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Evaluation of an activity connecting quantum technology and arts and craft for primary education

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Abstract

We have designed an activity to introduce primary school pre-service teachers and their students to quantum technology. The activity centers around the optical illusion known as Pepper's ghost and the function of a beam splitter. In designing the activity, we have taken an integrated approach combining science & technology (S&T) education with arts & craft (A&C) education. Pre-service teachers were interviewed after participating in the activity to evaluate their learning experiences and their attitude towards S&T education. The results indicate a positive effect on pre-service teachers' views on S&T education and its combination with A&C.

Keywords: quantum education, pre-service education, science & technology education, arts & crafts education

INTRODUCTION

The field of quantum technology (QT) is rapidly advancing and there is a strong sense that these new technologies will be transformative for industry and society. As such, there is an increasing need for non-physicists to have some understanding of basic concepts and terminology from QT (Greinert et al., 2023). It is common for education on topics related to QT to start in upper secondary school, though only for pre-university students (Stadermann et al., 2019). However, we suspect it is possible to already introduce elements of QT in a meaningful way at the primary school level. Thus, as part of a larger effort to develop suitable lesson materials on QT, we have designed an activity for pre-service teachers in primary education that centers around an optical illusion commonly known as Pepper's ghost, integrating art & science (A&S) education. In this study, we investigate how this activity influences pre-service teacher views on science & technology (S&T) education.

Science & Technology as a Mandatory Subject in Primary Education

Multiple Dutch universities of applied sciences offer four-year programs to become a primary school teacher, i.e., teaching the age range 4- to 12-year-olds. S&T is included as one of the subjects in these programs, with the central challenge being to prepare the pre-service teachers with sufficient subject-matter knowledge and pedagogical content knowledge. According to the curriculum guidelines for the Dutch elementary educational system, S&T education entails learning about one's surrounding world, based on wonder and curiosity. Specifically, S&T education rests on the following three pillars (van Graft et al., 2018):

- learning new concepts,
- learning to conduct experiments or work on a design, and
- fostering a scientific, curious attitude.

It is well documented that for many primary school teachers, their own limited experience with S&T and lack of pedagogical content knowledge leads to low self-efficacy (Rohaan et al., 2012; van Aalderen-Smeets et al., 2012). However, studies show that self-efficacy in teaching S&T can improve significantly during the first two years of the teacher training program (Schrumpf et al., 2019; Velthuis et al., 2014) due to specific S&T instruction at the teacher training program and gaining practical experience in teaching S&T in classrooms.

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Contribution to the literature

- A Pepper's ghost activity combining technology education with arts & craft (A&C) education is implemented to introduce concepts from quantum mechanics in the education of pre-service primary school teachers, a group that normally would not encounter such concepts in their formal training.
- This paper contributes to closing a gap in literature on educational quantum activities for primary school.

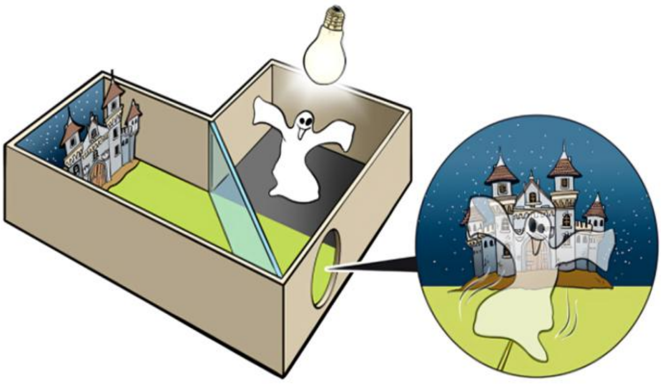

Figure 1. The principle of the Pepper's ghost illusion (when light emanating from an out of view object hits a semi-transparent mirror, a ghostly apparition appears in front of a background scene) (illustration used under license from Erwin Suvaal)

Introducing Concepts from Quantum Mechanics

Quantum mechanics (QM) has a reputation for being a difficult subject. This reputation is in part due to well-known (yet misunderstood) quotes by founding members of the field, e.g., the following quote by Feynman (1992):

> "I think I can safely say that no-one understands quantum mechanics."

