. The remaining participants predominantly responded neutrally and rarely negative.

These results indicate that the art-based science communication has slightly positive effects and minimal negative effects. Art-based science communication can increase knowledge, interest and promote a positive attitudes towards science. It can especially inspire citizens to attend similar activities related to quantum in the future, indicating an engaging experience. The reported positive effects are in line with the literature (Fraaije et al., 2022). However, the effects observed in this study were only slightly positive. This outcome might be explained by the study's small scale, potentially limiting engagement.

Sub research question 3: What is the relation between emotions and knowledge, interest, attitude, and behavioral intention regarding quantum?

Significant positive correlations were observed between certain emotions and the effect variables of knowledge and behavioral intention. Some emotions associated with intensity showed strong positive correlations with these effect variables. Emotions related to pleasure exhibited more

varied and generally weaker correlations, with happiness and satisfaction having significant positive correlations with behavioral intention, and only happiness being significantly correlated with knowledge.

This reveals that intense emotions, and to a lesser extent pleasure, can promote learning. Both intense and pleasurable emotions can create an engaging experience that citizens want to experience more of. These findings are in line with the expected effects of activating emotional memory (Bradley & Lang, 1994). In contrast, the anticipated effects of emotions on attitudes and interest towards quantum were not observed in this study. This suggests that even after an introduction through an art-based intervention, quantum may remain a daunting topic for participants.

Sub research question 4: What recommendations can be made for designing effective art-based science communication interventions based on the observed effects?

The art-based intervention evoked intense emotions, such as feeling energized and interested, and these emotions were significantly correlated with knowledge and behavioral intention. It is expected that by evoking such intense emotions, art-based interventions can provide engaging science communication. Provoking curiosity should be an aim.

Metaphor, narrative, and visualization (Dahlstrom & Ritland, 2012) in art seem to support science communication by making complex and abstract scientific topics tangible. It can make science more relevant and accessible to citizens, ensuring a positive science communication experience. Simplicity is tied to accessibility. Interactivity seems to elicit interest and energy, with movement encouraging playful exploration. This is in line with the ingredients driving science communication from Strick & Helfferich (2023). Interactivity in the form of collective reflection also shows potential (Fraaije et al., 2022), as supported by the observed positive interactions between participants around the artwork.

The public setting in a library made it possible to reach citizens who are not directly involved in science. However, exhibiting in a library could also have created a sampling group with higher science

capital and education than the general population. Nevertheless, the collaboration with the library showed the institution's commitment to science-related activities. In addition, the involvement of experts on quantum physics during the design process assured accuracy of the art-based intervention concept, avoiding contributing to hype and misinterpretation.

Having discussed the sub-questions, the overarching main research question can now be answered.

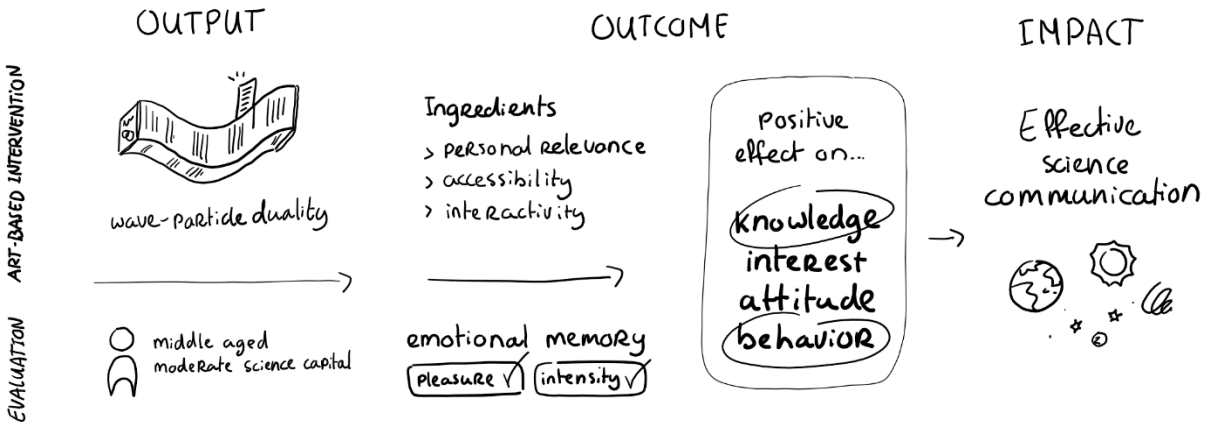
Main research question: What are the effects of art-based science communication, through eliciting emotions, on knowledge, interest, attitude, and behavioral intention of citizens regarding quantum?

In conclusion, the findings show how art-based science communication can elicit both pleasurable and intense emotions, providing an engaging experience that has positive science communication effects regarding quantum, although slightly. Some emotions were significantly correlated with knowledge and behavioral intention, while correlations with interest and attitude to quantum appeared weaker.

