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Can a one-day event trigger interest in quantum physics at the university level?

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Abstract
The ongoing second quantum revolution and the growing impact of quantum technologies on our society and economy are making quantum physics education even more important. Consequently, there is a lot of research on quantum physics education for university students and even the general public. However, studying quantum physics or any other topic is primarily voluntary and thus a matter of personal interest—and it can only grow from a seed planted earlier. Here, we describe and test how a one-day event designed to trigger interest and change perceptions about quantum physics among physics and mathematics students at the University of Turku, Finland succeeded in meeting its goals. The data was collected from participants through questionnaires and complementary interviews. We found that the event made attitudes and views toward quantum physics more positive, versatile, and realistic. Although the event was too short to notably or permanently elevate the phase of interest when evaluated externally on a four-level scale, self-evaluations still reported an increased interest for most participants. Thus, it appears that even a short event can cultivate the ground to make it fertile for maintaining and developing interest further, for example, by well-designed and -timed quantum physics curriculum.

Keywords: quantum physics, higher education, interest, attitude

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1. Introduction

Quantum physics is becoming increasingly omnipresent in everyday life, whether hidden in technologies like cell phones and screens or visible in the news and popular or social media—even to the point of quantum hype [1]. The ongoing second quantum revolution drives technological and scientific development further, as indicated by the ever-expanding job market of the quantum industry that requires people skilled in quantum physics [2–5]. Inevitably, the quantum drive also affects teaching [6]. A well-informed and forward-looking society does well to produce not only quantum-ready workforce but also next-generation quantum educators that, in turn, teach both new experts and the general public the fundamentals of quantum physics [7, 8]. Because quantum physics is the fundamental theory underlying most branches of modern physics research, knowledge of quantum physics is beneficial for all physics students, not only the ones specializing in quantum technologies [9].

The prerequisite for effective learning of quantum physics includes at least some level of interest in the subject. At universities, students often choose physics because of personal interest and curiosity [10]. Interest elevates understanding [11], promotes conceptual change [12–14], improves the quality of studying, helps to overcome difficulties [11, 12], and supports setting and achieving goals, such as completing a course or a degree [15, 16]. Interest encourages academic self-regulation [17] and sustains meaningful engagement [18]. It also stimulates voluntary learning opportunities [12] and aids in making beneficial decisions, like choosing relevant courses or minor studies [19]. In addition, more developed interest can have an influence on self-efficacy [12], which in turn affects students' interest and study choices [20, 21].

However, quantum physics is an abstract topic that is challenging to grasp [22], which makes the initial triggering of interest difficult. It describes phenomena that can be neither experienced directly nor explained by classical physics or intuition; instead, it requires learning through new, non-classical ways of thinking [23, 24]. Consequently, students struggle with both conceptual understanding and technical calculations, e.g. [24–31]. Without interest, these struggles are considerably harder to overcome [11, 12]. Negative attitudes toward physics and science further challenge the growth of interest during adolescence [32–35]. Quantum physics at high school is often taught by retaining the focus on the historical development of science instead of letting students get fascinated by the new phenomena and concepts [36]. Triggering interest remains difficult also at universities. Quantum physics courses have a fast pace and they focus on technical calculations [37], so students may end up mastering quantum-mechanical calculations without gaining conceptual understanding; interest in quantum physics may arise after the calculations have already been mastered.

To address these challenges, we arranged a one-day event deliberately designed to trigger interest in quantum physics and in theoretical physics more generally among physics and mathematics students at the University of Turku. Following Hidi's and Renninger's theoretical framework for interest development [12, 38], the event was designed to take optimal advantage of new information, active participation, and social interaction. The event was studied by pre- and post-questioning and interviewing part of the event's 60 participants. As a general result, we find that although such a short intervention can change students' impressions of quantum physics and cultivate fertile ground for interest development, achieving substantial changes in the interest phase requires more time, as also indicated by the literature [12].

2. Background

2.1. The process of interest development

According to the interest development framework of Hidi and Renninger, interest manifests itself in engagement and reactions to different contents, subjects, people, and tasks [12]. It consists of a psychological state which affects attention and effort during engagement and a motivational predisposition to re-engage with the content. Interest includes motivation, but motivation does not necessarily lead to interest. For example, a student without interest in physics may be motivated to study physics to get to medical school (external motivation).

According to Hidi [38], interest develops first in a situational, then in an individual fashion, following the four phases: triggered situational, maintained situational, emerging individual, and well-developed individual interest. The four phases are characterized by values, engagement, knowledge, and external support required for maintaining the interest. The first phase is often triggered by external variables like other people, personalized content, different activities, social games, and meaningful engagements [12, 39]. Then, interest can advance to the second phase, where a person starts to recognize the value in the subject, re-engage with it, and develop knowledge; sustaining the interest still requires external support. With sufficient support or opportunities, it may evolve into the third phase of more self-sustained individual interest. This phase may further evolve into a well-developed individual interest, where a person knows a good deal about the subject, re-engages with the subject independently, has a capacity for reflective thinking, recognizes the value of the subject, and can overcome challenges and frustration during the learning process [12]. Interest development is a gradual process that requires experiencing the psychological state of interest repeatedly over a long course of time [12]. Still, interest does not necessarily elevate upwards, for it can diminish or disappear altogether. Therefore, we speak about phases of interest instead of levels.

For example, consider a hypothetical student's development of interest in theoretical physics. The student's situational interest in theoretical physics is initially triggered by watching a cosmology documentary. If the student later hears about cosmology at school or comes across other cosmology content, the triggered interest is sustained. Upon maintained situational interest, this may lead to watching other documentaries about cosmology or other topics on theoretical physics. At first, watching may require external support, such as prompts by clever streaming service algorithms. Such external support gradually elevates the student's interest into an individual one. The student values content, re-engages independently, has more extensive knowledge, and participates voluntarily in seminars or webinars on theoretical physics. Ultimately, the phase rises to a well-developed individual interest, as indicated by self-regulation and the ability to value feedback, reflect on topics, set questions, and search for answers. The student can stand frustration and challenges without becoming discouraged.

2.2. Triggering interest

Anyone can develop or renew an interest in anything [11, 12, 38, 39]. Interest assists learning, guides attention, and aids memory, goal setting, and performance, independent of content or age of learners [16, 39–44]. Thus, triggering and supporting students' interest is critical [45, 46]. According to Hidi and Renninger [39, 47], triggering as the initiation of the psychological state of interest is activated by increased attention of individuals previously unfamiliar with the subject. Triggering is essential not only for initiating interest but also for deepening existing interest [39]. It occurs at all phases of interest development and is usually external at early phases and self-regulated at later phases of interest development [39, 48].