As such, to a lay audience, QM is shrouded in mystery. At the same time, we have concluded anecdotally that children are already familiar with the term quantum. Moreover, technologies based on QM are pervasive in our modern society: from LED lighting and flash memory to lasers and MRI machines, we regularly encounter QT in our daily lives. This leads us to believe that it could be worthwhile to discuss elements of QT with children and their teachers. Thus, our approach for designing S&T activities for primary education focuses explicitly on quantum technologies rather than quantum theories.

Pepper's Ghost Illusion and Quantum Technology

Pepper's ghost is an optical illusion used in, e.g., theatre productions and theme parks. It creates the effect of a ghostly apparition appearing on stage. This is achieved by illuminating an object or actor off stage with a bright light. Light scattered from the object or actor then hits a semi-transparent mirror at an angle so that it reflects towards the audience. At the same time, light from a background scene on the other side of the semi-transparent mirror, but in direct view of the audience, passes through the semi-transparent mirror. The audience now sees both the background scene and the ghostly apparition simultaneously (see **Figure 1**).

Clearly, the Pepper's ghost illusion can be described by classical optics via transmission and reflection coefficients for the semi-transparent mirror (Hecht, 2002). As the semi-transparent mirror splits an incident beam into a transmitted and a reflected beam, it is often referred to as a beam splitter. The link between a beam splitter and QT becomes clear when considering light not as a classical wave but as a collection of single photons. A photon is an indivisible quantum of light. When a photon hits a beam splitter its state will become a super position of a reflected and a transmitted photon. Crucially, when detecting the photon after the beam splitter, we can only ever detect the photon in its entirety, either in the reflected or transmitted state, without knowing in advance which state will be detected (Grangier et al., 1986). Beam splitters are thus optical devices that feature prominently in many quantum and quantum optics experiments. As such, we view beam splitters as a piece of QT.

Research Questions

To evaluate and improve the Pepper's ghost activity as a tool for introducing S&T education to pre-service primary school teachers, we have formulated the following research questions (RQs):

RQ1: What are the perceived learning experiences of pre-service primary school teachers regarding the Pepper's ghost activity?

RQ2: How were pre-service primary school teachers' attitudes towards S&T influenced by the Pepper's ghost activity?

RQ3: What opportunities and difficulties do pre-service primary school teachers see for integrating the Pepper's ghost activity in their own curriculum?

THEORETICAL BACKGROUND

Difficulties Regarding Science & Technology in Primary Education

It is important to offer S&T education to a broad age range of students, primarily for two reasons. First, having knowledge about S&T aids scientific literacy.

Second, by teaching S&T to all students from a young age onwards we may inspire a larger and more diverse group of future scientists and engineers. However, in the Netherlands, integrating S&T in primary classrooms has proven to be a serious challenge. Primary school teachers often lack background knowledge in S&T, have limited pedagogical content knowledge, and have an inadequate understanding of problem-solving skills combined with generally low self-efficacy in this domain (van Aalderen-Smeets et al., 2012). Given all other challenges facing primary education, it is not surprising that the level of S&T education varies greatly between schools.

Integrating S&T With Arts Education

Central to S&T education is doing research by conducting experiments or systematically testing and refining a design. Here, an important aspect is that experimentation and design occur in lockstep with new theoretical concepts being introduced: both hands-on and minds-on (Osborne, 2015; van Eijck et al., 2025). Additionally, the Pepper's ghost activity is an S&T design project which integrates aspects of arts education. The integration of arts into S&T is attractive, both to a broader group of pupils as well as teachers. In general, (pre-service) teachers often have a higher affinity for arts than S&T. As such, it is our assumption that an integrated approach, combining S&T and arts, can help to bring S&T into classrooms.

