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DOI
10.1007/978-3-030-34350-7_37

Publication date
2019

Document Version
Final published version

Published in
Games and Learning Alliance- 8th International Conference, GALA 2019, Proceedings

Citation (APA)
Dorland, B., van Hal, L., Lageweg, S., Mulder, J., Schreuder, R., Zaidi, A., Alderliesten, J. W. D., & Bidarra, R. (2019). Quantum physics vs. classical physics: Introducing the basics with a virtual reality game. In A. Liapis, G. N. Yannakakis, M. Gentile, & M. Ninaus (Eds.), *Games and Learning Alliance- 8th International Conference, GALA 2019, Proceedings: 8th International Conference, GALA 2019, Proceedings* (Vol. 11899, pp. 383-393). (Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics); Vol. 11899 LNCS). Springer. https://doi.org/10.1007/978-3-030-34350-7_37

Quantum Physics vs. Classical Physics: Introducing the Basics with a Virtual Reality Game

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Abstract. Unlike classical physics, quantum physics is harder to explain, as it involves very small scales and phenomena that are not visible to the naked eye. Understanding the differences between classical and quantum physics is difficult, especially for children, who cannot grasp the subtleties conveyed in complicated formulae.

We propose to achieve this in a playful and immersive manner, which is a more familiar and convenient way to introduce children to new concepts. For this we developed *Save Schrödinger's Cat*, a puzzle game in virtual reality featuring a classical physics mode and a quantum physics mode. As virtual objects and phenomena behave differently in each mode, this mechanic encourages players to toggle between modes, in order to explore the differences between quantum and classical physics in an immersive, entertaining and challenging way. A preliminary evaluation showed that players could better identify various distinguishing features of either mode.

Keywords: Classical physics · Quantum physics · Virtual reality · Educational games

1 Introduction

Differences between quantum physics and classical physics can be hard to convey without referring explicitly to in-depth formalisms like formulas [6]. Quantum physics is important for understanding concepts of the universe that are not explicable with classical physics. However, quantum physics is generally considered to be difficult to understand, since this requires knowledge of the underlying theories and classical physics.

How can one convey the differences between quantum physics and classical physics visually, without referring explicitly to in-depth formalisms like formulas? Apart from some videos, there are currently no known accessible mediums that have accomplished this goal successfully for a large audience. Understanding

A. Liapis et al. (Eds.): GALA 2019, LNCS 11899, pp. 383–393, 2019.
https://doi.org/10.1007/978-3-030-34350-7_37

quantum mechanics often involves being familiar with advanced physics concepts, as quantum mechanics go further beyond classical physics.

One possibility is to create an understanding of the basics by using a game. *Save Schrödinger's Cat* is a puzzle game, making use of the differences between classical and quantum physics for the design of puzzles. Players can decide when to enable quantum mechanical effects. All game objects behave differently when these effects are enabled.

1.1 Virtual Reality

The game uses virtual reality technology to immerse the player in an environment in which they can interact with classical and quantum physics directly. It is accessible to anyone with access to an HTC Vive[1] and is designed to introduce the player to differences between classical physics and quantum physics in a playful and visual way.

Empirical experiments involving quantum mechanics are not as easy to conduct as empirical experiments involving classical physics concepts [7]. Computer games allow the creation of a universe with alternate laws of physics, thus it makes sense to show the differences between quantum and macro physics with the use of computer games.

Virtual reality games improve on this by allowing the player to experience a game's universe, almost as if it is reality. By having the effects of quantum mechanics all around the players, they can interact with those effects in an immersive way. Such an environment helps the player learn by empirical experiments, which are shown to be more effective than studying the theory [3,4]. Hence, games in a virtual reality environment are very effective in the field of education.

1.2 Purpose and Idea

Save Schrödinger's Cat is a virtual reality game where the player can experience classical physics and quantum physics. The purpose of the game is to introduce a large audience to the differences between these two different types of physics.

