MODESTUM
EURASIA Journal of Mathematics, Science and Technology Education, 2026, 22(9), em2915
ISSN:1305-8223 (online)
OPEN ACCESS
Research Paper
https://doi.org/10.29333/ejmste/19280

Designing a one-day quantum technology workshop and evaluating its impact on affective variables in high school students

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Received 22 January 2026 ▪ Accepted 24 August 2026

Abstract
Evidence from physics education research highlights the importance of affective learning characteristics, such as interest, curiosity, and enjoyment, for students' engagement with complex and abstract topics like quantum physics. Students who show a greater interest in the subject tend to achieve better academic results, are more persistent, and are more likely to choose a university related to that subject. In recent years, one-day workshops and outreach formats have increasingly been used to introduce and promote quantum technologies at the secondary-school level. The goal of these programs is to widely disseminate new scientific findings, spark interest, and address the needs of academia and industry to fill labor shortages. However, the extent to which such short-term interventions influence students' affective outcomes remains insufficiently understood. There are only a few studies analyzing a workshop on quantum physics and quantum technology from the perspective of student interest, curiosity, and enjoyment, specifically at the upper-secondary school level. This paper addresses this gap by reporting findings from a pre-post study investigating the impact of a one-day, hands-on quantum technology workshop on upper secondary school students. Using established instruments to assess four facets of interest and descriptive measures of curiosity and enjoyment (N = 45), the study examines changes in students' affective learning characteristics. The results indicate no statistically significant changes in any interest dimension, while enjoyment and curiosity were reported at comparatively high levels. These findings suggest that single workshop events, such as the one described in this article, can foster positive learning experiences and situational engagement but are unlikely to support sustained interest development. Implications for the design and development of a secondary school level out-of-school quantum workshop are discussed.

Keywords: workshop, interest, enjoyment, quantum technologies, quantum physics

INTRODUCTION

One of the challenges in teaching-learning STEM subjects in schools is that students' attitudes toward these subjects show a steadily declining trend (Woithe et al., 2022). In recent decades, the number of students choosing STEM subjects has declined, and girls still remain severely underrepresented in these fields (OECD, 2007; Woithe, 2020). A particular issue is that as students get older, their interest decreases, so by the second half of high school – just when they should be considering their university – STEM subjects find themselves in a difficult position. Students often choose to major in physics when selecting a university because they have a personal interest in the subject. Furthermore, interest is a powerful internal motivator that drives students to achieve better results. As formulated by Hidi et al. (2004), *interest must be a central element of teaching practice*.

The decline in interest can be attributed to a lack of external environmental assistance or support. We have to note that it is difficult for teachers to stimulate and sustain interest; therefore, external educational programs play a significant role. However, previous research on out-of-school programs has significant limitations. Only a limited number of well-controlled

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Contribution to the literature

- Previous research has not yet specifically addressed the impact of a one-day quantum event aimed at high school students in terms of interest, curiosity, and enjoyment.
- Our findings confirm previous results, which indicate that the impact of one-day out-of-school programs can vary greatly depending on the topic and structure. We have seen no increase in interest; however, enjoyment and curiosity were at relatively high levels.
- Our findings can help guide the incorporation of key design principles when planning an out-of-school program that addresses an abstract physics topic.

studies are available, and replication studies and meta-analyses are still largely absent. Consequently, a deeper understanding is needed of the key factors influencing the effectiveness of out-of-school learning opportunities, both at the level of students and the learning environment (Hennig et al., s. a.; Woithe, 2020; Woithe et al., 2022).

In our research, we organized and tested an engaging program focused on a unique, albeit abstract, topic: quantum physics and quantum technologies. The innovative power of this research lies in the fact that while similar programs have become common in recent years (Quantum Technology Education Project, 2020), very few studies are available on their impact (Anttila et al., 2024; Moraga-Calderón et al., 2020); however, these focus on a totally different sample, university students. Since research on interest has shown that age and the subject matter under study are each very important factors influencing interest (Hennig et al., s. a.; Woithe, 2020; Woithe et al., 2022), a study of high school students in this regard is particularly relevant from a scientific perspective.

RESEARCH BACKGROUND

The Educational Relevance of Quantum Physics and Quantum Technology Workshops

During the latter half of the 20th century, quantum science entered what is commonly referred to as the second quantum revolution. As advanced quantum technologies – such as quantum computing, quantum communication, and quantum sensing – have moved increasingly toward real-world and industrial applications, the demand for a highly skilled workforce with robust foundations in quantum physics has grown substantially (Fox et al., 2020; Greinert et al., 2023; Hughes et al., 2022; Merzel et al., 2024; Meyer et al., 2024; Venegas-Gomez, 2020). In Europe, this demand has been addressed through coordinated initiatives such as the Quantum Flagship (2023), which places particular emphasis on integrating quantum-related knowledge into both secondary and higher education (European Quantum Technology Education, 2024; QTIndu, 2023; Quantum Technology Education Project, 2020; Sherson & Goorney, 2023). At a global level, this momentum is further reflected in the designation of 2025 as the International Year of Quantum Science and Technology by the United Nations General Assembly, marking circa one hundred years since the emergence of quantum science (Goorney et al., 2025; UNESCO, 2024).

Quantum technologies must be made part of everyday discourse; there is a need for a so-called *quantum-aware society*. Experts unanimously agree that the significance of quantum technologies – primarily quantum computing, quantum communication, and quantum sensing – will grow in importance in both industry and science in the future, and that educational programs on these topics are needed at all levels to familiarize broad segments of society with the subject (Greinert et al., 2023). In response to these developments, a broad range of educational resources for secondary education has been developed to promote quantum technologies and to foster students' engagement, understanding, and interest. These include curriculum materials and learning modules (Bernhardt, 2019; Billig, 2018; Bley et al., 2024; Bronner et al., 2009; Hughes et al., 2021; IBM, 2020; Kohnle et al., 2014, 2015; Microsoft, n.d.; Migdał et al., 2022; Müller & Greinert, 2024; Tóth & Bitzenbauer, 2025; University of St. Andrews, 2013), educational games (Castenmiller et al., 2026; Piispanen et al., 2025), and outreach and project-based learning formats (Anttila et al., 2024; Moraga-Calderón et al., 2020; Woithe, 2020). Our current research is also in line with this trend; in order to increase the number of students pursuing careers in quantum technology and to meet industry expectations, it is worthwhile to focus on sparking interest among high school students.