Triggers can emerge from personal relevance [49], meaningfulness [50, 51], challenge [52, 53], surprise [11, 47, 54], social interaction [55, 56], group work [39, 56], hands-on activities [39, 56], self-relatedness [39, 44], and authenticity of the event [57]. The potentials of triggers often depend on people, and their effect can vary during a single lesson because students connect triggers to prior knowledge, experiences, and previous interests [12, 39, 58]. In the context of quantum physics, for instance, novelty as a trigger of interest [12, 58] may operate differently for students with or without prior knowledge of quantum physics.

2.3. Quantum physics education

Due to the prominence of quantum phenomena as the driving force for future technologies, quantum physics education research is an important mediator between educators and the industry.

Research has helped to develop teaching approaches to overcome conceptual difficulties [26, 28–31, 59], advance assessment methods [60, 61], improve teaching and learning [62–70], and to create education programs that help in raising a new generation of quantum experts [8, 24, 71–75]. In addition to quantum physics education of physics and non-physics university majors [76, 77], studies have investigated quantum physics education at secondary schools [78–84], quantum outreach for general public [85, 86], and informal education up to university level [86–89], with which our one-day event is similar to.

Quantum physics education research has produced numerous visualization tools [85, 90], online resources [91–93], and the so-called quantum games [85, 94–96]. Defined by Piispanen *et al* [97], quantum games can sometimes help students understand quantum phenomena and create intuition to quantum formalism [24]. The benefits of quantum games in quantum physics education is a growing area of research [24, 98–101]. In addition, some recent studies have focused on various types of quantum education interventions [75], which can also provide a fruitful ground to test innovative approaches, such as quantum games [100].

Relevant are especially studies related to students' personal relationship to quantum physics. Corsiglia *et al* have studied university students' perspectives and expectations on intuition in quantum mechanics [102], Palmgren *et al* university students' self-efficacy beliefs in a quantum mechanics course during teaching reform [103], Testa *et al* the effects of instructions about introductory quantum mechanics on high school students' overconfidence bias [104], and Moraga-Calderón *et al* the relevance of learning quantum physics from a high-school student's perspective [105]. However, although interest is intimately related to relevance and self-efficacy [20, 39, 49], research on students' interest in learning quantum physics and its triggering remains sparse, especially at the university level.

In this article, we investigate physics and mathematics university students' experiences with a one-day event designed to trigger interest in theoretical physics in general and quantum physics in particular. Called *Fun in Theory*, the event brought students in touch with quantum physics through lecturing, playing games, and informal social interaction. Our research questions are

1. To what extent can Fun in Theory (FiT) trigger interest in quantum physics?
2. How does FiT change students' perceptions about quantum physics?

In what follows, we first describe the event, data collection, and analysis. Then we present the results and proceed to discuss limitations. Finally, we summarize, conclude, and discuss further research possibilities.

3. FiT: a one-day event for triggering interest

3.1. Overview of the event

FiT was created in 2014 at the University of Turku to attract bachelor physics students to choose theoretical physics for their master's studies. In order to graduate from Bachelor of Science in physics in University of Turku (180 ECTS), students must pass compulsory physics studies, some of which are common for all specializations and some are specialization-specific. The course *The basics of quantum mechanics* is the only compulsory theoretical physics course for all second-year bachelor physics students. After common compulsory bachelor studies, students may specialize in theoretical physics, experimental physics, physics education, or astronomy and space physics. Students continue with the same specialization for their masters' studies (120 ECTS). Each specialization contains some theoretical physics, but only a theoretical physics major involves a thorough education of the fundamental theories, like quantum mechanics, quantum field theory, and cosmology. Still, theoretical physics courses are available for physics and mathematics students from any specialization as a part of non-obligatory, free to choose study module in masters' studies. Therefore, a dedicated event has been necessary to raise awareness about theoretical physics courses and specialization and help students with their decision-making.

The event was open for all physics students, independent of whether they had taken the obligatory quantum mechanics course or not, and also for mathematics students. The event had no requirements for previous knowledge in theoretical physics and it was designed to

1. Trigger interest in theoretical physics.
2. Improve attitudes toward theoretical physics.
3. Connect theoretical physics to other subjects and students' everyday life.
4. Give students an overview of theoretical physics as a scientific field and study topic
5. Motivate students to be in touch with theoretical physics, and
6. Be a relaxed, fun, and mesmerizing experience.

The event was designed to be as authentic as possible, as authenticity is also one of the triggers of interest [57], and contains three elements: information, application, and reflection. The elements are implemented in three main parts:

1. A lecture (information, 2 h).
2. A social game (application, 1.5 h), and
3. Informal chatting with snacks (reflection, 1–2 h).

In the 2022 implementation of the event, the three elements were glued together through a playful overall theme *Relative Treasure Hunt*. The event had 60 participants, all of them bachelor students in physics or mathematics, and 15 of which participated in our study. The detailed activities in the three elements were as follows:

3.1.1. Informative lecture. The first element, a two-hour lecture proceeded according to the following plan:

1. Activating questions (responses used in panel discussion).
2. Motivational part: why should *you* care about theoretical physics?
   - Theoretical physics in consumer products, social media, videogames, and films: inspiration and hype.
   - Theoretical physics in news: analytical reality check.

   • Impact of theoretical physics on our society: from theoretical physics in present technologies to new research fields and employment possibilities.
3. Informative part: What is theoretical physics about
   • Theoretical physics: definition and requirements.
   • Five-minute crash course to different fields of theoretical physics: quantum physics, quantum optics, quantum field theory, theory of relativity, and cosmology.
4. Break (15 min).
5. Activating questions ('Explain the following memes and mistakes in movie episodes based on the information from the first lecture part'.)
6. Informative part: research in theoretical physics.
   • Main fields and future landscape of theoretical physics research.
7. Motivational part: connection of theoretical physics to other branches of science.
   • Activating questions ('Guess, is this a theoretical physics course or not?').
   • Diversity in theoretical physics research.
8. Informative part: theoretical physics at our university.
   • Theoretical physics courses: how they can be beneficial for *you*?
   • Local research groups: get to know lecturers and supervisors.
9. Call to action: low barrier, easy-to-follow resources for theoretical physics.
10. Panel discussion.

The lecture aimed to convey a realistic picture of theoretical physics as a research and study topic, address popular misconceptions in films and social media, and motivate students to connect with theoretical physics. From the pedagogical link-making point of view, lecture aimed to establish connections between theoretical physics and other subjects, and students' everyday life, using course material samples, news items, consumer products, and popular films [106].