METHOD

Activity Design

The Pepper's ghost activity was embedded in a larger five-days project week featuring various S&T and A&C activities at Thomas More University of Applied Sciences in the Netherlands. The activity was introduced on day one with a 45-minute lecture by the authors. This lecture explained the basic physics of light rays, transmission and reflection by a mirror as well as featuring several examples of Pepper's ghost illusions used in, e.g., theme park attractions and as a special effect in movies. Without going into specifics, the use of a beam splitter, or semi-transparent mirror, in QM research was explained. As such, a piece of QT and jargon was introduced. However, this was not the focus of the lecture.

On the second day, authors gave a short instruction on how pre-service teachers could make such an illusion themselves. The pre-service teachers were instructed to design a diorama of a playground, featuring a Pepper's ghost illusion using only simple craft materials. This included designing the enclosure holding the diorama, e.g., a suitably sized and shaped cardboard box. A thin 20x30 cm plastic plate was provided to act as a beam splitter mirror. Pre-service teachers were allowed to work in groups of three or four. There was to be an exhibition of the dioramas on the final day of the week. One of the authors was available during the days in between questions and guidance. The activity is centered around the following learning goals (LGs):

LG1: Students become acquainted with the concept of QT and its application.

LG2: Students can explain the action of a beam splitter on a beam of light and how this creates the Pepper's ghost illusion.

LG3: Students can apply this knowledge during the design of their own Pepper's ghost illusion in an A&S project.

LG4: Students practice design skills, such as ideation, prototyping, testing and collaboration.

Selection of Participants and Data Collection

An evaluation study using a semi-structured interview protocol was chosen to answer the RQs. Participants were selected from a group of 45 first year pre-service teachers enrolled at Thomas More University of Applied Sciences and participating in the A&S week. A total of 18 pre-service teachers, divided into six groups of three or four individuals, were interviewed on the fourth day of this week. The interviews were audio-taped and transcribed verbatim. The 15-minute interview protocol consisted of nine questions in total. In this study we focus on the perceived learning experiences, attitudes towards S&T and the opportunities and difficulties for integrating the Pepper's ghost activity into the students' classroom. Therefore, questions related to their final designs, and attitudes solely towards A&C were not part of this investigation. The following questions are included in this study:

- What did you learn about (the use of) S&T, based on your project?
- What did you learn about (the use of) A&C, based on your project?
- Can you explain the quantum concept behind the Pepper's ghost activity?
- Which opportunities do you see for embedding S&T in your own classroom, using a similar activity?
- Where do you see challenges or what seems complicated regarding the S&T aspect of such an activity?

Data Analysis

To compare the interviews, open coding was used to create codes and define emerging themes. Initially, two authors individually coded two out of six interviews and discussed their findings to reach consensus on an initial

Table 1. Codes within the emergent theme of pre-service teachers' knowledge of physics involved

Code description	Sample quote
The mirror is semi-transparent and/or that the light is partly reflected and partly transmitted.	Well, what I do remember is that it goes through the glass and that it also reflects.
The incidence and path of light in the illusion.	Light shines on [an actor] and reflects off the mirror, making it seem to the audience as if someone is standing there, while in fact [the actor] is […] not on stage.
Light entering the eye and image formation by the brain.	Your brain always thinks light is coming from the front, and that's why you see it right in front of you through [the mirror].
The mirror must be at a (45 degree) angle.	There's a [mirror] here at a 45-degree angle […] and some of the light is reflected into your eye, so at that 45-degree angle.
Light intensity and paint color influences the visibility of the illusion.	We ourselves made the mistake of making that thing red. You must give it a color that reflects light well, otherwise you won't see it here. It's also important to keep your box dark so you can still see the image.

coding scheme. This initial coding scheme was then used for the remaining interviews, where the researchers remained open to additional (sub)themes emerging. Overarching themes in the resulting code book were found to show a large overlap with the three pillars of Dutch S&T education (van Graft et al., 2018), i.e., learning new knowledge, working on new skills and having a critical, and curious attitude. Hence, we decided to arrange the code book according to the themes knowledge, skills, and attitude, with the addition of the theme difficulties.