Beyond cognitive learning outcomes, prior research has consistently emphasized the central role of students' interest as a key prerequisite for sustained engagement, deeper conceptual understanding, and long-term learning in science education (Hidi et al., 2004; Renninger & Hidi, 2020). This appears to be particularly relevant for abstract and conceptually demanding domains such as quantum physics. Accordingly, interventions that aim to introduce quantum technologies at the secondary-school level should be evaluated not only in terms of knowledge acquisition but also with respect to their potential to foster students' interest.

Interest, Curiosity, and Enjoyment in Physics Education

Interest, curiosity, and enjoyment are three different concepts often used in educational psychology. The following sections describe these concepts and highlight their differences.

Interest

Prior research emphasizes that interest is a universal phenomenon and that every individual can develop some form of interest (Renninger et al., 2019a, 2019b). As summarized by Anttila et al. (2024), interest in a topic increases understanding (Renninger & Hidi, 2020), promotes conceptual change (Linnenbrink-Garcia et al., 2012; Nieswandt, 2007), improves the quality of learning, helps overcome difficulties (Renninger & Hidi, 2020), and supports goal setting and achievement, such as completing a course or degree (Harackiewicz et al., 2008; Lee et al., 2014), encourages academic self-regulation (Lee et al., 2014), and maintains meaningful engagement (Azevedo, 2013). It also stimulates independent learning and promotes engagement with the quantum sciences (Lent et al., 2008). As Renninger et al. (2019b, p. 2) define, *"Interest described as a variable that develops [...] refers to individuals' psychological state during engagement with some content, as well as to their motivation to reengage with that content"*.

Research on interest conceptualizes interest development using the *Four-Phase Model of Interest Development* (Hidi & Renninger, 2019; Hidi et al., 2004; Renninger et al., 2019a, 2019b). As described by Renninger et al. (2019a, 2019b), an individual's interest can be classified into four distinct phases:

1. *Triggered situational interest:* An individual may develop interest when engagement with particular subject content is initially triggered.
2. *Maintained situational interest:* This phase occurs when the initially triggered situational interest is sustained over time.
3. *Emerging individual interest:* The transition from maintained situational interest to emerging individual interest is driven by a person's curiosity-driven questions about the content. This process is accompanied by increasing efforts at self-regulation and a growing sense of identification with the content.
4. *Well-developed individual interest:* With further development of self-regulation and identification with specific content, learners enter the final phase, referred to as well-developed individual interest.

Because interest can easily diminish, these phases do not necessarily follow one another in a sequence and therefore cannot be considered stages. A new interest may emerge or evolve in all phases when something captures a learner's attention. This process is referred to as *triggering* or *catching facets* (Woithe, 2020). Triggered situational interest can support students in engaging more seriously with subject matter and in improving their performance (Crouch et al., 2018). Since initial interest is fleeting, the external environment plays a substantial role in sustaining it. The factors that sustain this interest are called the *hold effects*. High situational interest can transform into more stable interest constructs under appropriate conditions (Woithe, 2020). As Woithe (2020) states, students' involvement in the learning process is a vital tool for triggering and maintaining situational interest; for example, students can become active participants by doing hands-on activities instead of listening to a lecture.

In this study, we focus specifically on the "triggered situational interest" stage, as our sample consists of students who have had little or no prior exposure to quantum physics and quantum technologies. Woithe (2020) reviewed 16 previous studies that examined the impact of out-of-school STEM programs on interest. This review found that 15 of the programs were able to effectively trigger interest. This means that a one-day quantum physics program has the potential to trigger situational interest, as this preliminary phase may enhance students' engagement with quantum technologies and improve their performance (Crouch et al., 2018).

Dopatka et al. (2020) used two theoretical frameworks for interest that differ from the four-phase model mentioned earlier. One approach distinguishes between interest in specific physical contents (e.g., black holes and quantum physics) and interest in physics as a school subject (Häussler & Hoffmann, 2000; Hoffmann et al., 1998). This distinction effectively captures a common classroom experience: a student may be interested in physics as a discipline, for instance, because they have a strong aptitude for it, even if they find a particular topic unengaging. Conversely, students who generally dislike physics as a school subject may still develop a strong interest in certain chapters or themes within it.

The second theoretical framework, rooted in educational psychology, conceptualizes interest along two dimensions: an emotional dimension and a value-related dimension, referring to the perceived emotional enjoyment of an activity or its content and its perceived usefulness or significance, respectively (Krapp, 2007). From this perspective, interest may arise depending on whether students enjoy what they are learning and/or whether they perceive it as useful. For example, a student may regard learning physics as practically meaningless yet still find it interesting because they enjoy the lessons themselves. Conversely, a student's interest may be strengthened by recognizing the societal relevance or utility of physics, even if they derive little

Table 1. The four dimensions of interest based on the study by Dopatka et al. (2020)

Interest			
		Topic-related	Subject-related
Valence	Emotional	**TE**: topic-related interest with emotional valence	**SE**: subject-related interest with emotional valence
	Value-related	**TV**: topic-related interest with value-related valence	**SV**: subject-related interest with value-related valence

intrinsic enjoyment from studying the specific instructional material.

Dopatka et al. (2020) investigated whether the two conceptually distinct frameworks for categorizing interest can be integrated. Their study involved a sample of 1,529 students from grades 7 and 8. Drawing on the literature by Hoffmann et al. (1998), Häussler and Hoffmann (2000), and Krapp (2007), they operationalized interest using a 2×2 framework comprising four categories. Within the emotional dimension, they distinguished between topic-related interest with emotional valence (TE) and subject-related interest with emotional valence (SE). Analogously, the value-related dimension was divided into topic-related interest with value-related valence (TV) and subject-related interest with value-related valence (SV). Their large-sample analysis indicated that only three of these categories were empirically necessary, as the two emotionally based dimensions (TE and SE) were not statistically independent.

Although Dopatka et al. (2020) do not discuss the four-phase model of interest, the two can be readily reconciled. The four-phase model describes the development of interest, thus providing a vertical description of interest. Dopatka et al.'s (2020) research, however, fits well into each of the four phases of the model, thereby offering a horizontal perspective. In our research, we therefore defined the phase of interest on which we are focusing (triggered situational interest) and broke this phase down into four dimensions (TE, SE, TV, and SV).