To reach students at different phases of interest development, we used various triggers [12, 48]. We crafted presentation slides to display the content in a *highly visual* way [39]. The lecture's topics and more detailed information were chosen to be *personally relevant* to students as much as possible [49]. For example, we discussed how specifically they might benefit from theoretical physics courses, depending on their physics major. Related to the impact of quantum physics in our society, we elaborated on how the Finnish government supports building quantum computers using taxpayers' money—and reminding students that they are taxpayers as well. Throughout the lecture we included *novel* and *surprising* information [11, 39, 47, 54]. For example, we discussed how certain well-known movies implement quantum hype or actual physics theories and presented an assortment of 'quantum' products, such as quantum deodorant and quantum magnesium pills. (Students were particularly surprised by the existence of a Quantum Stylist sewing machine by Singer!) The lecture also had *an alternating structure* [39, 58]: we shifted between motivational parts, informative parts, and activating questions. The lecture finished with a call to action, which provided resources for later voluntary engagement for sustaining interest [107]. Throughout the lecture, we used humor and memes to make the lecture more fun, enjoyable, and memorable, as *heightened emotions* can work as interest triggers as well [12, 39, 47]. The panel discussion introduced potential role models [12], discussed questions *personally relevant* to students and provided them with a sense of community to the end.

At the beginning of the lecture, as an essential part of triggering interest [39, 47], capturing initial attention, and exposing students' personal inclinations, we collected responses to activating questions about students' perceptions and preconceptions about theoretical physics (anonymously on a paper), following the first step of the lecture plan. The questions were ‘Why is theoretical physics important?’, ‘What are your expectations for theoretical physics?’ and ‘If you could ask a theoretical physicist anything, what would it be?’ Responses to these questions were then used as a basis for the end-of-lecture panel discussion among teachers and under- and postgraduate theoretical physics students. The responses were collected and inspected before the panel discussion, and some concerns were already addressed during the lecture. The panel discussion made the students familiar with the panelists’ personal stories, career stages, and interest development in theoretical physics. Panelists discussed research and work in theoretical physics and reflected on students’ concerns about the difficulty and requirements of studying theoretical physics, addressing typical questions like ‘Would you be able to learn theoretical physics if you do not feel gifted?’, ‘What is the best in theoretical physics?’ and ‘Will we ever understand all physics?’ In addition, panelists suggested courses, discussed skills beneficial for theoretical physics studies, and generally provided encouragement to engage with theoretical physics.

3.1.2. A Social Game: Relative Treasure Hunt. The second element, the *Relative Treasure Hunt* game, took place in an imaginary quantum network. Teams of 5–8 students performed tasks in different ‘quantum network nodes’ to collect ‘diamonds’ and other prizes, and the team collecting the most treasures won the game. Overall, the game had eight 10 min tasks, run by moderators familiar with the related physics. Tasks began with the moderator explaining the rules and physics concepts for completing the task. Providing support as necessary, moderators ensured that all teams completed all the tasks. They also aimed to eliminate any related physics misconceptions.

In practice, the game took place using the office rooms of the theoretical physics laboratory so the participants would familiarize themselves with the local premises. Just like the lecture, the game was also designed to include multiple triggers, maximizing its potential for interest triggering. The game was based on *social interaction* among students [55, 56]. Moreover, theoretical physics staff members and master’s students were chosen as game moderators in order to facilitate interaction between students and their potential role models. Many tasks encouraged students to *group work* [39, 56], and the rules of the game encouraged everyone to work on team dynamics and participate in the team effort. We acknowledge that some students may not be comfortable with the triggers based on social aspects, so the students were informed about the overall course of the game in advance. As an extra measure, task moderators could suggest alternative ways for students to participate in the team effort, allowing them to deviate from the original rules when necessary.

All tasks were designed to have *a suitable challenge* [52, 53, 108] and enable feelings of success and achievement [39, 109]. They provided direct links to the lecture and taught something new about theoretical physics, making the game *meaningfully engaging* [12, 39, 50, 51].

Still, all tasks were designed to be *fun* and relaxed [12, 39, 47], and left room for creativity.

An obvious reason for including the game in the event was the utilization of *gamification* to improve students’ motivation and to increase their involvement [110, 111]. Gamification in higher education is also known to increase understanding and conceptual learning, promote collaboration between students and increase satisfaction [112]. Because the effect of gamification and its triggering potential varies [39, 113], the tasks were planned with different characteristics; certain tasks were performative, others physical, and some focused on theoretical physics concepts. The tasks in the game were as follows:

1. *Quantum product*: the team invents and advertises a quantum product based on a realistic utilization of quantum phenomena.
2. *Trailer to a sci-fi movie*: the team randomly chooses one place, two characters, two actions, one theoretical physics concept, and one treasure hunt object from a given set of options. The team then uses the chosen items to create and perform a trailer for a sci-fi movie.
3. *Network formation*: the team forms assigned classical networks. (Students are nodes; the network is formed by holding hands, touching legs, and other creative link-making.)
4. *Meme explanation*: the team explains quantum physics phenomena or concepts presented in a given meme.
5. *Telephone game* (Chinese whispers): a cosmology-related sentence is being passed from person to person in whispers; the final message is compared to the original one after the sentence has gone through the entire team.
6. *Quantum Tiq Taq Toe* (figure 1): the team aims to win the task moderator in the Quantum Tiq Taq Toe game.
7. *Bell state creation*: the team creates Bell states by applying Hadamard and CNOT gates to the initial state $|00\rangle$ on the whiteboard.
8. *Crossword*: the team fills a theoretical physics -related crossword on the blackboard.

Regarding known interest triggers, task 1 included *hands-on activity* [39, 56] (students drew necessary visualizations for their quantum product advertisement). Tasks 6 and 8 included *the use of technologies* [39, 56] (Quantum Tiq Taq Toe was played on a tablet, and search engines were allowed while solving the crossword).

Teams earned 'diamonds' in tasks 3, 4, 7, and 8 in proportion to the number of correct responses and in task 6 upon winning the game. These tasks rewarded teamwork and creativity through extra 'diamonds' or a bonus. In the rest of the tasks, teams earned 'diamonds' from creativity, performance, and teamwork; the correct use of physics gave a bonus. The 'diamonds' were dealt by task moderators.

3.1.3. Informal chatting with snacks. The third element, a sort of after-party, consisted of offering the participants snacks and chatting with peers, faculty members, and lecture panelists. The emphasis was on a relaxed atmosphere, reflective analysis of the event, and informal, low-barrier discussions about theoretical physics and related studies with teachers. This setting aimed to repeat and emphasize the triggering of participants' interest in theoretical physics topics [39, 58, 115]. The framed informal chatting also aimed to establish better relationships with the teachers of theoretical physics and create role models [12].