This indicates that art-based science communication is especially effective in informing citizens and inspiring them to attend similar engaging science communication events in the future. In the literature, Fraaije et al. (2022) and Strick and Helfferich (2023) emphasize the value of art-based public engagement. The current study supports these findings, showing that art can effectively foster public engagement by eliciting emotions. However, while previous research suggests that art-based interventions can significantly influence knowledge, interest, attitude, and behavioral intention toward scientific topics, this study found that the impact was only slightly positive. In Figure 9 an illustrated overview of the findings is presented.

Figure 9

Overview of the Findings



Limitations

Since science communication is applied in public settings, it is important to research it within its context. However, while conducting the study in a public library setting enhances ecological validity, it may also introduce unaccounted variables. It is possible that the emotions elicited among participants were influenced by factors other than the art-based intervention.

The convenience sample used in this study may have influenced the demographic characteristics of the participants. Visitors of the library are assumed to have higher science capital and education in comparison with the general population. Furthermore, self-selection bias, where participants voluntarily chose to engage in the study, could lead to more positive responses. The self-reported nature of the survey measuring feelings and opinions, introduces subjectivity.

The significance of this study lies in the exploration of the potential of art-based science communication. However, given the small scale of the study with a sample of 55 participants, caution should be exercised when generalizing the findings to the general population. The small scale of the art-based intervention and the participants' short exposure to it during their library visit may have limited their level of engagement. Together with minimal explanatory content (aiming to encourage

exploration), and the already high educational level of the participants, this could have led to smaller observable changes in the effect variables.

The cross-sectional design of this study is efficient and provides immediate measurement of the effects of art-based science communication on the participants. As an explorational study, it can generate valuable directions for future research. However, this study design limits the ability to observe changes over time and thereby cannot establish causality, only associations.

Future Research

Considering the limitations of this research, future research should aim to verify the conclusions. Future studies with control groups and longitudinal measurements could help establish causality between the emotions elicited by art and science communication effects. Although not measured in this study, long-term effects of art-based science communication appear promising, given how strong emotional experience enhances memory retention (Peeters et al., 2022). Broader studies involving diverse settings and demographics are recommended for a better understanding of the generalizability of the findings. When more science communication efforts are evaluated, evaluation measurements should be further refined. Additionally, exploring various scientific topics and types of art-based engagement could provide valuable insights into how art-based science communication can be employed effectively.

Despite the limitations, this exploratory study supports the potential of art-based science communication and provides directions for future science communication research. Especially given how quantum and its technology becomes increasingly integrated into society, this research contributes to a more scientifically informed and engaged public, promoting inclusive and responsible scientific research.

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Appendix A

Design of the Art-Based Intervention

This document describes the design process of the art-based intervention. The art-based intervention was designed following the guide for designing and evaluating Media and Arts Technology interventions by Bryan-Kinns & Reed (2023).

Aim

The aim is to positively affect the knowledge, attitude, interest, and behavioral intention of citizens regarding quantum physics by communicating the quantum phenomenon of wave-particle duality. Since the literature shows that public knowledge of quantum physics is minimal (Busby et al., 2018; Van De Merbel et al., 2024), this goal primarily focuses on enriching participants' awareness and attitudes toward quantum physics (Land-Zandstra et al., 2023). Focusing on introducing the topic makes the experience accessible and can serve as a foundation for further theory building (Faletic et al., 2023).

The Quantum Phenomenon of Wave-Particle Duality

The phenomenon of wave-particle duality was chosen as it is one of the fundamental phenomena of quantum physics. Wave-particle duality describes that quantum particles exhibit both particle-like and wave-like behavior. The famous double-slit experiment demonstrates this duality. Quantum particles passing through two slits create an interference pattern on a screen, reflecting their wave properties. Measurement, however, collapses the superpositions of the wave, revealing the particle properties. It is one of the paradoxical quantum phenomena challenging to communicate.

Wave-particle duality is deemed "the heart of quantum mechanics" by Feynman et al. (1963) and intersects with the concepts of superposition, measurement, and quantum state which are identified as most important in outreach efforts by experts (Seskir et al., 2024). Citizens lack a basic understanding of these fundamental concepts (Busby et al., 2018; Van De Merbel et al., 2024). Hype around the appliances of quantum mechanics in new technologies without an understanding of the

fundamentals causes misinterpretation and mistrust among the public (Achiam et al., 2024). Therefore, it is important to communicate on the fundamental quantum phenomenon of wave-particle duality.

Inspiration

To define features and gather inspiration for the design of the art-based intervention, various approaches were explored. This included reviewing insights from existing literature, documenting artists who work with quantum, and attending relevant events. The gathered inspiration was synthesized into a mind map.

Literature

There have been few cases where art-based public engagement has been employed in science communication events. However, valuable insights can still be drawn from the existing literature.