Even though Dopatka et al. (2020) found that the two emotional dimensions of interest (TE and SE) were not statistically independent, we still included these two dimensions in our research (see **Table 1**), as our research is conducted with a fundamentally different sample and in a markedly different context, since numerous studies emphasize that age is a very important parameter in interest research (cf. Hidi et al., 2004; Woithe et al., 2022). Our participants comprised students at upper secondary schools who did not participate in a formal school setting but instead took part in a specialized, university-organized quantum physics day. Both the instructional environment and the structure of the activities differed substantially from regular classroom physics instruction. We therefore argue that, in this context, emotional interest may decouple from the physics school subject, and students' interest in specific topics may not be directly associated with their enjoyment of physics lessons.

Curiosity

While *"interest defines a psychological state that occurs and develops during interactions between persons and their environment (e.g., objects, topics, contents, and ideas)."* (Woithe, 2020, p. 16); curiosity can be defined *"as the desire for knowledge or information in response to experiencing or seeking out collative variables, which is accompanied by positive emotions, increased arousal, or exploratory behavior"* (Woithe, 2020, p. 22). The constructs of interest and curiosity differ in several ways, including their focus and the types and stability of their objects.

Different types of curiosity can be identified based on its object, degree of stability, and reason. In this article, we focus on the type of curiosity characterized by the following factors: the desire for knowledge, the search for opportunities for intellectual activities, and the acquisition of knowledge and facts about a given topic. This type of curiosity is called *epistemic curiosity* (Grossnickle, 2016; Woithe, 2020). One reason for interest that is relevant to our research may be the desire to learn new things and the positive emotions experienced during activities.

Both situational interest and epistemic curiosity can improve learners' motivation. However, according to Grossnickle (2016) and Woithe (2020), the constructs of interest and curiosity differ in their directional focus as well as in their typical stability. Since interest is produced in the interaction between an individual and the environment, it is always identified with a specific topic, for instance, physics. On the contrary, curiosity targets perceived knowledge gaps regardless of topic. According to Grossnickle (2016), this interest independence enables curiosity to transcend one's specialty, fostering broader awareness and occasionally revealing relevant connections outside one's field. Although both curiosity and situational interest can be sparked by uncertainty, the latter can be directly and universally elicited by certain emotionally charged topics (like death or violence) without an antecedent knowledge gap. We examine curiosity after the workshop because it can be a strong trigger and catalyst for triggered situational interest, and numerous articles argue that research on interest should also extend to curiosity (Hidi & Renninger, 2019; Woithe, 2020; Woithe et al., 2022). It may happen that curiosity is satisfied and nothing else happens—the learner finds the answer and stops looking for further information. However, it is possible that satisfying curiosity triggers situational interest: the learner perceives personal relevance in the content and wishes to engage with it further. This interest can then be further developed.

Enjoyment

As summarized by Woithe (2020), a primary goal of out-of-school learning is to provide enjoyment – a pleasurable exploration free from overwhelming pressure. Research on the affective outcomes of such experiences highlights their significance. For instance, Rennie (1994), in a study of hands-on science center visits, found that both affective and cognitive outcomes are crucial: enjoyment can facilitate further cognitive learning, while optimal cognitive learning itself depends on a positive affective experience. Beyond enjoyment, Rennie (1994) identified components such as perceived helpfulness and ease as key elements of students' affective outcomes.

Enjoyment and interest are often treated as closely related constructs and are sometimes even used interchangeably, with enjoyment frequently regarded as an essential component or prerequisite of interest (Woithe, 2020). PISA 2006 examined students' enjoyment of science as an indicator of their intrinsic motivation to learn science and found a strong alignment between enjoyment and general interest in the subject (OECD, 2007). Moreover, students who reported greater enjoyment of learning science also tended to achieve better performance across many countries, suggesting that enjoyment is meaningfully linked to successful learning outcomes (OECD, 2006).

Experiences of One-Day Events in the Context of Interest

Molz (2016) systematically investigated the effects of novelty on cognitive and affective outcomes. The study confirmed that preparatory activities aimed at reducing novelty have a positive impact on curiosity and motivation. Moraga-Calderón et al. (2020) examined university students' perceptions of the importance and relevance of quantum physics and technology, and how these perceptions changed after participating in a special quantum thematic intervention called "Quantum Rules". Using qualitative and quantitative analysis, they found that the intervention positively influenced students' views, particularly regarding the societal importance of quantum science. Students agreed significantly more with the statement *"Quantum science is important for society"* after the visit and saw the learning of quantum physics as more valuable. However, they revealed a disconnect between recognizing quantum physics as important for society and perceiving the learning of quantum physics as personally relevant. Students tend to view learning quantum physics as relevant only when they find it interesting, leading to the recurring attitude of "important, but not for me". Students tend to perceive the individual dimension as the most crucial factor in learning quantum physics: personal interest motivates their willingness to engage with and understand the subject. Accordingly, when students lack interest in quantum physics, they are unlikely to perceive learning it as meaningful. For these students, the societal relevance of quantum physics alone is insufficient to serve as a compelling motivation for learning. The study suggests that this perception stems from students' limited understanding of the societal relevance of learning quantum physics itself.

Students do not see that quantum literacy as a useful tool for their future as citizens, and acknowledging the technological applications of quantum is not enough to see the societal relevance of learning it (Moraga-Calderón et al., 2020; Raved & Assaraf, 2011). The findings of Moraga-Calderón et al. (2020) therefore indicate that a key objective of such one-day events may be to stimulate students' interest – which, in turn, can foster engagement with learning quantum physics – and to highlight the benefits of studying quantum physics for broader segments of society, for instance by showcasing relevant technologies that (will) shape everyday life. These results align well with the broader literature on interest (Dopatka et al., 2020), underscoring that effective interventions should simultaneously address both emotional engagement and perceived value.

Anttila et al. (2024) conducted a qualitative study in which they organized a one-day quantum-physics-themed event ("Fun in Theory") for 15 undergraduate students majoring in mathematics and physics, with the aim of triggering students' interest in theoretical physics, particularly quantum physics. Although the event did not produce a clear shift within the four-phase model of interest, it positively influenced participants' attitudes toward and perceptions of quantum physics and fostered an overall sense of increased interest—an encouraging indication of successfully triggered interest.

Despite the limited impact, interview data led Anttila et al. (2024) to conclude that such an event was capable of shaping participants' attitudes and views, as well as their quantum-physics-related topics of interest. One week after the event, most participants self-reported an increase in their interest in quantum physics. This suggests that, for some students, interest may continue to develop further, for example through well-designed compulsory quantum physics courses following the event. The event also proved beneficial in additional ways. Participants perceived it as useful because it clarified the content and expectations of theoretical physics studies and helped them reflect on whether they would like to pursue theoretical physics as a major.