4. Data collection and analysis

4.1. Data collection

To address the first research question, 'To what extent can FiT trigger interest in quantum physics?', we developed preliminary research instruments, three questionnaires and structured interviews. Each questionnaire had six to nine questions related to interest development (appendices A–C). The first questionnaire was sent to FiT participants by email before the event, while we asked everyone to register their participation not only for the purposes of the research but also to prepare for the event, especially for the game and snacks. The second questionnaire was filled right after the game, and the third questionnaire was sent by email one week after the event. The three questionnaires had the same questions, phrased differently; the second

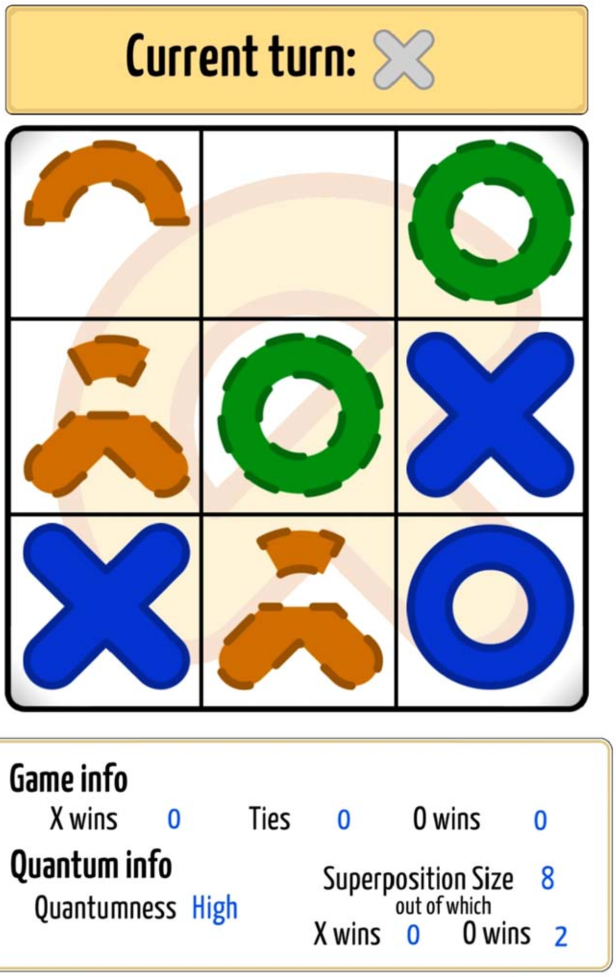

Figure 1. Snapshot of Quantum TiqTaqToe quantum game [114], which the participants played against a task moderator using a tablet during one task of the Relative Treasure Hunt game. In this quantum version of TicTacToe, zeros and crosses can be in superposition and in entangled states, such that the winner can be declared only after measuring the state of the board.

questionnaire merely omitted some redundant questions. The questionnaires were filled by 15 Finnish-speaking physics and mathematics students (nine men, five women, and one other), five of whom volunteered for additional interviews after the final questionnaire.

In the spirit of triangulation and to gain more detailed knowledge of the participants' experiences during FiT, we conducted interviews to provide complementary information [12]. The 15 min interviews focused on two topics: the event as a learning experience and as a process to develop an interest in quantum physics. For interview questions, see appendix D.

4.2. Designing the questionnaires

The effects of different triggers have previously been detected by observational methods and psychophysiological measures [116]. Unfortunately, validated tools to probe the triggering of interest by questionnaires are missing, especially in the context of interventions. Therefore, for the purpose of probing the triggering potential of our specific event, we needed to design questionnaires and interviews of our own.

Because the event was short and we wanted to retain the emphasis on the actual activities, the questionnaires were designed short and easy to complete. We asked the participants if their interest in quantum physics increased due to the event, but we did not ask directly about triggering; it is unlikely that the participants are able to describe it reliably. For example, in early phases of interest development, triggering may express itself as either positive or negative feelings, or it may remain completely unnoticed [11, 12]. Overall, the questionnaire probed the phase of interest toward quantum physics (three items) and aspects related to interest triggering, including a self-evaluated change in interest (one item), changes in attitude toward quantum physics (one item), quantum physics topics of interest (one item), self-evaluated knowledge gain (one of the three items for the phase of interest), and experiences about the event itself (one item). These aspects are then combined to construct an overall picture of the triggering of interest and the possible change in the phase of interest.

The above aspects were chosen due to their relevance in triggering interest. Attitudes towards quantum physics were probed because preconceptions, values, and beliefs can affect interest [12, 117, 118]. Also, feelings are related to interest through reactions to different contents and situations [12, 119]. Early phases of interest development can be accompanied by positive and negative feelings, whereas later phases are usually accompanied by positive feelings [12]. Changes in knowledge and topics of interest are relevant due to their relation to the perception of novelty and meaningfulness, or even personal relevance [12, 48–51, 58]. Finally, the fulfillment of participants' expectations was probed to monitor participants' overall impression and the potential feeling of surprise [11, 47, 54, 57].

Questions related to interest were designed to probe two different aspects: students' self-evaluated changes in interest towards quantum physics, indicating immediate changes due to the event, and external evaluation of students' phase of interest, which is more robust and not easily affected by a single event [12]. Overall, the questionnaires were planned and discussed extensively by the research team.

4.3. Questionnaire data analysis

We analyzed the data for (1) change in the phase of interest in quantum physics, (2) self-evaluated change of interest in quantum physics, (3) self-evaluated gained knowledge, (4) change of attitudes in quantum physics, (5) change in topics of interest within quantum physics, and (6) fulfillment of expectations.

4.3.1. Phase of interest analysis. To determine the participants' phase of interest according to the four-phase interest development before and one week after the event, we used a table of behavior indicators, first introduced by Hidi and Renninger [12] (table 1). The indicators include voluntary re-engagement and the depth of knowledge, as well as the frequency and independence of re-engagement. While we adapted our table from the one introduced by Habig and Gupta [120], we merged behavior indicator criteria for frequency of engagement and capacity of independent engagement. In addition, we examined the results for the compound categorization of situational and individual phases of interest development.

The behavioral criteria in table 1 formed the basis for the questions of the first questionnaire. For the third questionnaire, we made two changes. First, for the voluntary re-engagement indicator, we also considered engagement with quantum physics because of inspiration from the event (for maintained situational interest) or tools provided by the event

Table 1. Behavioral criteria for different phases of interest in quantum physics (QP) for the first questionnaire responses.

Behavioral indicator	Triggered situational (1)	Maintained situational (2)	Emerging individual (3)	Well-developed individual (4)
Frequency of re-engagement and capacity for independent re-engagement	Engages with QP in their free time never or rarely	Engages with QP in their free time rarely or occasionally	Engages with QP in their free time occasionally or often	Engages with QP in their free time often
Depth of knowledge	Lacking or minimal knowledge of QP, of which most is forgotten; free time engagement does not involve studying QP	Minimal knowledge, of which most is forgotten; free time engagement involves studying QP at least rarely	Some knowledge in QP, of which something is remembered	Knows QP and can teach it to others
Voluntary re-engagement	Engages with QP due to extrinsic factors, like benefits for studies or friends' interest in QP, or both	One of the reasons for engagement is an intrinsic interest in QP; engages never, rarely, or occasionally	One of the reasons for engagement is an intrinsic interest in QP; engages occasionally or often	Engages often, because is interested in QP

(for triggered situational interest). Second, for the depth of knowledge, we made a separate criterion that considered responses to the first and the final questionnaire.