Strick & Helfferich (2023) attended a science festival and found that personal relevance, accessibility, and interactivity increased knowledge and familiarity with science. Emotion was an essential factor. Decaroli & Malinowski (2022) organized an art exhibition on quantum physics and found that art-based engagement provokes questions and inspires, making it a powerful approach in explaining complex quantum physics concepts such as error correction in quantum computation and entanglement. Walker & Von Ompteda (2014) brought quantum interaction to a human scale in their art exhibition. They closely collaborated with researchers in the field of quantum physics. They found that using of the narrative aspect of art yielded positive results, as evidenced by positive feedback from participants. Fraaije et al. (2022) conducted a meta-analysis reviewing the effects of art on public engagement around emerging and controversial technologies. They found art primarily supported engagement by reaching wider audiences, fueling individual reflection, and making science more tangible. They recommended evaluation and collective reflection as important aspects for the future of art-based engagement.

Artists and Artworks

The following list is a documentation of artists who create quantum related artworks.

- Grenville Davey is an artist who makes sculptures around mathematical sciences.
- Conrad Shawcross is an artist who makes sculptures around philosophy and physics.
- Victoria Vesna is an artist who makes immersive installations based on scientific insights.
- Julian Voss-Andreae is an artist who makes sculptures inspired by quantum.
- Libby Heaney is an artist who makes installations about quantum.
- Evelina Domnitch and Dmitry Gelfand are artists who make installations about physics.
- Jonathon Keats is an artist who makes installations based on science.
- Antony Gormley is an artist who makes sculptures about materiality.
- Daniel Crooks is an artist who makes visual art about movement.

Explorations

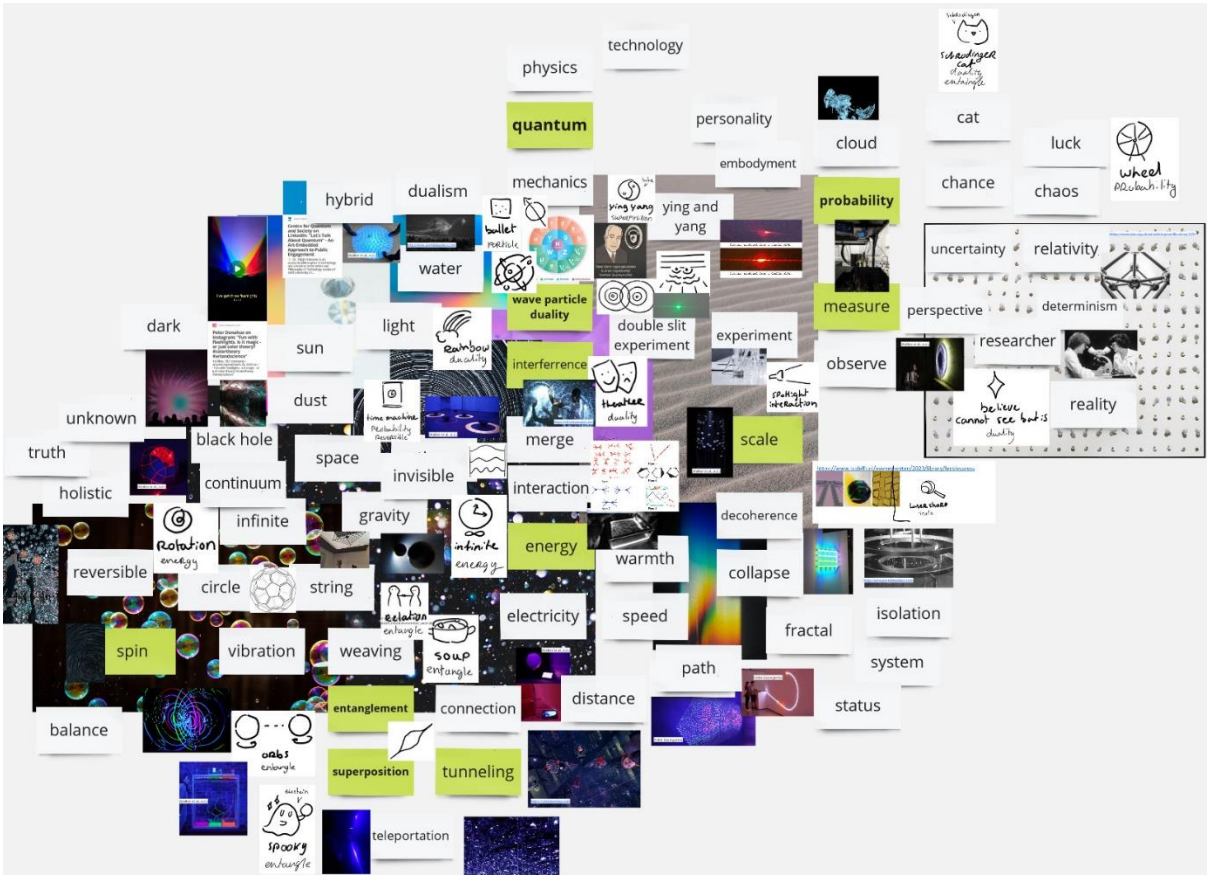
To gather inspiration, various explorations were undertaken. This included attending Studium Generale lectures on quantum and art, a Responsible Quantum Technologies conference, and the symposium 'Art Participating in Tech' presented by the Emergence Dream Team of TU Delft, which works on a project that combines art and quantum. A science museum was visited to observe how they approach engaging science communication. Quantum was also explored in self-study, including creative experiments such as replicating the double slit experiment with a laser. Discovering quantum and its relation to art was highly informative and inspiring.