The programs by Moraga-Calderón et al. (2020) and Anttila et al. (2024) were effective but produced mixed results. An important difference, however, is that their sample consisted of university students preparing for STEM careers, which could lead to fundamentally different results regarding interest. Therefore, it remains an open question about what kind of impact can be achieved with high school students.

RESEARCH QUESTIONS

In this study, we are interested in whether a one-day quantum event focusing on quantum technologies and targeting high school students is suitable for triggering students' situational interest and improving their curiosity and enjoyment. Therefore, our research questions are:

RQ: How does a program on quantum technology influence upper secondary school learners'

a) facets of interest?

b) curiosity and enjoyment?

Based on these experiences, the workshop structure can be refined to better address different triggers of students' interest and to make future implementations more effective in fostering situational interest.

METHODS AND MATERIALS

Workshop Design

To address the research questions, we developed a station-based workshop on quantum technologies for upper secondary school students. The design of the workshop was guided by two complementary considerations. First, the workshop should provide students with active and experimentally grounded access to central concepts of quantum physics and quantum technologies. Second, the three stations should remain independent of one another, so that students could rotate through the project day without requiring a fixed conceptual sequence. Across all stations, two-state quantum systems served as the unifying conceptual framework. This choice was motivated by their central role in quantum technologies, where qubits are represented by two-state systems, and by their suitability for introducing core quantum ideas such as superposition, measurement, interference, and state transformations (Bitzenbauer et al., 2024; Tóth et al., 2025).

The instructional structure of the workshop was informed by Kolb's (2014) theory of experiential learning. In this framework, learning is understood as a process in which knowledge is created through the transformation of experience. The learning cycle comprises concrete experience, reflective observation, abstract conceptualization, and active experimentation. This structure was adopted as a guiding principle for the development of the three stations. Each station begins with a concrete phenomenon, experimental task, or game-based situation. Students are then asked to observe and document what happens, interpret their observations, and connect them to quantum-physical concepts. Finally, they apply these concepts in a further experimental, mathematical, or interpretive task. In this sense, the stations were not designed as demonstrations of pre-given theory, but as learning environments in which conceptual understanding emerges from structured engagement with phenomena.

The workshop design was also aligned with principles for effective workshop development described by Zenni and Turner (2021). They emphasize that effective workshops should include active learning, build on learners' prior experiences, provide opportunities for application, and include phases of reflection and consolidation (Zenni & Turner, 2021). These principles were operationalized by minimizing purely expository instruction and centering each station on hands-on work. Students assembled, calibrated, manipulated, and interpreted the experimental setups using structured worksheets. At each station, an expert was available to provide technical support, scaffolding, and short conceptual impulses when necessary. Thus, the expert role was not primarily to lecture, but to support students' progression through the experiential learning cycle.

We note that the real experiments were not true quantum-optical, single-photon experiments, as such experiments are difficult to perform. The students conducted these experiments using classical laser light. The discoveries in quantum physics arose from the need to interpret the phenomena at the level of photons. The resulting workshop consisted of three stations.

1. *Station A: Interference and quantum eraser* focused on qubits, superposition, and interference in a Michelson interferometer. Students first constructed and aligned the interferometer, observed the resulting interference pattern, and then investigated how polarization filters affect the visibility of interference. The station culminated in an analogy experiment for the quantum eraser, in which a third polarization filter can restore interference by erasing available which-path information.
2. *Station B: Quantum cryptography and BB84* introduced superposition and measurement in the context of quantum key distribution. Students first worked with the idea of binary encryption and then implemented the BB84 protocol by encoding bits in polarization states. They generated a key without an eavesdropper and subsequently repeated the procedure with an eavesdropper, allowing them to observe how measurement can disturb the transmitted states and produce detectable errors.

Table 2. Literature-based design principles and their implementation in the workshop

Design principle	Implementation in the workshop
Experiential learning	Each station followed the sequence of concrete experience → observation/reflection → conceptualization → application.
Active learning	Students assembled, calibrated, manipulated, documented, and interpreted the experimental setups themselves.
Concepts emerging from phenomena	Formal ideas such as which-path information, measurement disturbance, and the Hadamard operation were introduced after students had encountered a phenomenon requiring explanation.
Two-state systems as a unifying framework	All stations used two-state descriptions: interferometer paths or polarization states in station A, polarization-encoded bits and bases in station B as well as $\|heads\rangle$ and $\|tails\rangle$ states in station C.
Modular station design	The three stations could be completed independently while contributing to the shared theme of quantum technologies.
Scaffolding and expert support	Worksheets guided the experimental process, while experts provided technical assistance, scaffolding and short-term impulses.
Reflection and consolidation	At the end of the project day, students participated in a final reflection phase in which the central take-home messages across the three stations were collected.

Table 3. Overview of the topics, the experiment that was used, and the reasoning tools that were addressed, as outlined by Müller and Mishina (2021), for each station

Station	Content	Experiment	Addressed reasoning tools
A	Qubits, superposition and interference in a Michelson interferometer	Michelson interferometer, which is gradually being expanded into a quantum eraser	- Quantization - Probabilistic nature - Interference of single quantum objects - Delocalization - Complementarity
B	Superposition and measurements in the context of quantum cryptography	Experimental setup for the BB84 protocol from ThorLabs	- Quantization - Probabilistic nature - Quantum measurement - Statistical behavior
C	Superposition and basic quantum gates	Construction, investigation and mathematical description of quantum gates using a reduced Dirac notation (Hennig et al., 2024a, 2024b, 2024c) and the Quantum FlyTrap (Migdał et al., 2022)	- Quantization - Probabilistic nature - Statistical behavior - Interference of single quantum objects - Quantum measurement - Delocalization

3. *Station C: Quantum Penny Flip and basic quantum gates* used a simple game as an entry point into quantum computing. Students first played and analyzed a classical penny-flip game, then described the game mathematically using state notation and the identity and NOT operations. The game was then extended by introducing the Hadamard operation, which creates a superposition state and allows a quantum strategy with a systematic advantage. Finally, students implemented the idea in a simulation using single photons and polarization states.

Although the stations addressed different quantum technologies, they followed a common design rationale. Each station began with an accessible phenomenon or problem, led students toward observation and interpretation, introduced formal concepts only after the need for explanation had emerged, and ended with a task in which the newly developed concept was applied. The stations were therefore independent at the operational level but coherent at the conceptual level. Their common structure was intended to support students in recognizing two-state systems as a shared foundation of different quantum technologies. Our design principles are summarized in **Table 2**.