RESULTS AND DISCUSSION

Knowledge of Underlying Physics

Table 1 presents the coding used for the emergent themes regarding pre-service teacher knowledge of the physics underpinning the Pepper's ghost illusion at the end of the Pepper's ghost activity.

The function of a beam splitter as a device that acts as a semi-transparent mirror was widely recognized and this shows evidence for the achievement of **LG2** and **LG3**. However, we found that the pre-service teachers could not comment meaningfully on the connection between QT and the Pepper's ghost activity, thus not achieving **LG1**. This is illustrated by the following interview responses:

> Student 1: What I do remember is that it goes through the glass and that it also reflects. And how it is also positioned at an angle, because it is of course such an L shape that the glass must be tilted to see it.

> Student 2: I find [quantum] a bit of a difficult word. I'll be very honest: quantum aspect, what exactly does that mean?

Pre-service teachers were able to reason in broad terms about the path light traverses inside their own Pepper's ghost box. This was often supported by mentioning the importance of a 45-degree angle for the placement of the semi-transparent mirror. Students also

Figure 2. An example of a Pepper's ghost illusion made by a group of pre-service teachers (it shows the outside of the box, and the inside of the box with and without the illusion) (the authors' own elaboration)

recalled how light entering the eye is interpreted by the brain to form an image. The emergence of these themes was in line with the lecture given at the start of the activity.

We note the emergence of an additional theme on the use of light and dark paint colors. Some groups were dissatisfied with the visibility of the illusion in their initial trial and decided to experiment with different paint colors for either background or subject, looking for optimal reflection of incident light. They discovered that a bright colored subject placed in dark surroundings provided the best ghosting effect.

All students were able to construct a working Pepper's ghost illusion, such as the one in **Figure 2**. This further supports the achievement of **LG3**. However, not all students were confident that they understood the theory well enough to explain it in their own classrooms, as evidenced by the following interview response:

> Student 3: The challenge with Pepper's ghost is that it is actually quite difficult, of course. I find it hard to understand myself, so I can imagine that primary school children find it even harder. So I

Table 2. Coding for the emergent theme of skills used or acquired by pre-service teachers

Code description	Sample quote
Recognize Pepper's ghost and S&T in their world.	[In] the Efteling theme park, where I think you have The Little Match Girl. The effect is used there too. It's quite interesting to figure out how these effects actually work.
Construct (a lot of) things with simple craft materials.	You can really get far with different materials […] like putting cotton wool in a piece of paper and making a ball out of it. […] We did that with the tree, […] You can make a lot of art with recycled materials.
Collaborate during the Peppers ghost project.	I think we've also learned that we have to work together, so you really have to think about it together, not just trying to get it your way.

Table 3. Codes within the emergent theme of pre-service teachers' attitudes towards S&T education

Code description	Sample quote
The pre-service teacher has experienced that he/she understands and remembers the technical principles better because he/she made it himself/herself.	When you do it yourself, you remember it better and you really understand how it works.
The pre-service teacher has learned that S&T lessons can also be practical/hands-on, instead of just theoretical lessons.	If I look at myself, a whole project about [theoretical] science, yes, I would [do that], […] but I think the combination of being active, doing things, and designing—I really enjoy it.
The pre-service teacher is enthusiastic about the Pepper's ghost project.	You don't usually think this is possible, but when you see it like this, it's just funny. I really like the end result.
The pre-service teacher expects that their students like to work on the Pepper's ghost project.	I think [the students] would also get really excited if something suddenly appears, I think they would find that really cool.
Explain how S&T may enhance art and vice versa.	Well, I think that when you use science in art, you understand what you're doing better, and it can lead to other things.

> think it mainly requires extra explanation. That makes it quite difficult.

Skills Used or Acquired

Table 2 shows coding for the skills pre-service teachers said to have used or developed throughout the Pepper's ghost activity.

In line with **LG4**, students demonstrated several design skills, as evidenced by the following interview response.

> Student 4: And it is also fun to see what works and what doesn't. To get started with different materials and generate new ideas through that. Then you develop new insights as well, by doing things this way together. I have certainly learned from that.