Mind Map

All inspiration was synthesized into an encompassing mind map (see Figure 10) and expanded with creative associations.

Figure 10

Mind Map



Features

Required features based on the literature are:

- The intervention should improve participants' knowledge of the quantum topic of wave particle duality.
- The intervention should use metaphor to make abstract scientific concepts tangible (Smedinga et al., 2023)
- The intervention should evoke emotions by using narrative (Dahlstrom & Ritland, 2012) for personal relevance and reflection (Fraaije et al., 2022; Van De Merbel et al., 2023) since emotion has a strong positive impact on knowledge and familiarity with science (Strick & Helfferich, 2023).
- The intervention should use visualization to make abstract scientific concepts intuitive (Dahlstrom & Ritland, 2012) in an aesthetically pleasing way to attract a wider audience (Born & Barry, 2010).

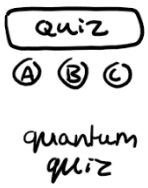
- Interactivity should be part of the intervention to enhance engagement (Strick & Helfferich, in press)
- Complexity should be minimized to make the intervention accessible. An informative description can be provided (Van De Merbel et al., 2023) (Strick & Helfferich, 2023).

Conceptualization

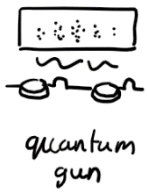
Based on the required features and gathered inspiration, eight concepts were created to convey wave-particle duality:

Particle Perspective: Spheres hang from the ceiling. Viewed from the front, the spheres form a wave. Viewed from the side, the spheres appear as a dot. These different perspectives illustrate wave-particle duality.

Observe Reality: This concept presents a virtual reality experience. Wearing the VR glasses, the center of your vision is clear and defined, but in the periphery, your view is progressively unclear and wavy. This illustrates defined particles against the probability of unobserved particles.



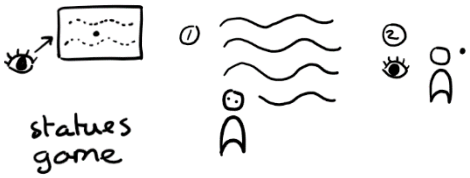
Quantum Quiz: This concept originated from discussions on how people can also embody dualities. A quantum personality quiz explores multiple personality traits.



Quantum Gun: Clearly based on the double-slit experiment, participants shoot particles toward a screen by pressing buttons. Depending on which slits are open, different (interference) patterns appear.

Waterfall: Water droplets represent particle properties, falling down the waterfall into a water pool and creating ripples that represent wave properties. This illustrates wave-particle duality.

Many Worlds: In a space, a chaos of images from multiple places and times flashes around. When two people are in the space together, they “measure” each other. As this measurement occurs, one image clearly appears, and the chaos fades away. This shows uncertainty against clearly defined particles when measured.



Statues Game: This concept is based on a children's game. When you do not look, a wavy pattern is projected. When you look at the projection, only a dot appears, illustrating duality influenced by measurement.

Disco: In a disco setting, people can dance and interact with wave (function) projections and music. Suddenly, the wave function collapses, the lights flash on, and the music stops, depicting the collapse of the disco. This embodies wave-particle duality through the wave-function collapse.

Feedback

Feedback was gathered through discussions with experts in physics and arts (Leiden University, TU Delft and KABK in The Hague) and regular library visitors, concerning about ten people in total.

According to the feedback, the concepts Particle Perspective and Waterfall have simple and clear metaphors but lack direct interaction. However, these simple ideas are more practical both in creating and in their alignment with participants' expectations. Complex concepts such as Disco are more unpredictable, relying more on participants reactions. Using new technologies can add to the wow-factor but may also add complexity and distract from the educational aspect (e.g., VR). In contrast, concepts like the Quantum Gun are scientifically accurate and quantum specific but have less aesthetical and engaging qualities. Realizing multiple concepts and presenting them in an exhibition together, can provide a more complete picture of the quantum phenomenon. Providing context through a description and linking the quantum phenomenon to broader concepts or even applications could increase relevance for the participants. In the feedback, provoking curiosity was considered essential for an engaging and informative experience.

Final Concept

The final concept for the art-based intervention was chosen in collaboration with the library representative since the library hosts the exhibition space. The informative aspect, safety, and minimal disturbance to the study area were important for the library. Quantum experts from the research group Quantum and Society at Leiden University have verified the accuracy of the concept.