Following the station rotation, the project day concluded with a collective reflection phase (cf. **Table 3**). This phase did not aim to repeat the detailed content of each station, but to synthesize the central take-home messages across the workshop. In particular, the reflection was used to connect the three station experiences to the overarching theme of two-state systems in quantum technologies and to make explicit how concepts such as superposition, measurement, interference, and state transformations appeared in different technological contexts. Thus, the workshop combined modularity with conceptual coherence: students could work through the stations

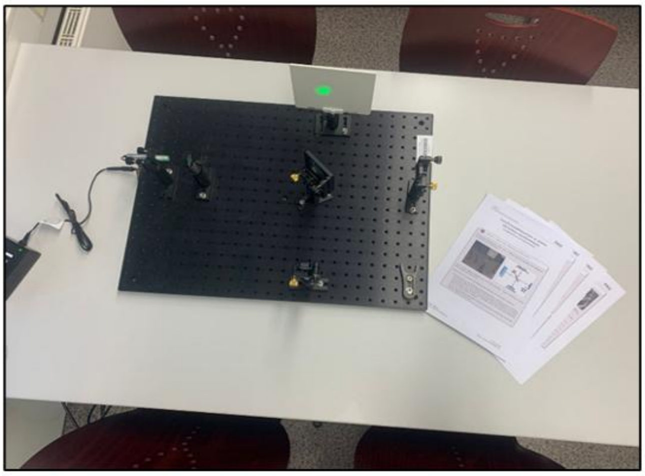

Figure 1. Hands-on station thematizing qubits, superposition and interference in a Michelson interferometer (the authors' own photograph)

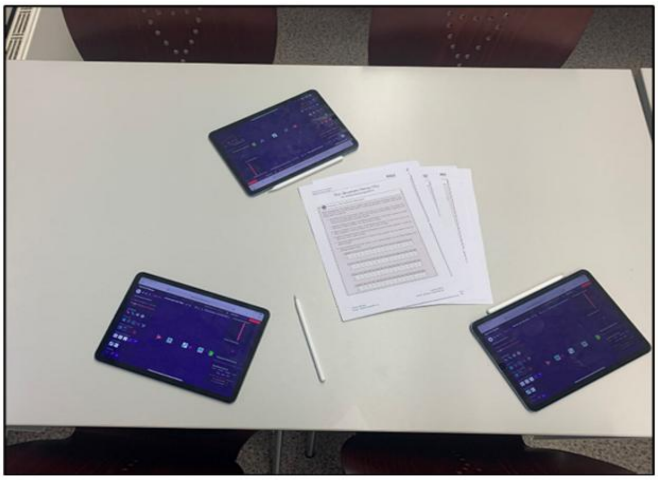

Figure 3. Tablet-based hands-on station thematizing superposition and basic quantum gates using Quantum FlyTrap (Migdał et al., 2022) (the authors' own photograph)

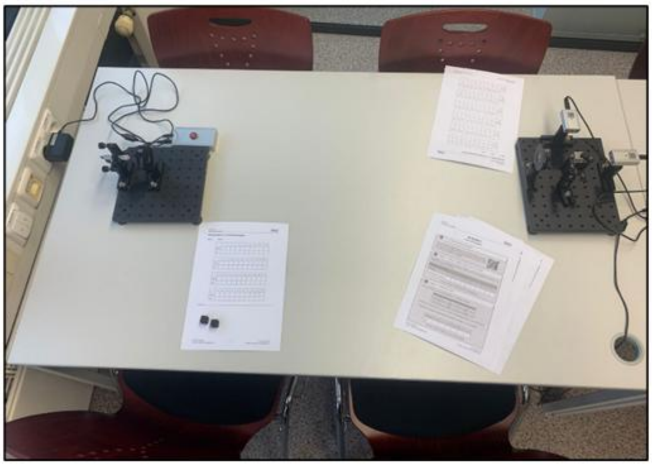

Figure 2. Hands-on station thematizing superposition and measurements in the context of quantum cryptography (the authors' own photograph)

independently, while the overall design supported a unified understanding of quantum technologies through the lens of two-state quantum systems.

Figure 1 shows the hands-on station thematizing qubits, superposition and interference in a Michelson interferometer.

Figure 2 depicts the hands-on station thematizing superposition and measurements in the context of quantum cryptography.

Figure 3 shows the tablet-based hands-on station thematizing superposition and basic quantum gates using Quantum FlyTrap (Migdał et al., 2022).

Table 4 presents the identified triggers of interest in the quantum workshop. We rely on the work of Renninger et al. (2019b).

Table 4. Identified triggers of interest in the quantum workshop. We rely on the work of Renninger et al. (2019b)

Trigger	Definition	The context of quantum workshop
Affect	Heightened emotion that emerges during activity or some aspect of an activity.	The stations featured spectacular optical experiments. The laws of quantum physics are astonishing.
Autonomy	Learner-directed activity, often involving answering a personal question.	The students shared their own decisions and thoughts and were free to conduct the experiments on their own.
Challenge	Content, skills, or anything else that is difficult for the learner.	The counterintuitive nature of quantum physics is a great intellectual challenge and adventure.
Character identification	Seeing oneself as a scientist or other relevant character.	The tutors were women who served as professional role models for the group of girls.
Computers, technology	Participants use computer-based, technological, and high-tech tools.	The experiments included single-photon quantum optics experiments conducted in a computer simulation (Bronner et al., 2009). We also presented some spectacular quantum animations (Migdał et al., 2022).
Group work	Work with others, where others are peers and not instructor.	The program is deliberately designed to foster teamwork.
Hands-on activities	An activity or component of an activity that is interactive or involves the use of one's hands.	The students were able to try out the experimental equipment for themselves.

Table 4 (Continued).

Trigger	Definition	The context of quantum workshop
Instructional conversation	A conversation that engages with content and enables a learner to reach a new understanding.	The students were free to ask questions and discuss topics with one another, and at the end of the project day, there was a summary and reflective discussion.
Novelty	Anything that is new, including new insight into something that is familiar.	Quantum technology is a new field of science and students have not previously encountered this topic.
Personal relevance	A connection between an activity or aspect of an activity and a learner's past experience.	The quantum workshop is introduced through the question of whether absolutely secure data encryption is possible, illustrated using the example of a spam text message.