This quote shows that the students generated new ideas and insights through prototyping and making, indicating that indeed there was the desired combination of hands-on and minds-on during design based learning.

The lecture at the start of the Pepper's ghost activity explained how the Pepper's ghost illusion is used in theme park *Efteling* and the movie *Home Alone*. The pre-service teachers valued and enjoyed how they are now able to recognize the illusion in such instances and being able to explain it. They also expect such real-life examples to be a good way to introduce the activity to their students.

The pre-service teachers were given simple, low-cost materials to work with during the activity, e.g., cardboard, paint, yarn and wooden sticks. They expressed surprise about the wide range of objects that they were able to make with such simple materials. They found that experimentation spawned new and creative ideas. Moreover, through collaboration with classmates, pre-service teachers exchanged and acquired new construction techniques. For instance, one group of pre-service teachers investigated how to construct gears, needed to move a merry-go-round in their design, from cardboard and have them turn reliably. Working in groups also led to pre-service teachers to the realization that it is important to think of a concept together instead of only pushing one's own ideas.

Attitudes Towards Science &Technology Education

Table 3 presents how the Pepper's ghost activity shaped the attitude of the pre-service teachers towards S&T. In general, they expressed a positive attitude towards the project.

They appreciated doing something new and being able to try out such an activity themselves before using it in a classroom setting with (future) students. Learning through hands-on experimentation is cited as clear opportunities for engaging classroom activities.

Table 4. Difficulties pre-service teachers expect to encounter when using the Pepper's ghost activity with their primary school students

Code description	Sample quote
Students may not be able to make the illusion work, finding it difficult to meet the technical criteria, leading to disappointment.	They just do whatever and expect it to show up eventually, but [then] it doesn't show up at all.
Students will not understand how the illusion works.	The thing itself is fun to do with children, but I think the science behind it will turn them off. I don't know if they can make the connection yet.
Students won't know where to start or what to make.	For children, it's really difficult to figure this out on their own.
Not enough time in class for the full activity.	Constructing an entire box from scratch takes too much time.

The pre-service teachers appreciated the context of optical illusions. They thought it likely that their own (future) students would appreciate this activity and the context as well. They expect that seeing the illusion suddenly appear will spark interest and enjoyment with children. Then, replicating that illusion for themselves could offer children a motivating experience of success.

Interestingly the Pepper's ghost activity also led to two attitude changes. Firstly, the pre-service teachers experienced that they understood theoretical concepts better because they had to apply these concepts during the activity. This has also been found by Smit and colleagues in a professional development program in which teachers themselves were involved in experimental inquiry to get a better understanding of the scientific phenomena (Smit et al., 2018). For example, in the group that constructed cardboard gears, one pre-service teacher found the working of gears difficult to grasp. During the project she made them together with a peer and after that she was able to explain how they work. This also ties into the value of collaboration mentioned above. Secondly, the pre-service teachers have learned that in addition to the possibility of S&T education being hands-on, S&T by itself can also be a creative process, linked to A&C. This is in contrast to their experience and beliefs as first year students of S&T being merely a theoretical subject taught by explaining theories. They expect that this hands-on way of working with S&T will increase the engagement of their students.

In addition, the pre-service teachers were able to articulate the added value of combining arts and science aspects. They recognized that S&T can support A&C education, as technology can be integrated into an artwork which then also leads to new design ideas being explored. They also expected that combining arts with S&T will increase engagement of their students overall, as some show a higher affinity for S&T rather than arts, and vice versa. As such, they expect a combined arts & science project to appeal to a broader group of students.

Difficulties

Table 4 shows the difficulties pre-service teachers expect to encounter when implementing the Pepper's ghost activity in their own curriculum.

Though they anticipate that crafting a Pepper's ghost style illusion is feasible for students from a wide age range, some of their students may find the illusion puzzling. Specifically, they point out the fact that knowledge of S&T is not a requirement for building a successful working Pepper's ghost diorama. The pre-service teachers suggest that the S&T aspect of the activity can be implemented successfully with students around the age of 10 years and up.