The final concept is an enhanced version of the 'Particle Perspective' concept, adapted to the library environment and featuring a book metaphor. Wave-particle duality is explained as a book. Information is flowing through the pages, which together make up the complete book. This represents the wave properties in quantum. The individual cumulative

pages represent the defined particle properties in quantum. When you closely observe the book, focusing on a page, the wave properties are lost, representing the collapse of the wave-function.

As required by the literature, the artwork incorporates metaphor, narrative, and visualization, in addition to the active ingredients of science communication (personal relevance, accessibility and interactivity). The artwork uses the metaphor of a book, visualizing wave-particle duality and tells a story through movement. Participants encounter quantum through a recognizable object from daily life, namely a book. The installation is accessible since participants do not need special skills to experience it. The interaction is based on movement. Since the installation hangs in an open space, participants can walk around and under it, encouraging playful exploration and making it possible to experience the artwork together.

Realization

The spatial installation hangs in the air. A wooden board contains the electronics. Pages hang down, including a book cover, together forming a book. The pages move up and down in a wave pattern. An Arduino board powered by a battery, controls servo motors that drive the movement. An ultrasonic distance sensor is mounted on the side of the artwork. It senses if participants come close to it, then the movement of the pages stops. In Figure 11 the sketched practical design for the art-based intervention. is presented. A close up of the moving mechanism is presented in Figure 12.

The installation went through several iterations, first testing the mechanism on a small scale. Various slight changes in the design were tested throughout the design process, leading to the final realization.

Figure 11

Practical Design of the Art-Based Intervention

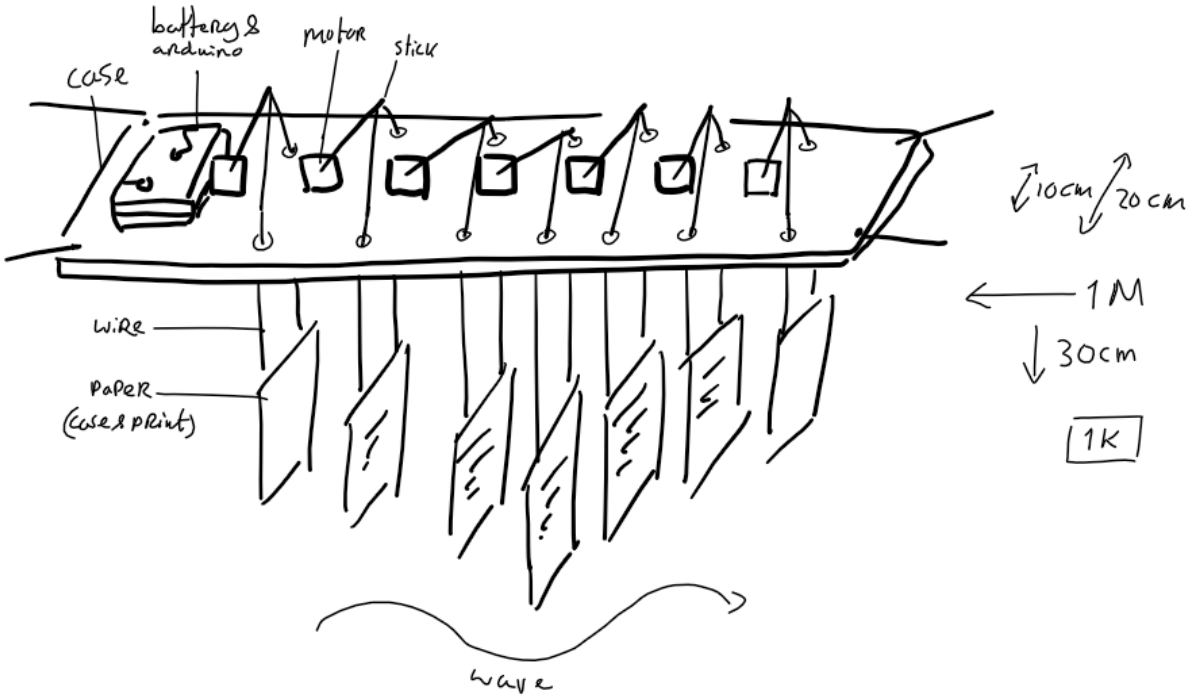


Figure 12

Mechanism of the Art-Based Intervention

The art-based intervention is presented in an exhibition format as an artwork in a public space, allowing it to reach a wide and diverse audience. A description with explanation is provided in both Dutch and English. The artist was around for comments and questions.

See the final realization of the art-based intervention exhibited in Figure 13.

Figure 13

Exhibited Art-Based Intervention

The following video provides an impression of the realized work: https://youtu.be/-A6pF1pIHiE.

Appendix B

Description of the Art-Based Intervention

Quantumdeel(tje) van het Boek

Dit kunstwerk is gemaakt door Anna Sivera van der Sluijs als onderdeel van haar afstudeeronderzoek over op kunst gebaseerde wetenschapscommunicatie van quantum mechanica bij de Universiteit Leiden.