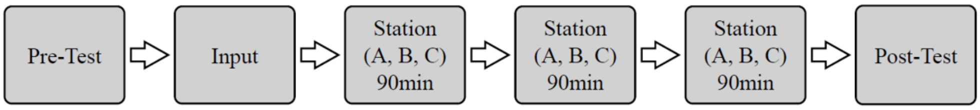

Figure 4. An overview of the study (the authors' own elaboration)

Table 5. The number of questions relating to the various dimensions of interest and their internal consistency

Subscale	N	Anchor example	α
Topic-related interest with value-related valence (TV)	5	Physics can explain many events from everyday life.	0.911
Topic-related interest with emotional valence (TE)	5	In general, I enjoy engaging in topics in physics.	0.946
Subject-related interest with emotional valence (SE)	5	I like attending physics class.	0.949
Subject-related interest with value-related valence (SV)	3	In physics class, we are informed that this content is important for other topics.	0.892

Note. N: Number of items & α: Cronbach's alpha

Design-Based Research

One of the goals of the research is to organize an engaging workshop on quantum technologies for high school students. In line with this, our pilot study also serves as a basis for further developing the project based on the insights gained. The research methodology for this is provided by the principle of design-based research (Anderson & Shattuck, 2012), which involves the cyclical organization of educational materials. The results of the research will enable the further development of this pilot project.

Study Design and Sample

The study employed a pre-post design (see **Figure 4**), using a single cohort to examine changes in the measured variables. Data were collected at two measurement points: the pre-test was taken immediately prior to the introductory presentation at the beginning of the project day, and the post-test was administered immediately after students had completed all three stations.

The workshop was conducted during a scheduled school project day and took place within regular class time. The sample consisted of N = 45 female students from a German upper secondary school. Participants were between 16 and 18 years of age.

In the preceding physics lessons, students covered basics of wave optics as well as the principles of quantized energy absorption and emission. However, the regular curriculum does not include applications of quantum technologies or advanced concepts of quantum physics.

Instruments

To assess the four facets of interest, the instrument developed by Dopatka et al. (2020) was employed. The scale comprises 18 Likert-type items distributed across four subscales, summarized in **Table 5**. The pre- and post-tests are available in **Appendix A**.

All items were rated on a five-point Likert scale ranging from *strongly disagree* (1) to *strongly agree* (5).

To assess students' enjoyment of the workshop, three additional items were adapted from Woithe (2020). These items were thematically adjusted to the context of the workshop and were administered only in the post-test. The resulting scale exhibited high internal consistency (Cronbach's α = 0.899), indicating sufficient reliability.

To assess students' curiosity regarding quantum physics following the workshop, five items were adapted from Woithe (2020). These items were thematically adjusted to the context of quantum physics and were administered only in the post-test. The resulting scale showed high internal consistency (Cronbach's α = 0.848), indicating sufficient reliability.

Table 6. Overview about the M and the SD as well as the median of the subscales (the highest possible score is 5)

	Pre			Post		
	M	*SD*	*Median*	*M*	*SD*	*Median*
Topic interest with emotional valence (TE)	2.80	0.99	2.60	2.81	1.02	2.80
Subject interest with emotional valence (SE)	2.60	1.02	2.60	2.54	1.05	2.60
Topic interest with value valence (TV)	3.80	0.68	4.00	3.69	0.68	4.00
Subject interest with value valence (SV)	3.10	0.83	3.00	3.13	0.89	3.00

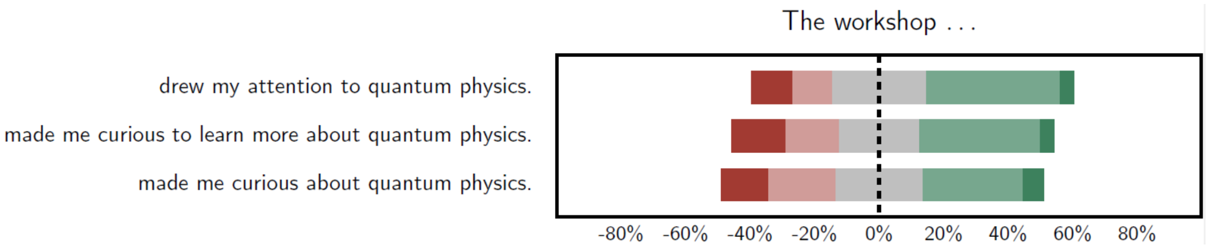

Figure 5. Diverging stacked bar charts presenting the results from the curiosity scale (the colors represent a scale of opinion, ranging from red, indicating a strong disagreement with the statement, to dark green, indicating a strong agreement) (the authors' own elaboration)

Data Analysis

Data analysis began with the computation of subscale means using *Jamovi*. No inverted items were included in the instrument.

To assess distributional assumptions, Shapiro-Wilk tests were conducted for each subscale. While the assumption of normality was violated for the remaining subscales, non-parametric methods were employed for all inferential statistical analyses to ensure a consistent analytical approach (**Table 6**).

Changes between pre- and post-test mean values were examined separately for each subscale using Wilcoxon signed-rank tests. The results of the Wilcoxon tests are reported using the standardized z-statistic and the p-value. For statistically significant results, the rank-biserial correlation *r* as measure of the effect size is reported.

Enjoyment of the workshop and curiosity about quantum physics were assessed only in the post-test and analyzed descriptively. Absolute frequencies and standard deviations (SDs) were reported, and response distributions were visualized using stacked bar charts.

FINDINGS

The subscale *topic-related interest with emotional valence* (TE) showed no statistically significant increase from pre-test to post-test. The Wilcoxon signed-rank test indicated no significant difference between measurement points (z = 0.02, p = 1.00), with nearly identical mean scores in the pre- and post-test.

Furthermore, no statistically significant change was observed for *topic-related interest with value-related valence* (TV) between the pre- and post-test (z = 1.74, p = 0.083). Descriptive statistics likewise indicated only minor differences between measurement points.

Similarly, no significant difference was found for *subject-related interest with emotional valence* (SE) (z = 0.80, p = 0.426), and mean values remained largely stable across measurement points.

For *subject-related interest with value-related valence* (SV), the Wilcoxon test also revealed no significant change (z = -0.01, p = 0.992), with nearly identical mean scores in the pre- and post-test.

The evaluation of the scale measuring curiosity about quantum physics demonstrated that a few pupils became aware of the topic of quantum physics (mean [M] = 3.13, SD = 1.10) and that some pupils became more aware of quantum physics as a result of the workshop (M = 2.96, SD = 1.18) (**Figure 5**).

However, the evaluation of the enjoyment scale revealed that, overall, the majority of pupils reported positive experiences during the workshop (M = 3.90, SD = 0.83). In particular, the pupils reported high levels of enjoyment in working with the experimental materials (M = 3.83, SD = 0.66) (**Figure 6**).