Pre-service teachers expect some of their students will not know where to start in crafting their own diorama. A possible solution to this would be to show a ready-made example of a finished diorama. However, the pre-service teachers recognize that this would come with its own shortcomings, specifically, that children will simply copy the example. This would hinder a scaffolding approach and prevent students from coming up with their own ideas. These two competing difficulties would lead to some students messing around without much purpose or intent. Ultimately, the pre-service teachers fear that students will be disappointed, should the students fail to produce a visible illusion in their own product.

For the pre-service teachers, Pepper's ghost activity was spread out over multiple days during a week of arts and S&T projects. The pre-service teachers feel that stretching out the activity over multiple days would take too long and is not feasible timewise for their classes. They indicate that due to a lack of time, either the A&C or S&T aspect of the activity may suffer. They suggested that it may be possible to speed up certain aspects of the activity. For instance, instead of having to construct a box out of raw cardboard, a template could be provided.

Several pre-service teachers expect that students will not understand the illusion and the theory behind it. However, one could argue that this may be due to pre-service teachers themselves feeling insecure about their own content knowledge, and therefore believing the topic also being too difficult for their students, as has been reported in a previous study by Smit and colleagues (Smit et al., 2018).

Figure 3. A prototype of a ready-made cardboard box to build the Pepper's ghost illusion (the authors' own elaboration)

CONCLUSION AND OUTLOOK

Main Conclusions

To further enhance S&T education in primary school and help introduce QT from an early age, we designed an activity involving the construction of a Pepper's ghost diorama. This activity was part of an integrated arts and science project week for primary school pre-service teachers and evaluated by conducting interviews at the end of the week. Our analysis of these interviews shows that the activity helps pre-service teachers appreciate S&T as part of their everyday lives and how S&T may be integrated with A&C education. Specifically, we noted a shift in attitude of the first-year pre-service teachers, where S&T was no longer viewed only as a theoretical subject, but also having the potential of being a hands-on experience.

It was evident that the activity encouraged the pre-service teachers to experiment more broadly with S&T. For instance, some investigated the influence of color and the use of light and dark on the illusion. Others successfully incorporated movement in their diorama by constructing a system of self-made cardboard gears.

We found that with the help of a short lecture at the beginning of the project week, followed by the construction of a Pepper's ghost diorama, pre-service teachers understood the action of a beam splitter on a beam of light. They were able to reason about the illusion using concepts from classical optics on a rudimentary level. Even though little to no quantum mechanical reasoning was introduced in the activity, we value that pre-service teachers have become acquainted with the workings of a beam splitter and how it acts on a beam of light. This can be used as a basis for follow-up discussions and activities, introducing the concept of superposition and the photon nature of light. As such, our Pepper's ghost project offers an entrance to the quantum realm for primary school education.

Addressing Difficulties and Outlook

Our study suggests clear improvements to be made to the teaching and learning sequence and lesson materials used in the activity and revealed avenues for further study. We expect that most difficulties implementing the Pepper's ghost activity in the classroom can be addressed by introducing a cardboard template or ready-made box to build the diorama in. Hence, we've started development of a template that can quickly be folded into an L-shaped box and ensures a 45-degree angle for the beam splitter. This should minimize technical requirements for students and ensure a successful experience in creating the illusion. Naturally, it would shorten the time required to conduct the activity. This time saved can be used to expand either the S&T or A&C part of the activity, or both. A prototype of this cardboard template is shown in **Figure 3**.

The lecture at the start of the project week was appreciated by the pre-service teachers and all were able to apply some information from the lecture to their own diorama. However, at the end of the project some groups of pre-service teachers expressed doubt about their own understanding and content knowledge. It is our suspicion that this also has consequences for pre-service teacher self-efficacy and the willingness to incorporate the Pepper's ghost activity in their own curriculum.

Finally, we aim to add some rudimentary treatment of the quantum properties of light to the activity by discussing the action of the beam splitter when light is to be understood as a collection of indivisible photons. Given that the concepts of classical optics seem to be well within the grasp of pre-service teachers, we believe that adding a touch of quantum reasoning to be feasible.

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