Draag bij aan het onderzoek door de QR-code te scannen!

Informatie vloeit door de pagina's die samen het complete boek vormen. Het golvende boek bestaat ook uit individuele, gedefinieerde pagina's. Hele kleine quantumdeeltjes zijn tegelijkertijd een vloeiende golf en een gedefinieerd deeltje, dit heet golf-deeltjes dualiteit. De vloeiende beweging van het boek representeert de golfeigenschappen van quantumdeeltjes, terwijl de afzonderlijke pagina's de gedefinieerde deeltjeseigenschappen van quantumdeeltjes tonen.

Bij observatie van quantumdeeltjes verdwijnen de golfeigenschappen en neem je alleen de deeltjeseigenschappen waar. Dit wordt het vervallen van de golffunctie genoemd. Volgens de natuurkundige Heisenberg is het onmogelijk om de snelheid en de plaats van een quantumdeeltje tegelijkertijd te meten. Probeer het kunstwerk eens van dichterbij te bekijken en zie wat er gebeurt!

Quantum Part(icle) of the Book

This artwork is created by Anna Sivera van der Sluijs as part of her thesis on art-based science communication of quantum mechanics at Leiden University.

Contribute to the research by scanning the QR code!

Information flows through the pages that together form the complete book. The individual pages are each a defined part of the book. Very small quantum particles are simultaneously a flowing wave and a defined particle, this is called wave-particle duality. The flowing movement of the book represents the wave properties of quantum particles, while the separate pages reflect the defined particle properties of quantum particles.

When observing quantum particles, the wave properties disappear and only the particle behavior occurs. This is known as the wave function collapse. According to the physicist Heisenberg, it is impossible to measure both the velocity and the position of a quantum particle at the same time. Try to take a closer look at the artwork and see what happens!

Appendix C

Full Survey

Universiteit Leiden
The Netherlands

Nederlands

Informatie en toestemming

Informatie

Dank je wel voor je interesse in het onderzoek. Hier volgt eerst informatie over het onderzoek, daarna kan er toestemming gegeven worden voor de deelname.

Over het onderzoek

Het onderzoek gaat over de evaluatie van op kunst gebaseerde wetenschapscommunicatie op het gebied van quantum. Voor het onderzoek worden er vragen gesteld om achter de impact van het kunstwerk te komen. Het ervaren van het kunstwerk en het invullen van de vragenlijst duurt ongeveer een kwartier.

Vrijwillige deelname

Deelname is volledig vrijwillig. Het onderzoek kan op ieder gewenst moment gestopt worden. Na het deelnemen kan je de gegeven toestemming binnen een maand intrekken, dit is mogelijk zonder reden of consequenties. Neem hiervoor tijdig contact op. Voor het deenmen aan dit onderzoek krijg je geen vergoeding.

Verzamelde gegevens

Er worden gegevens verzameld in de vorm van antwoorden op de vragenlijst en er kunnen foto's, filmpjes en notities worden gemaakt op basis van observaties door de onderzoeker. Alle verzamelde gegevens worden geanonimiseerd (in het geval van beeldmateriaal worden personen onherkenbaar in beeld gebracht). De verzamelde antwoorden van de vragenlijst worden gebruikt om conclusies te trekken voor het onderzoek en zullen getoond worden in het onderzoeksverslag en de bijbehorende presentatie.

Delen van de resultaten

Wanneer het afstudeeronderzoek af is, kan het verslag online worden ingezien via de Thesis Repository van de opleiding Media Technology van de Universiteit Leiden. De verzamelde

gegevens worden opgeslagen in het beveiligde Media Technology archief van de Universiteit Leiden. De gegevens kunnen mogelijk gebruikt worden voor vervolgonderzoek, maar zullen nooit gebruikt worden voor andere doeleinden of gedeeld worden met derden buiten de universiteit.

Contact
Het onderzoek wordt uitgevoerd door Anna, student van de Master Media Technology aan de Universiteit Leiden voor haar afstuderen. Het onderzoek wordt begeleid door dr. Max van Duijn. Als je vragen of opmerkingen hebt over dit onderzoek, mag je haar gerust aanspreken. Ook kan je later contact opnemen via het e-mailadres s3652254@vuw.leidenuniv.nl.

Toestemming

- De verzamelde antwoorden worden gebruikt om conclusies te trekken in mijn afstudeeronderzoek. De antwoorden kunnen mogelijk gebruik worden voor vervolgonderzoek, maar zullen nooit gebruikt worden voor andere doeleinden of gedeeld worden met derden buiten de Universiteit Leiden.
- Er kunnen ook foto's, filmpjes en notities worden gemaakt op basis van observaties door de onderzoeker. Deze data worden gebruikt om conclusies te trekken voor het onderzoek. Daarnaast kan de data gebruikt worden in de publicatie van het onderzoeksverslag en presentatie.
- Deelname is volledig anoniem.
- Deelname is volledig vrijwillig. Het onderzoek kan op ieder gewenst moment gestopt worden.