An introduction to the physics types is given in the form of various puzzle rooms. These puzzle rooms utilize the differences between the two physics types by offering the player the ability to switch between two modes with different physics systems. The modes determine the behavior of certain objects, for instance, magnets attract metal boxes in classical mode and bend lasers in quantum mode. Some puzzles can only be solved when being approached in classical mode, others can only be finished in quantum mode or a mix of both. It is up to the player to find out the right way to utilize objects that work differently in each mode for each puzzle.

The most important aspect of this game is the educative part. To support the learning process, the game also has a small story, which is conveyed with the use

[1] https://www.vive.com/eu/product/.

of voice lines. The theory about the quantum mechanics that are displayed in the game is explained through a narrative, where the protagonist, Schrödinger, tries to save his cat from the antagonist by beating all the puzzles described earlier. By letting the player find out how the various objects in the game environment react to quantum physics and classical physics, these mechanics can be experienced.

2 Related Works

Earlier work attempted to find the benefits of gamification in the teaching of quantum physics [2]. The result was that gamification supports education and that educative games are motivating for students. However, the research did not bring conclusive results for all types of games yet.

There are alternative games with similar goals and ambitions to *Save Schrödinger's Cat*. Most have the primary goal of giving the player an enjoyable experience, but some of them focus more on educating the user. Some notable games with the former goal are *Quantum Game with Photons*[2], *Laser Puzzle in VR*[3], and *qCraft*[4]. These games are designed for a wide audience and published on popular platforms to reach this audience. The purely educational games, however, are less known, as they were created as research experiments and abandoned afterwards. Bjaelde and Petersen mention eleven examples of such games during their tests on gamification [2].

Quantum Game with Photons is a game which teaches the player about quantum mechanics. It makes the player solve puzzles with lasers using quantum mechanics. This game is set in a 2D environment instead of in VR, goes a lot more in-depth, and does not show the differences between quantum and classical physics. This game does teach quantum mechanics rather well, but requires prior knowledge about quantum mechanics to properly play. As such, it does not serve as a basic introduction to quantum mechanics.

Laser Puzzle in VR is a VR game in which you have to solve laser puzzles by placing mirrors and other building blocks. It is not very useful for players wanting to learn about quantum mechanics, as it does not cover quantum effects at all.

qCraft is a mod for the game *MineCraft*[5] which adds some new blocks to the game which have quantum properties. This mod focuses on teaching just a couple of different quantum mechanics, but does seem to be doing this rather well. It is very accessible to new users who can quickly learn a couple of things about quantum mechanics by directly interacting with these blocks.

3 Game Design

Before and during development, design decisions were made with regards to the various game mechanics and components. Most of the quantum effects were exaggerated to more clearly communicate them to the player. The story does clearly

[2] http://quantumgame.io/.
[3] https://vr.arvilab.com/products/games/laser-puzzle-in-vr.
[4] https://minecraft.curseforge.com/projects/qcraft.
[5] https://minecraft.net.

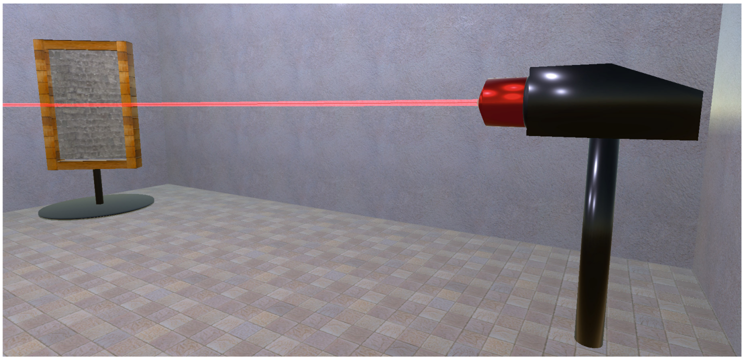

Fig. 1. A laser instead of single photons.

specify that these effects are exaggerated. This way, the player can experience the effects, but still understand that this is not a completely accurate simulation of real life. The goal of the design is to make sure the player can always interact with objects without visual clutter through the scenes. The trailer [6] gives a good idea of the developed game.