To determine the participants' phases of interest, we used the table to identify the phase of interest for each behavior indicator separately and then took an average of the indicators' numerical values.

4.3.2. Self-evaluated change in interest. The first and second questionnaires asked questions about the perceived interest in quantum physics. The final questionnaire asked participants to evaluate how their interest in quantum physics had changed after the event. We categorized students' responses into different behaviors (four different behaviors emerged).

4.3.3. Self-evaluated gained knowledge. Self-evaluated knowledge gain was probed through the question, 'How much has your knowledge of quantum physics changed because of the event and things you did in your free time after the event?' in the third questionnaire. Among two other questions, this question was used to determine the change in the phase of interest. In the results, we just summed up the raw count data.

4.3.4. Change in students' attitudes. In each questionnaire, students' attitudes were probed by an adjective test, in which participants described quantum physics with three self-picked adjectives. This test resulted in 42 (before the event), 45 (right after the game), and 45 (one week after the event) adjectives (including a couple of technical rejections). The adjectives from each questionnaire were categorized through emergent coding into six bundles that revealed attitude development during the course of time.

4.3.5. Change in topics participants want to learn. Each questionnaire also requested to write a list of quantum physics topics of further interest. The lists accumulated into 17 (before the event), 19 (right after the game), and 19 (one week after) topics or phrases, which were categorized into five motifs.

4.3.6. Expectations and their fulfillment. The first questionnaire asked about potential expectations toward the event and the second questionnaire asked if these expectations were fulfilled. For both questionnaires, we categorized the free form responses into four groups.

4.4. Interview data analysis

After the third questionnaire, we interviewed all five volunteered participants using the same questions. The interviews were recorded and transcribed. These interviews were designed to provide more insight into the experiences of participants related to interest development, different triggers, attitude changes, learning new knowledge, and the event in general. For this article, we present an overview of the interviews and three explicit samples to convey personal stories and explicate thoughts that underlie the otherwise quantitative analysis. The three samples were chosen to illustrate diverse experiences of FiT.

5. Results

5.1. Development of interest

Before the event, seven participants had a triggered situational interest, six had a maintained situational interest, and two had an emerging individual interest in quantum physics. No participant had a well-developed individual interest.

As a case example, Charlie (see sections 5.4 and 5.7) indicated that he is familiar with quantum physics topics but has forgotten almost everything, and does not study quantum physics in his free time (depth of knowledge at triggered situational interest level). He has rarely engaged with quantum physics in his free time (frequency of re-engagement and capacity for independent re-engagement also at triggered situational interest level). Yet he considers quantum physics interesting (voluntary re-engagement at maintained situational interest level). On average, the interest remains at the triggered situational level (arithmetic mean of the corresponding numerical values).

After the event, there was no elevation from situational interest (13 participants) to individual interest (two participants). One week after the event, three participants had changes in the phase of interest. One participant had the phase elevated from triggered to maintained situational, and two participants had it the other way around. To conclude, apart from small natural fluctuations and methodological limitations (see section 6), the phases of interest remained essentially unchanged for all participants. This aligns with interest development theory, which suggests that while a short-term event may trigger an interest, it is not enough to elevate one phase of interest to another [12].

5.2. Self-evaluated change in interest

In the first two questionnaires, the participants self-evaluated their level of interest before and right after the event. One week after the event, in the third questionnaire, the participants estimated the overall *change* in their interest due to the event. Most participants estimated an increase in interest (11 participants), others no change in interest (4 participants). These self-evaluated interests revealed four behaviors:

1. Interest was the same before and right after the event, but elevated interest was self-reported one week after (8 participants);
2. Interest was increased right after the event, and elevated interest was also self-reported one week after (3 participants);
3. Interest was increased right after the event, but no change of interest was self-reported one week after (2 participants); and
4. Interest was decreased right after the event, but no change of interest was self-reported one week after (2 participants).

Eleven participants reported an elevated interest one week after; eight had the level unchanged in the first two questionnaires. Participants were also inclined to self-evaluate a positive change, irrespective of phases analyzed externally. Further studies are needed to confirm this observation and revise the questions used for self-report from a triangulation point of view.

5.3. Self-evaluated knowledge gain

Most participants reported self-evaluated increase in knowledge related to quantum physics (figure 2). Because the phases of interest remained relatively stable (section 5.1), the depth of

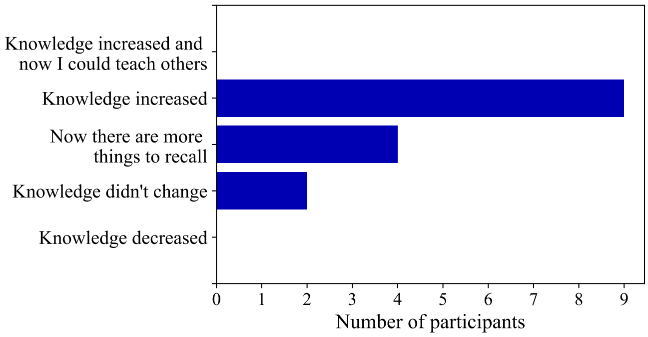

Figure 2. Gained knowledge, probed a week after the event.

knowledge criterion suggests no significant changes in participants' free time behavior. Therefore, as the majority of students remained in situational interest phase with rare or occasional engagement with QP in free time, we may infer that the knowledge was increased primarily due to the information included in the event.

5.4. Changes in attitudes

The adjectives from the three questionnaires provide a revealing view into participants' attitudes (figure 3). The categories include *appealing* (interesting, fun, great, beautiful, appealing, fascinating), *important* (fundamental, important, useful, visible, universal, current), *informative* (informative, large, deep, generally educating, general, versatile, every-day), *difficult* (difficult, challenging, hard), *weird* (unknown, scary, distant, weird, complex, hard to demonstrate, bizarre, non-logical, counter-intuitive, unsure, mystical, special), and *scientific* (scientific, mathematical, random, nondeterministic, new, futuristic). Here, the adjectives in brackets represent English translations of all the adjectives students used in their responses.

Overall, the attitudes and impressions towards quantum physics right after the event were exceedingly positive. There was a noticeable decrease of *weird* and *difficult* and an increase of *appealing*, *informative*, and *scientific* (figure 3(a)). All these changes are beneficial for triggering interest. The largest changes happened during the first and second questionnaires; changes after one week were less pronounced. Adjectives at an individual level reveal three patterns (figure 3(b)): a pattern with a shift from somewhat negative and confusing adjectives (*weird* and *difficult*) towards positive and confident adjectives (*appealing*, *informative*, and *important*; upper block); a pattern with a shift from negative and confusing adjectives to more versatile (middle block); and a pattern without a clear trend or shift (lower block).