DISCUSSION

Discussion of the Research Questions a) and b)

The findings indicate that no statistically significant change was observed in any dimension of interest. This result should be interpreted in light of the constructs measured in the present study. Although the workshop was designed to provide interest-triggering experiences, two interest facets assessed by the pre-post instrument may refer to relatively stable subject-related orientations with emotional and value-related valence. They therefore may not capture momentary situational interest in the narrow sense, but rather more stable affective and value-related relations to physics and quantum physics. From this perspective, the absence of statistically significant pre-post changes in subject-

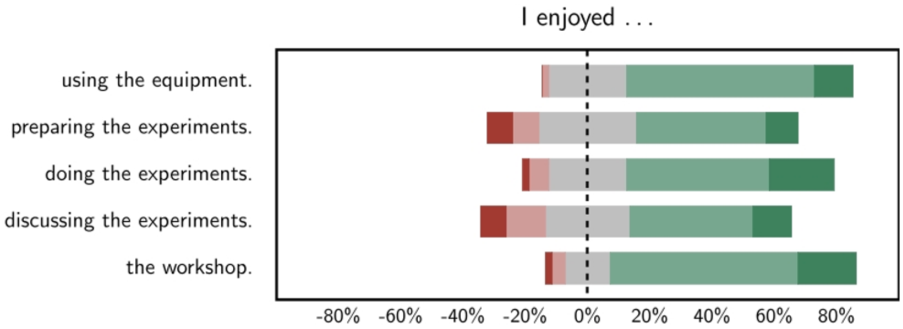

Figure 6. Diverging stacked bar charts presenting the results from the enjoyment scale (the colors represent a scale of opinion, ranging from red, indicating a strong disagreement with the statement, to dark green, indicating a strong agreement) (the authors' own elaboration)

related interest is theoretically plausible and in line with previous research on interest development. Although out-of-school programs can provide powerful triggers for situational engagement (Woithe, 2020), our findings suggest that such short-term experiences do not necessarily translate into measurable changes in more stable interest-related constructs, including regarding topic-related interest. In this respect, the results show similarities to previous studies on one-day quantum events, which also indicate that short interventions may shape students' experiences, attitudes, or curiosity without necessarily producing robust changes in interest development (Anttila et al., 2024; Renninger & Hidi, 2016; Renninger et al., 2019a, 2019b). Although we did not measure cognitive load, the high working memory demands of quantum physics (Hennig et al., 2024c) may have caused this barrier. Woithe et al. (2022) and (Hennig et al., s. a.) argue that although cognitive load did not predict changes in students' interest, this may have been largely because it was kept at a low level throughout the study. High cognitive load may hinder interest. In the future, it would be worthwhile to conduct studies on cognitive load as well, because if it is high, it could be a serious obstacle to sparking interest.

A further explanation is that the interest-triggering features implemented in the workshop may not have been sufficiently well matched to the target group. The stations included several elements that are typically considered promising for triggering situational interest, such as hands-on experimentation, novelty, surprising quantum phenomena, and references to modern technologies. However, these triggers may have primarily affected students' immediate workshop experience, as reflected in the relatively high descriptive values for curiosity and enjoyment, rather than their more stable interest-related orientations and may have remained too local and short-lived to produce measurable changes in students' broader interest in quantum physics or physics as a subject. For upper secondary school students, quantum technologies may be intellectually intriguing but still rather distant from their prior experiences, everyday contexts, and personally meaningful questions. In addition, some parts of the workshop required substantial effort for technical setup, calibration, and formal interpretation. These activities may have supported enjoyment and curiosity during the workshop, but they may not have provided enough personally relevant or value-related connections to sustain interest beyond the immediate situation. This distinction helps explain why students could report comparatively high curiosity and enjoyment after the workshop while the pre-post measures of interest remained stable. Curiosity and enjoyment can be understood as immediate affective responses to the learning environment, whereas the measured interest facets reflect more persistent relations to topics and subjects. This interpretation suggests that future iterations should not only include interest-triggering elements but should align them more closely with the learners' prior knowledge, perceived relevance, and need for orientation. For example, the workshop could include stronger links to societal applications, career perspectives, or students' own questions about quantum technologies, as well as more explicit reflection phases that connect the individual station experiences to personally meaningful take-home messages.

The results regarding subject-related interest are not surprising, because attitudes develop over the course of years, and a short intervention therefore appears to be insufficient to bring about meaningful change. This is particularly relevant because subject-related interest is directed not only toward the specific workshop topic but toward physics as a school subject more generally. A one-day quantum technology workshop, even if experienced positively, is therefore unlikely to substantially alter students' broader relation to physics as a subject. A clear increase in interest would likely require repeated triggering experiences, external support, and deeper, more sustained engagement with quantum physics (Anttila et al., 2024; Renninger & Hidi, 2016; Renninger et al., 2019a, 2019b).

We therefore refrain from interpreting the small descriptive differences between pre- and post-test scores as evidence of change. Instead, the stability of the interest measures is treated as an important finding in itself: positive experiences during a workshop do not automatically translate into measurable changes in more stable interest-related constructs. Value-based interest (i.e., the extent to which physics or the topic is perceived as important) is generally more resistant to change than affective dimensions. This stability was therefore an expected outcome.

It is worth highlighting the high mean score of the experimental work in the enjoyment dimension. This finding underscores the importance of constructivist pedagogy in quantum physics: abstract theory became accessible and enjoyable through the use of tangible, hands-on tools. Molz (2016) systematically investigated the effects of novelty on cognitive and affective outcomes. The study confirmed that preparatory activities aimed at reducing novelty have a positive impact on curiosity and motivation.

In the present study, the high enjoyment scores suggest that the hands-on and experimental structure of the workshop provided students with a positive affective learning experience. However, the lack of significant changes in the interest scales indicates that such positive experiences should be interpreted as a prerequisite or possible starting point for interest development, rather than as evidence that interest itself has already changed.

The workshop achieved some of its primary goals – providing a positive experience and fostering orientation toward modern physics – while also confirming that more stable interest-related constructs are unlikely to change substantially through a single one-day intervention. Measurable changes in these constructs would likely require a longer time frame, repeated triggering and holding experiences, and a closer alignment of the workshop’s interest-triggering features with the target group. Thus, rather than contradicting previous research, our findings refine it: one-day quantum technology workshops may successfully support curiosity and enjoyment, but changing stable interest-related orientations requires sustained and personally meaningful engagement.

Refinement of the Workshop

Based on the results, the workshop could be further developed through the following ideas.