Lasers Instead of Single Photons. Most quantum phenomena only work on single photons. The quantum effects were applied to an entire laser, because this would communicate more clearly to the player what is happening. If only single photons would be used, there would have to be a delay between the effects, and the player would have to wait to see what effect a change he has made. The player can now, for example, rotate a mirror and see it affect the laser in real time, allowing for more responsive and clear gameplay (see Fig. 1).

Magnets Bend Lasers. Even though photons have no electric charge, it is possible for magnets to interact with them [1]. However, the effect would be so limited that it would not be visible in the game if it would be implemented realistically. Therefore, the interaction between magnets and photons had to be exaggerated by clearly making entire laser beams bend around a magnet instead of single photons (see Fig. 2).

Metal Box Attraction by Magnets. Magnets will always interact with ferrous objects. However, to allow for more easy to understand features that force the user to keep switching between quantum and classical mode, a decision was made to disregard this fact while the game is in quantum mode. This could have been solved differently by changing the material of the metal objects to something non-ferrous, but that would not be intuitive in this game (see Fig. 3).

[6] https://drive.google.com/file/d/1O27HqhHi5Y2puhz_5sC6iHUy2norCgbx/view?usp=sharing.

Fig. 2. A magnet bending a laser.

Fig. 3. A magnet attracting a metal box.

Enhanced Tunneling Effect. The tunneling effect is usually barely noticeable, even for very thin surfaces. To clearly show this effect to the player, the effect was greatly enhanced by always letting entire lasers tunnel through thin surfaces in quantum mode. This way, the player can see this theoretical effect with their own eyes (see Fig. 4).

Quantum Teleportation. In quantum physics, information can be transferred at extremely high speeds, making it appear as if the information is teleported. The game shows this by letting photons appear instantly in another place. The place is determined by two portals that are linked together in one scene (see Fig. 5).

Hong-Ou-Mandel Effect. The Hong-Ou-Mandel effect is simulated by a beam splitter, which combines two lasers into one stronger laser, or splits one laser into two weaker lasers (see Fig. 6).

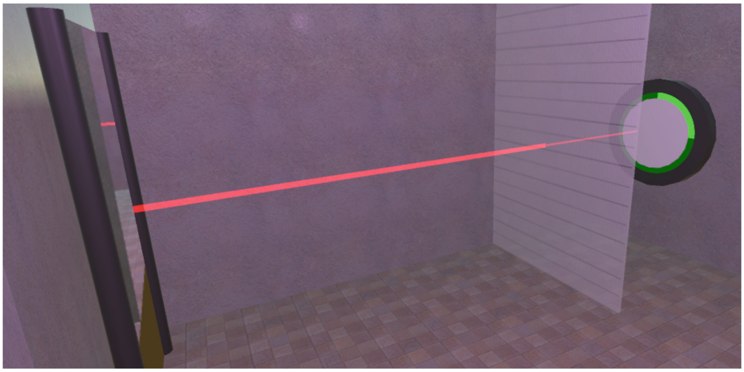

Fig. 4. A laser tunneling through a thin wall.

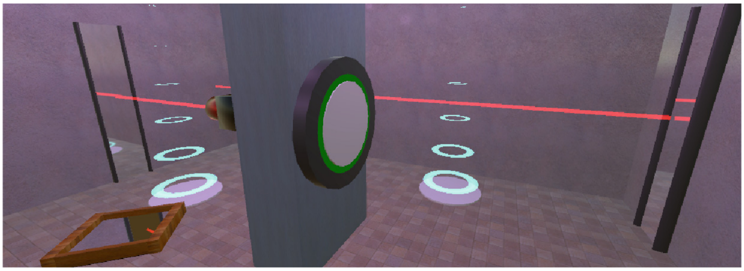

Fig. 5. A portal through which a laser can be teleported.

4 Technology

Save Schrödinger's Cat uses various existing technologies to increase immersion, which consequently improves the educational performance of the game.