From an individual viewpoint (figure 3(b)), the attitudes one week after the event seemed more versatile and mainly included more *weird* or *difficult* adjectives than right after the event (middle and lower blocks). These changes appear reasonable, as the social aspect one week after is missing, but it would be interesting to investigate more closely the processes governing these changes in the future.

5.5. Change in topics of interest

Analogously to the adjective test, the topics the participants wished to learn were divided into five categories (figure 4). Categories include *theoretical concepts* (e.g. quantum field theory, particle and nuclear physics topics, mathematical quantum physics, and tunneling), *applications of quantum physics* (quantum computing and medical physics topics), *everything*

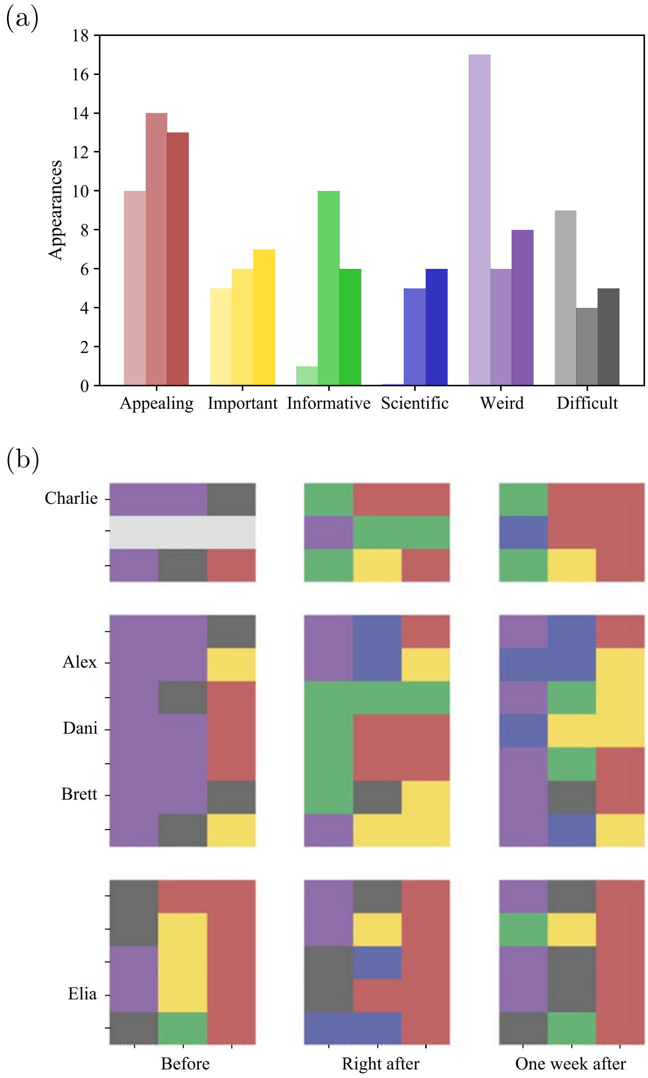

Figure 3. Attitude changes based on the adjective test. (a) The cumulative appearances of different groups of adjectives before (left bars), right after (middle bars), and one week after the event (right bars). (b) Adjectives given by individual participants (rows) before, right after, and one week after the event. Color coding is the same as in panel (a); one participant gave no acceptable adjectives in the first questionnaire (light grey). The horizontal gaps separate the three patterns of attitude changes, and vertical gaps separate the three questionnaires. The five names refer to the pseudonyms used in the interviews (section 5.7).

(responses like 'I want to start studying quantum physics one way or another' or 'Interested on a general level'), *nothing* ('I do not know' or similar responses), and *non-quantum physics topics* (cosmology and theory of relativity).

Right after the event, the responses excluded *nothing* but instead included a large number of topics not related to quantum physics (figure 4). The surge of unrelated topics like cosmology and the theory of relativity can be understood by participants' sloppy reading of the

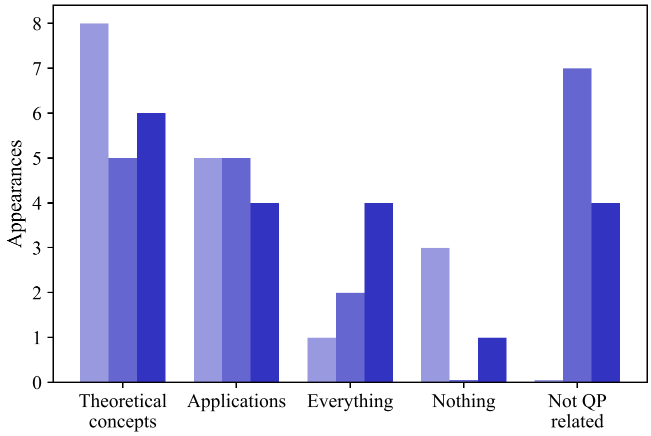

Figure 4. The topics participants wished to learn before (left bars), right after (middle bars), and one week after the event (right bars) in five categories.

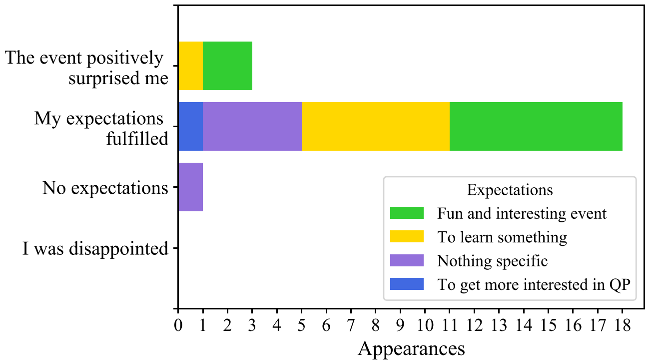

Figure 5. The fulfillment of participants' expectations of the event according to their expectations.

questionnaires, for the event covered topics in theoretical physics beyond mere quantum physics. It is curious that right after the event, the number of topics related to theoretical concepts decreased, remaining at the same level one week after, and the number of topics related to applications remained roughly constant. These results indicate that the participants were familiar with most concepts and applications already before the event. Overall, the event made the topics participants wish to learn more versatile.

5.6. Expectations and their fulfillment

The main expectations for the event were wishes to have fun and to learn something new and interesting (figure 5). Few participants had no expectations, and one participant was specifically expected to get more interested in quantum physics. Most of the expectations were fulfilled, independent of what they were. This implies that the implementation of the event had been successfully aligned with the event's advertisement. There were no disappointments, but few positive surprises occurred among participants that expected a fun event or wished to learn something.

5.7. Interviews

The five volunteers for the interviews were Alex, Brett, Charlie, Dani, and Elia. The event did not change the phase of interest for Alex (emerging individual), Brett (triggered situational), or Dani (maintained situational). For Charlie, the phase of interest elevated from triggered situational to maintained situational and for Elia, it dropped from maintained situational to triggered situational. Interview responses align with self-reported gained knowledge and the list of the adjectives the interviewees had written down (figure 3(b)).