- At the end of the workshop, students could be provided with “take-home” challenges or access to a digital platform that allows them to continue experimenting beyond the workshop itself. In addition, the workshop could be further developed into a longer program series, to reduce cognitive load. Another option for reducing the cognitive load is to clarify certain basic concepts of quantum physics in school, thereby reducing the amount of new concepts they need to learn during the workshop.
- The individual stations could be shortened and focused more strongly on selected core concepts and activities. Rather than attempting to provide a comprehensive overview of each topic, the stations could concentrate on the aspects that are most relevant to the workshop’s learning objectives. This would help prevent cognitive overload and give students more time to engage with the central ideas.
- Short instructional videos could be used to introduce the workshop and present theoretical content. Such videos could reduce the amount of text students are required to read and make complex concepts more accessible. They could either be provided before the workshop as preparatory material or integrated directly into the individual stations.
- Technically demanding experiments should be prepared and tested in advance. In particular, setting up and aligning an interferometer can be difficult and time-consuming. A partially preconfigured experimental setup would allow students to focus more on observation, experimentation, and conceptual understanding rather than on technical troubleshooting. Nevertheless, students could still be involved in selected setup procedures where these contribute meaningfully to the learning objectives.
- Although students clearly enjoyed the experiments, the value-based interest indicators showed little change, suggesting that they did not fully grasp the societal or personal relevance of quantum physics. As Moraga-Calderón et al. (2020) pointed out, students often think that quantum physics is “important, but not for me”. Recognizing the social benefits and value of learning quantum physics can help spark interest. We therefore believe it would be beneficial to incorporate elements that explicitly focus on technological applications, societal impacts, career opportunities, and ethical considerations.
- We also think it valuable to complement the workshop with social interactions that are not explicitly centered on physics, but rather on team building and the potential formation of friendships. Social relationships may play an important role in fostering interest. We find Anttila et al.’s (2024) method particularly exciting, in which a one-day quantum event included explicitly informal programs: games and informal chats with snacks. These ideas are worth adopting. The workshop could thus include a phase in which students engage in discussions and articulate their views to peers or to an expert. Experts, in turn, can provide inspiration and offer

clearer insights into their profession and career pathways.

Limitations

Although the study provides valuable insights into the affective impact of quantum physics workshops, several limitations must be considered when interpreting the results. The research was conducted with a moderate sample size (N = 45) among female students from a single secondary school. This sample size limits statistical power, which may explain why the modest increases in scores did not reach significance in the Wilcoxon tests.

The study employed a single-cohort pre-post design without a control group. Consequently, it cannot be ruled out that the observed stability in attitudes or the high enjoyment levels measured post-workshop were influenced by factors other than the intervention itself, such as students' prior engagement with physics.

Certain variables (enjoyment and curiosity) were measured only at post-test. Although descriptive statistics indicate positive outcomes, the absence of pre-test data for these scales prevents precise quantification of changes relative to baseline. Moreover, self-report measures carry the risk of social desirability bias, in which students may report more positive experiences out of consideration for the workshop facilitators.

Students also arrived with prior knowledge, which, on one hand, supported comprehension but, on the other hand, may have produced a ceiling effect on the interest scales if students were already highly motivated before the workshop.

CONCLUSION

The present study investigated the effects of a one-day, hands-on workshop on affective learning characteristics – specifically interest, curiosity, and enjoyment – in the context of quantum technologies. The results indicate that no statistically significant changes were observed across the different facets of interest (TE, TV, SE, and SV). At the same time, learners reported high levels of enjoyment, indicating that the workshop was perceived as a positive and engaging learning experience. In particular, the experimental and hands-on components appear to play a central role in shaping this favorable perception. From a theoretical perspective, such experiences can be understood as opportunities to evoke situational engagement through affective and experiential involvement. Consequently, promoting sustained interest in quantum technologies likely requires repeated, curriculum-embedded learning opportunities that build on situationally triggered engagement and explicitly address the personal, societal, and technological relevance of quantum science. Embedding experimental learning experiences within a coherent instructional sequence may therefore be a promising avenue for supporting the development of situational interest in quantum technologies. In addition, we consider the role of informal conversations and the role of female tutors as role models to be important. Based on our experience, we have made important suggestions for refining a workshop on quantum technologies; others may draw on these insights in the future.

Author contributions: KT and **FH** contributed equally to the research. **MSU** provided valuable advice and constructive feedback on the manuscript. All authors agreed with the results and conclusions.

Funding: Supported by the Open Access Publishing Fund of Leipzig University. KT is supported by the EKÖP-26-4-II-SZE-12 UNIVERSITY RESEARCH FELLOWSHIP PROGRAM of the Ministry of Science and Technology from the source of the National Research, Development and Innovation Fund.

Ethical statement: Ethical review and approval were not required for the study on human participants in accordance with the local legislation and institutional requirements.

AI statement: The English language of this manuscript was refined with the assistance of an AI-based language tool; all content was subsequently reviewed and verified by the authors.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: The collected data can be accessed online at https://zenodo.org/records/22126444.

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APPENDIX A

Table A1. Scales

	DT	RD	N	RA	AT
The scale regarding curiosity about quantum physics was adopted from Woithe (2020)					
The workshop drew my attention to quantum physics.					
The workshop made me curious to learn more about quantum physics.					
The workshop made me curious about quantum physics.					
The scale regarding the enjoyment of the workshop was adopted from Woithe (2020)					
I enjoyed using the equipment.					
I enjoyed preparing the experiments.					
I enjoyed doing the experiments.					
I enjoyed discussing the experiments.					
I enjoyed the workshop.					
The scale regarding the four facets of interest was adopted from Dopatka et al. (2020)					
In general, I enjoy engaging with topics in physics.					
Physics can be used to explain many processes in nature.					
I like physics.					
In physics, we learn where the content can be applied in practice.					
I like reading about physics.					
Physics helps to understand how technical devices work.					
Physics is one of my favorite subjects.					
I enjoy working on physics problems.					
In physics class, it becomes clear that the material we learn is also important for everyday life.					
I enjoy physics class.					
Physics can explain many events from everyday life.					
I usually look forward to the next physics lesson.					
Physics is a field that will become increasingly important in the future.					
I am interested in learning new things in physics.					
Physics has many practical applications.					
I like acquiring new knowledge in physics.					
I like attending physics class.					
In physics class, we are informed that this content is important for other topics.					

Note. DT: Disagree totally; RD: Rather disagree; N: Neutral; RA: Rather agree; & AT: Agree totally