4.1 Engine

The game was created on the Unity[7] game engine, utilizing SteamVR[8] for virtual reality support. Unity has a large asset store that provides free assets, which can be used to reduce development time. By using a commercial game engine, *Save Schrödinger's Cat* can promise that there will not be any engine-related problems, except for the limitations that affect all games created in Unity. This is important to ensure that the interaction with objects is stutter-free, as one would expect when physically interacting with objects outside a virtual environment as well.

[7] https://unity.com/.
[8] https://store.steampowered.com/steamvr.

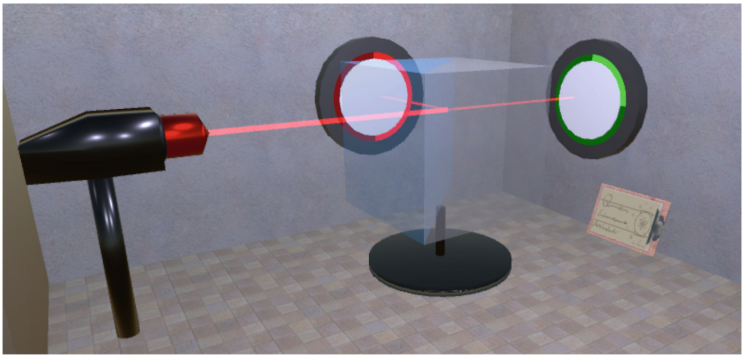

Fig. 6. A beamsplitter, splitting the laser beam into two.

4.2 Hardware Setup

The virtual reality setup that was used includes HTC Vive gear on PC platforms. Other VR hardware was not used due to budget limitations. The hardware components required for playing, besides the headset, are (HTC) controllers and any audio device (see Fig. 7).

Fig. 7. Player using the virtual reality setup.

The controllers are used as interaction tools to be able to engage with the game's mechanics such as rotating mirrors or picking up boxes. For moving or teleporting the user, the controllers use the touch-pad buttons. For grabbing objects, the trigger buttons on the back of the controllers are used.

Technically, audio is not an essential component for the gameplay. However, the audio does provide some needed clues and explanations about quantum physics and adds another level of immersion that, when missing, may leave users confused or uninterested. Ideally, headphones are used as audio device for an even more immersive experience.

The game does not require a very large play area. The minimum recommended play area has a size of $5\,\mathrm{m}^2$. The ideal play area is a space of at least $8\,\mathrm{m}^2$, as it allows users to walk around freely without bumping into anything.

5 Evaluation

In order to assess whether the game has achieved its educational goal, we invited students to answer questions about differences between quantum physics and classical physics after playing the game, and some others to answer the same questions without playing the game. This way, we could see whether players learned about quantum physics concepts they did not know about before while playing *Save Schrödinger's Cat*. The main question to be answered by the results of these evaluation sessions was: *Does* Save Schrödinger's Cat *manage to teach people with no knowledge of quantum physics some differences between quantum physics and classical physics?* We also asked testers to give their general opinion on *Save Schrödinger's Cat* after playing the game. This would show whether the game provides enough immersion and entertainment, as well as educative elements. Appendix A shows the questionnaire that was used for the evaluation sessions. Appendix B shows the results of the evaluation.

6 Conclusion

Introducing a young audience to concepts of quantum physics and how they compare to classical physics can be done by means of an immersive game for virtual reality. We presented *Save Schrödinger's Cat*, a game developed for young visitors of the Science Centre[9] at Delft University of Technology. Players can directly interact with (virtual) objects or phenomena, in either quantum or classical physics mode, and see the results of the physical laws that apply to them. As a result, it overcomes the need to explain in-depth formalisms (e.g. formulas) with a more experiential and intuitive approach.

The game is aimed at young people with no understanding of quantum physics, as the virtual visualizations help them understand the phenomena. This is an important goal because quantum physics explains phenomena in the universe that are not explicable via classical physics, and quantum physics looks to be an important factor in future technologies and industries [5].