All five participants had some interest in theoretical physics before the event. Alex, Charlie, and Dani mentioned FiT having improved their attitudes toward quantum physics. FiT raised Charlie's, Dani's, and Elia's interest in quantum physics and Alex's interest in cosmology, but it did not affect Brett's attitudes or interest in quantum physics. Yet all five, Brett included, self-reported positive change of interest in quantum physics one week after the event.

All but Brett felt that FiT increased their understanding of quantum physics as a scientific field and its connections to other subjects and everyday life. FiT helped Alex, Brett, Charlie, and Elia decide on their bachelor studies; Alex, Charlie, and Elia expressed their interest in taking some theoretical physics courses as a minor. Brett had decided not to study theoretical physics, even as a minor.

The various triggers had different effects on the participants, as anticipated. Charlie considered the game particularly good for increasing interest and bringing positive feelings (social interaction, group work, gamification, heightened emotions): '*...that we did things together [with group members], it made the learning so much more fun*'. He also found appeal in things he had special experience with (personal relevance): '*... and then I remember the info about quantum computer, where our tax money goes, so that kind of things might feel small for someone, but for me they felt awesome, they were big things for me*'. Alex considered FiT functional as a social and relaxed event (social interaction): '*Of course it is a social event, one gets to see their peers, whom we did not get to see for a couple of years now [because of Covid-19]. Overall as an event it was quite enjoyable. A little more relaxed, even though it included some brain activation*'. Dani and Elia valued new knowledge, especially provided by the lecture (novelty), as Dani well said: '*Maybe, as the lecture was more informative than the game, so then it triggered more interest*'. Dani further experienced the event unexpectedly positive (surprise), as they were waiting '*for the lecture to be more boring, but then it was very interesting*', and filled with memorable details (meaningfulness, personal relevance), like '*the things, that were interesting for me, were significant and memorable*'. Brett found that the event did not have '*any specific affect*' on their interest or attitudes. All but Brett commended the role of game moderators' enthusiasm in interest development (social interaction, role models).

Interviews brought up the problem of students' lack of free time. Although all participants reported interest in attending quantum physics in their free time, none of them followed the extra material sent after the event. Elia and Brett were explicitly concerned about the lack of free time, to cite Brett: '*the studies have been like overall pretty heavy*', and the rest claimed they would explore the material at a suitable time later. Still, Alex, Charlie, and Elia mentioned their earlier experiences in studying quantum physics in their free time via media, news, and popular literature. Thus, students' limited free time emphasizes the importance of resources providing quick and easy information.

Next, we present more detailed insights from three participants, Alex, Brett, and Charlie. They were selected because they are a compact sample but still illustrate versatile experiences of the FiT -event.

5.7.1. The event helped Alex in decision-making. '*It is indeed significant. It [the event] kind of deepened the idea, where I think to continue studies and where not to [which specialization to choose]. And this I think now for sure, that at least as a major I will not study theoretical physics. It is pretty mathematical*'.

Alex (emerging individual interest) was interested in quantum physics already before the event and continued to be interested after the event. The event gave Alex a deeper and more structured understanding of the fundamentality of quantum physics in physics hierarchy. It also changed attitudes toward quantum physics from more negative towards more neutral and increased the feeling of respect towards quantum physics. Alex realized that, for its mathematical and challenging nature, theoretical physics would be better as a minor instead of a major topic. Alex considered this realization to be a significant and positive one.

Overall, Alex considered the event a social one, with topics in quantum physics investigated from different perspectives. A common theme made the event appealing, and group dynamics worked well. Alex could participate in a similar event also next year.

5.7.2. The event made no impact for Brett. '*I do not think that it [the event] had any specific affect [on interest development*]'.

Brett (triggered situational interest) had been interested in quantum physics earlier, and the event did not develop their interest further; it gave no significant new insights. Brett had been considering quantum physics studies but in the end found out that there was no place for them among other studies. The event did not change Brett's attitude, and quantum physics ranks low for free time activities. Brett considered the event good but not particularly appealing. Participation in a similar event next year will depend on Brett's mood at that time.

5.7.3. The event expanded Charlie's understanding of the topic. '*Originally, before this event I had mixed feelings about it [quantum physics], but then after the event it became clear what it [quantum physics] really is, and it triggered more interest, so that more positive feelings appeared then*'.

Before the event, Charlie (from triggered situational interest to maintained situational interest) was interested in the theory of relativity and black holes. The event taught Charlie about superposition, network theory, the nature and role of quantum physics, and many other topics of theoretical physics that were new to Charlie. The game triggered interest and caused positive feelings. Overall, the event changed the originally mixed feelings about quantum physics to positive ones and elevated Charlie's interest in quantum physics. Charlie got more interested in connecting with quantum physics in his free time. After the event, Charlie discussed with his friends about possible courses to study, even as a minor subject.

Charlie saw that the interest might have been influenced by the lecturer, task moderators, or fellow participants. Charlie thought the event was well prepared, successfully executed, and took the audience into account properly. The group dynamics had worked well. Charlie could participate in a similar event also next year.

6. Limitations

As a first-step study of interest triggering in quantum physics in higher education, our study does have certain limitations. We designed a questionnaire that was based on various aspects known for their solid relevance for triggering interest, even though it was not explicitly validated. The small sample size, the possibility of misinterpreting the questions, simplifications in table 1, and minimal approach to questionnaire design challenged the interpretation of the results and the accurate determination of participants' phase of interest [12]. Some answers may be biased by students answering what they think authors expect. In addition, we can only speculate about the processes behind the attitude changes after the event and the improved self-reported interest one week after the event.

Also, as Brett pointed out in the interview, university students have little free time to engage in any extracurricular activities, which may reflect the four-phase interest analysis. Similarly, although differences in the background of quantum physics knowledge probably affected phases of interest, we did not use such information here, because it was unnecessary for interest-triggering considerations, which were the main focus of our research.

Moreover, although the event covered several branches of theoretical physics, the questionnaires and our research focused on quantum physics. Some participants failed to recognize this and read the questionnaires sloppily, as observable e.g. in the number of unrelated topics in figure 4. In other words, the aim of the event was broader than the focus of our research. Nevertheless, we think that many of the observations regarding the interest in quantum physics apply to theoretical physics more generally.

7. Conclusions and discussion

To conclude, the event fell short of clearly growing interest in quantum physics—at least by itself or at the time scale of one week, in agreement with the literature [12]. For a clear growth of interest, one would need repeated triggering, external support from others, and more meaningful engagement with quantum physics [12, 38, 39].

Yet the event seemed to have planted seeds for potential later growth. The event affected participants' attitudes and views (figure 3) as well as the topics of interest (figure 4) related to quantum physics. These aspects became more positive, realistic, rational, and versatile. Interviewees described how different triggers positively affected their interest or overall impression of the event. In addition, one week after the event, most participants self-reported an increase in interest in quantum physics. Thus, interest for some of them could possibly grow further, for example, through well-designed obligatory quantum physics courses following the event.