Ik verklaar hierbij dat ik bovenstaande informatie heb gelezen en geef de onderzoeker toestemming om de resultaten op anonieme wijze te bewaren, verwerken en rapporteren.

○ Ja ○ Nee

Geen toestemming

Om mee te doen aan het onderzoek is het nodig om toestemming te geven om je resultaten op anonieme wijze te bewaren, verwerken en rapporteren.

- ○ Sluit de vragenlijst zonder mee te doen aan het onderzoek

Demografische gegevens

Voordat je goed naar het kunstwerk kijkt, wil ik graag weten wie heeft meegedaan aan het onderzoek. Om daar achter te komen worden eerst de volgende **algemene vragen** gesteld.

Hoe oud ben je?

Ik ben

Man	Vrouw	Anders
○	○	○

Wat is je laatst voltooide opleiding (of vergelijkbaar)?

basisschool	lbo	mavo	vmbo	mbo	havo	vwo	hbo	universiteit	anders:
○	○	○	○	○	○	○	○	○	○

Wetenschapskapitaal

Het is interesant om te weten wat jij al van **wetenschap en onderzoek** vindt. Wetenschap gaat over vragen stellen, nieuwsgierig zijn, oplossingen zoeken, experimenteren en nieuwe dingen ontdekken. Wetenschap kan bijvoorbeeld te maken hebben met de natuur, de ruimte, mensen, taal en quantum.

Lees de zin en kies het antwoord dat het beste bij jou past.

	Helemaal mee oneens	Oneens	Neutraal	Eens	Helemaal mee eens
Ik ben in het algemeen op de hoogte over wetenschappelijke ontwikkelingen.	○	○	○	○	○
Ik heb interesse in de inzichten en methodes uit de wetenschap.	○	○	○	○	○
Ik doe soms dingen waarbij ik iets kan leren over wetenschap, zoals een museum bezoeken, informatie op internet opzoeken, televisie of video's kijken over wetenschap.	○	○	○	○	○
Ik praat regelmatig over wetenschap met anderen in mijn studie, baan of vrije tijd.	○	○	○	○	○

Kunstwerk

Bekijk nu het kunstwerk. Neem hier even de tijd voor.

Emotioneel geheugen

Wat was je **beleving** van het kunstwerk?

Beantwoord de volgende vragen door de cirkel te kiezen die het beste bij jouw gevoel past.

Hoe voel je je na het ervaren van het kunstwerk?

ongelukig	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	gelukig
verveeld	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	ontspannen
hopeloos	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	hoopvol
ontevreden	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	tevreden

Welke woorden omschrijven jouw gevoel bij het kunstwerk het best?

saai	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	spannend
heel duf	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	vol energie
kalm	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	opgewonden
niet interessant	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	interessant

Effectanalyse

Lees de zin en kies het antwoord dat het beste bij jou past.

	Helemaal mee oneens	Oneens	Neutraal	Eens	Helemaal mee eens
Door het kunstwerk weet ik nu meer over quantum.	○	○	○	○	○
Na het kunstwerk wil ik meer weten over quantum.	○	○	○	○	○
Na het kunstwerk wil ik nog eens zulke activiteiten doen in de toekomst.	○	○	○	○	○

Ben je anders gaan denken over quantum door het kunstwerk?

- ○ Ik denk nu veel positiever over quantum.
- ○ Ik denk nu iets positiever over quantum.
- ○ Mijn mening over quantum is niet veranderd.
- ○ Ik denk nu iets negatiever over quantum.
- ○ Ik denk nu veel negatiever over quantum.

Einde

Einde van de vragenlijst

Dank je wel voor het meedoen aan mijn (Anna's) afstudeeronderzoek over het evalueren van op kunst gebaseerde wetenschapscommunicatie op het gebied van quantum voor mijn Master Media Technology aan de Universiteit Leiden. Het onderzoek wordt begeleid door dr. Max van Duijn.

Als je vragen of opmerkingen hebt over dit onderzoek, mag je me gerust aanspreken. Je kan ook later contact opnemen via het e-mailadres s3652254@vuw.leidenuniv.nl. De gegeven toestemming voor het verwerken van de data kan binnen een maand ingetrokken worden, dit is mogelijk zonder reden of consequenties. Neem hiervoor tijdig contact op. Voor verder vragen over je rechten als deelnemer van het onderzoek kan ook contact opgenomen worden met de Ethiek Commissie van de Universiteit Leiden ethicscommitee@science.leidenuniv.nl.

Wanneer het afstudeeronderzoek af is, kun je het verslag online inzien via de Thesis Repository van de opleiding Media Technology van de Universiteit Leiden.

Klik verder om de vragenlijst te voltooien.