Results from the evaluation show that *Save Schrödinger's Cat* was capable of visually conveying many differences between quantum physics and classical physics. Players were able to identify more quantum physics concepts and differences between quantum physics and classical physics than people who did not play the game. We can, therefore, conclude that this game is a successful addition to the educational exhibit of TU Delft Science Centre.

[9] https://www.tudelft.nl/sciencecentre/.

Appendix A Evaluation Questionnaire

The following two pages were given to play-testers in the TU Delft VR Zone and Science Centre.

Save Schrödinger's Cat - Quiz

Please answer the following questions based on the experiences you gained while playing *Save Schrödinger's Cat*.

Which of the following concepts is possible according to quantum physics but would not be possible in classical physics?
Put a checkmark ✔ in the box next to the applicable concepts.

Concept	**This is made possible by quantum physics**
Tunneling light through thin walls	
Teleportation of light	
Teleportation of a human	
Cloning a cat	
Bending light rays with magnets	
Splitting beams into two weaker beams using a *beam splitter*	
Combining beams into one stronger beam using a *beam splitter*	
Travelling through time	
Evil scientists stealing your cat	
Attracting a metal box with a magnet	
Tunneling light through mirrors	
You cannot know the state of an object before observing it	

	DISAGREE	SOMEWHAT DISAGREE	NEITHER DISAGREE NOR AGREE	SOMEWHAT AGREE	AGREE
1. I understand the **goal of the game** after playing the levels made available for the playtest session.	1	2	3	4	5
2. The **controls are intuitive** and easy to get used to.	1	2	3	4	5
3. The game is **entertaining**.	1	2	3	4	5
4. After playing the game, I feel **I know more about quantum physics** than before playing the game.	1	2	3	4	5
5. Playing the game with **virtual reality hardware has an added value** compared to playing the game on a single screen.	1	2	3	4	5

☐ I participated in this evaluation voluntarily.

☐ I agree to have this data used for further research without any personally identifiable information.

Signature ____________

Thank you on behalf of Quantum Studios for taking time to support the development of Save Schrödinger's Cat!

Appendix B Results

Two questions were left out, because of different reasons. The first was "Splitting beams into two with a beam splitter", because the game logic contradicts the real world, so players that have experience in physics will check the box while players that do not will not check the box. The second that was left out was "Evil scientists stealing your cat", because the majority of players considered it a joke and did not seriously answer the question.

Table 1 presents the raw data of filled-in questionnaires, including a computed average for the aggregate of the rows. Each row represents one valid questionnaire. Table 2 presents the results with regard to the questionnaire statements on the game itself.

Table 1. Questionnaire results about differences between quantum physics and classical physics, given to both play-testers and control group members.

	True positive/negative	False positive	False negative
Tester A	100%	0%	0%
Tester B	100%	0%	0%
Tester C	60%	20%	20%
Tester D	30%	40%	30%
Tester E	70%	10%	20%
Tester F	90%	0%	10%
Tester G	80%	0%	20%
Tester H	50%	10%	40%
Tester I	60%	10%	30%
Tester J	80%	0%	20%
Average	**72%**	**9%**	**19%**
Control A	50%	10%	40%
Control B	40%	0%	60%
Control C	70%	0%	30%
Control D	50%	0%	50%
Control E	70%	0%	30%
Control F	60%	10%	30%
Control G	50%	0%	50%
Control H	50%	0%	50%
Control I	50%	20%	30%
Control J	50%	0%	50%
Control K	60%	0%	40%
Control L	50%	0%	50%
Control M	70%	0%	30%
Control N	70%	10%	20%
Control O	60%	10%	30%
Average	**56.7%**	**4%**	**39.3%**

Table 2. Scores for the statements on *Save Schrödinger's Cat*

Question	Average score
I understand the **goal of the game** after playing the levels made available for the playtest session	4.33
The **controls are intuitive** and easy to get used to	3.70
The game is **entertaining**	4.57
After playing the game, I feel **I know more about quantum physics** than before playing the game	3.40
Playing the game with **virtual reality hardware has an added value** compared to playing the game on a single screen	4.47

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