The event also showed benefits in other ways. Participants considered the event beneficial because it clarified the topics and requirements of theoretical physics studies and helped them realize that they do not want to study theoretical physics as a major.

More generally, our study opened a conversation about interest—interest triggering in particular—in quantum physics higher education. We learned that students' limited free time is one factor preventing them from engaging with the subjects of their scientific interest. Moreover, an interest in a topic does not automatically guarantee choosing it as a study major or even as a minor. These practical realities complicate supporting interest development in quantum physics at universities. We hope our first steps will eventually be followed by a validated research instrument to measure the triggering of interest. One only needs to recognize that, with short events like FiT, the instrument should remain compact enough to avoid undermining and interfering with the event itself. All of the above findings are also an important prerequisite for developing a four-phase interest analysis instrument for higher education.

To summarize, we presented a one-day event, FiT, that was aimed to trigger interest in theoretical physics among physics and mathematics university students, and preliminary measurement tools to test interest triggering potential of the event. Although the event made no clear impact on the four-fold phase of interest, it did make participants' attitudes and views toward quantum physics more positive and endowed an overall feeling of increased interest—a satisfactory indication of successfully triggered interest.

In the future, based on both the results and the limitations of this study, further studies could explore factors that govern the way students react to various triggers and regulate the changes in attitudes and perceptions during and after a triggering intervention. This knowledge would clarify how the triggers and their effects are connected to the physics identity of students, which in turn would help develop quantum physics higher education research. It would also be tempting to conduct a longitudinal study to see how an interest in quantum physics triggered by FiT could be maintained by a carefully planned and timed curriculum of quantum mechanics courses. Research could also be expanded to other branches of theoretical physics.

Acknowledgments

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Data availability statement

The data cannot be made publicly available upon publication because they contain sensitive personal information. The data that support the findings of this study are available upon reasonable request from the authors.

Ethical statement

All participants of the study gave their informed consent to participate in the study and for these results to be published. The study was conducted according to the ethical policy of the European Journal of Physics and the Declaration of Helsinki. According to the ethical guidelines by the University of Turku, this study did not require an approval from the Ethical committee of the University of Turku.

Appendix A. First questionnaire (before the event)

1. Your name
   Free response
2. Your email
   Free response
3. Your gender
   Single choice responses:
   • Male
   • Female
   • Other
   • I do not want to respond.
4. How much are you interested in quantum physics?
   Single choice responses:
   • Not interested at all

- I could be interested
- Interested a little
- Interested a lot.

5. Describe quantum physics with three adjectives.
   Free response.
6. What topics of quantum physics would you be interested in studying?
   Free response.
7. How well do you know quantum physics before the event?
   Single choice responses:
   - I do not know anything about quantum physics.
   - I am familiar with quantum physics topics but have forgotten almost everything.
   - I am familiar with quantum physics topics, and some of them I remember.
   - I am familiar with quantum physics topics, and I could teach them to others.
8. How often do you do the following things in your free time?
   (a) Study quantum physics.
   (b) Read scientific articles about quantum physics.
   (c) Read news or newspaper/journal articles about quantum physics.
   (d) Google quantum physics topics.
   (e) Listen to podcasts and/or watch videos or programs about quantum physics.
   (f) Talk about quantum physics with my friends.

Single choice responses:
   - Never
   - Rarely
   - Occasionally
   - Often.

9. Why do you do the previously mentioned things in your free time?
   Multiple choice responses:
   - I do not do them.
   - Because they support my studies.
   - Because my study friends are interested in quantum physics.
   - Because quantum physics interests me.
   - Something else. What?
10. What expectations do you have for the event?
    Free response.

Appendix B. Second questionnaire (after the game part of the event)

1. Your name
   Free response.
2. To what extent are you interested in quantum physics now?
   Single choice responses:
   - Not interested at all
   - I could be interested
   - Interested a little
   - Interested a lot.
3. Describe now quantum physics with three adjectives.
   Free response.

4. What topics of quantum physics would you be interested in studying now?
   Free response.
5. Did the event fulfill your expectations?
   Free response.
6. Can we be in touch with you regarding the interview?
   Single choice responses:
   - Yes
   - No.

Appendix C. Third questionnaire (one week after the event)

1. Your name
   Free response
2. How has your interest in quantum physics changed after the event?
   Single choice responses:
   - My interest has not changed
   - My interest has increased
   - My interest has decreased.
3. Describe quantum physics with three adjectives.
   Free response.
4. What topics of quantum physics would you be interested in studying now?
   Free response.
5. How often after the event did you do the following things in your free time?
   (a) Study quantum physics.
   (b) Read scientific articles about quantum physics.
   (c) Read news or newspaper/journal articles about quantum physics.
   (d) Google quantum physics topics.
   (e) Listen to podcasts and/or watch videos or programs about quantum physics.
   (f) Talk about quantum physics with my friends.

Single choice responses:
   - Never
   - Rarely
   - Occasionally
   - Often.

6. Why did you do the previously mentioned things in your free time?
   Multiple choice responses:
   - I do not do them.
   - Because the event inspired me.
   - Because the event provided easy tools to get to know quantum physics.
   - Because they support my studies.
   - Because my study friends are interested in quantum physics.
   - Because quantum physics interests me.
   - Something else. What?
7. How much has your knowledge of quantum physics changed because of the event and the things you did in your free time after the event?
   Single choice responses:
   - My knowledge decreased.
   - My knowledge did not change.

- Now there are more things to recall.
- My knowledge increased.
- My knowledge increased, and now I could teach others.

8. Would you participate in the next iteration of the Fun in Theory next year?
   Single choice responses:
   - Yes
   - No.

Appendix D. Interview questions

1. Your name
2. Why did you participate in the event?
3. Did you have some expectations for the event, for example, because of what you heard from other students?
4. What have you learned during the event? In which event part did you learn it?
5. Did you feel that things you learned were relevant to you?
6. Were the things you learned interesting to you?
7. After the event, are you planning on taking some theoretical physics courses?
8. Did you want to take some theoretical physics courses also before the event?
9. Are you interested in getting in touch with quantum physics in your free time? Are you planning to use the tools provided during the event for that purpose?
10. How has the event overall affected your attitude towards quantum physics?
11. How lecture, game, and snacks and chat have separately affected your attitude?
12. How lecture, game, and snacks and chat have affected your interest development in quantum physics?
13. How the event environment (physical environment, social environment) has affected your interest development?
14. Was the environment safe and supportive?
15. How has the lecturers', task moderators', and other event organizers' possible enthusiasm affected your interest and attitude towards quantum physics?
16. Could you mention some elements, which made the event appealing?
17. Have you participated in any similar events before?
18. Would you like to participate in Fun in Theory next year? What about other similar events? Why?

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