Universiteit Leiden
The Netherlands

English

Informatie en toestemming

Information

Thank you for your interest in this research. Please read the text first, and give permission to participate in the research below.

About the research

This research is about evaluating art-based science communication of quantum physics. The questions provide insight into the impact of the artwork. Experiencing the artwork and completing the questionnaire will take approximately fifteen minutes.

Voluntary participation

Participation is completely voluntary. The research can be stopped at any time. You can withdraw your consent within a month, you do not have to justify your decision, and there are no consquences. Please contact the researcher in time If you wish to withdraw. There are no reimbursements for participating in this research.

Gathered data

Data is collected in the form of answers to the questionnaire. Photos, videos, and notes can also be recorded based on observations by the researcher. All gathered data will be anonymised (in the case of recordings, people will be unrecognisable). The collected answers will be used to draw conclusions for the research and will be used in the publication of the research report and presentation.

Sharing the results

When the research is completed, you can read the report online in the Thesis Repository of the Master Media Technology at Leiden University. The gathered data will be saved in the secured Media Technology archive of Leiden University. The data may be used for follow-up research but will never be used for other purposes or shared with third

parties outside the university.

Contact
The research is conducted by Anna, a student of the Master Media Technology at Leiden University and supervised by Dr. Max van Duijn. If you have any questions or comments about this research, please feel free to contact me. You can also contact me later through the email address s3652254@vuw.leidingenuniv.nl.

Information and consent

- The collected answers will be used to draw conclusions of my graduation research. The answers may be used for follow-up research but will never be used for other purposes or shared with third parties outside the university.
- Photos, videos and notes can also be recorded based on observations by the researcher. This data will be used to draw conclusions in the research. The data can also be used in the publication of the research report and presentation.
- Participation is completely anonymous.
- Participation is completely voluntary. The research can be stopped at any time.

I declare that I have read the information mentioned above and give the researcher permission to store, analyse, and report the anonymised results.

○ Yes ○ No

Geen toestemming

To participate in the study, you must give permission to store, analyse and report the anonymised results.

○ Close the questionnaire without participating in the study

Demografische gegevens

Before you look at the artwork, I would like to know who participated in the research. Therefore, the following **general questions** are asked.

How old are you?

I am

Man Woman Other

Which level of schooling have you last completed?

primary school lbo mavo vmbo mbo havo vwo hbo university other:

Wetenschapskapitaal

I would like to know what you think about **science and research**. Science is all about asking questions, being curious, looking for solutions, experimenting, and discoveries. It can be about nature, space, people, language, and quantum.

Read the sentence and choose the answer that best reflects your opinion.

	Fully disagree	Disagree	Neutral	Agree	Fully agree
I am generally aware of new scientific discoveries and developments.	○	○	○	○	○
I am interested in the scientific process and the results it yields.	○	○	○	○	○
In my spare time, I participate in activities that allow me to learn something about science, such as visiting museums, looking up information online or watching science-related tv shows or videos.	○	○	○	○	○
I regularly talk about science with other people, e.g. in my free time or in the context of my studies or job.	○	○	○	○	○

Kunstwerk

Now look at the artwork. Take your time.

Emotioneel geheugen

How did you **experience** the artwork?

Answer the following questions by choosing the circle that best reflects your feelings.

How do you feel after experiencing the artwork?

unhappy	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	happy
annoyed	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	pleased
despairing	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	hopeful
unsatisfied	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	satisfied

Which words describe your feelings about the artwork best?

relaxed	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	thrilled
dull	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	full of energy
calm	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	excited
not interesting	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	interesting

Effectanalyse

Read the sentence and choose the answer that best reflects your opinion.

	Fully disagree	Disagree	Neutral	Agree	Fully agree
Because of the artwork I now know more about quantum.	○	○	○	○	○
After experiencing the artwork I want to know more about quantum.	○	○	○	○	○
After experiencing the artwork I would like to attend similar activities in the future.	○	○	○	○	○

Has your opinion of quantum changed after experiencing the artwork?

- ○ I feel a lot more positive about quantum now.
- ○ I feel a little more positive about quantum now.
- ○ My opinion on quantum has not changed.
- ○ I feel a little more negative about quantum now.
- ○ I feel a lot more negative about quantum now.

Einde

End of the questionnaire

Thank you for participating in my (Anna's) graduation research about the evaluation of art-based science communication of quantum physics for my Master Media Technology at Leiden University. The research is supervised by Dr. Max van Duijn.

If you have any questions or comments about this research, please feel free to contact me. You can also contact me later through the email address s3652254@vuw.leidingenuniv.nl. You can withdraw your consent within a month, you do not have to justify your decision and there are no consequences. Please contact the researcher in time If you want to withdraw. For further questions about your rights as a participant, please contact the Ethics Commision of Leiden university ethicscommitee@science.leidenuniv.nl.

When my research is completed, you can read the report online in the Thesis Repository of the Master Media Technology at Leiden University.

Please continue to complete the questionnaire.