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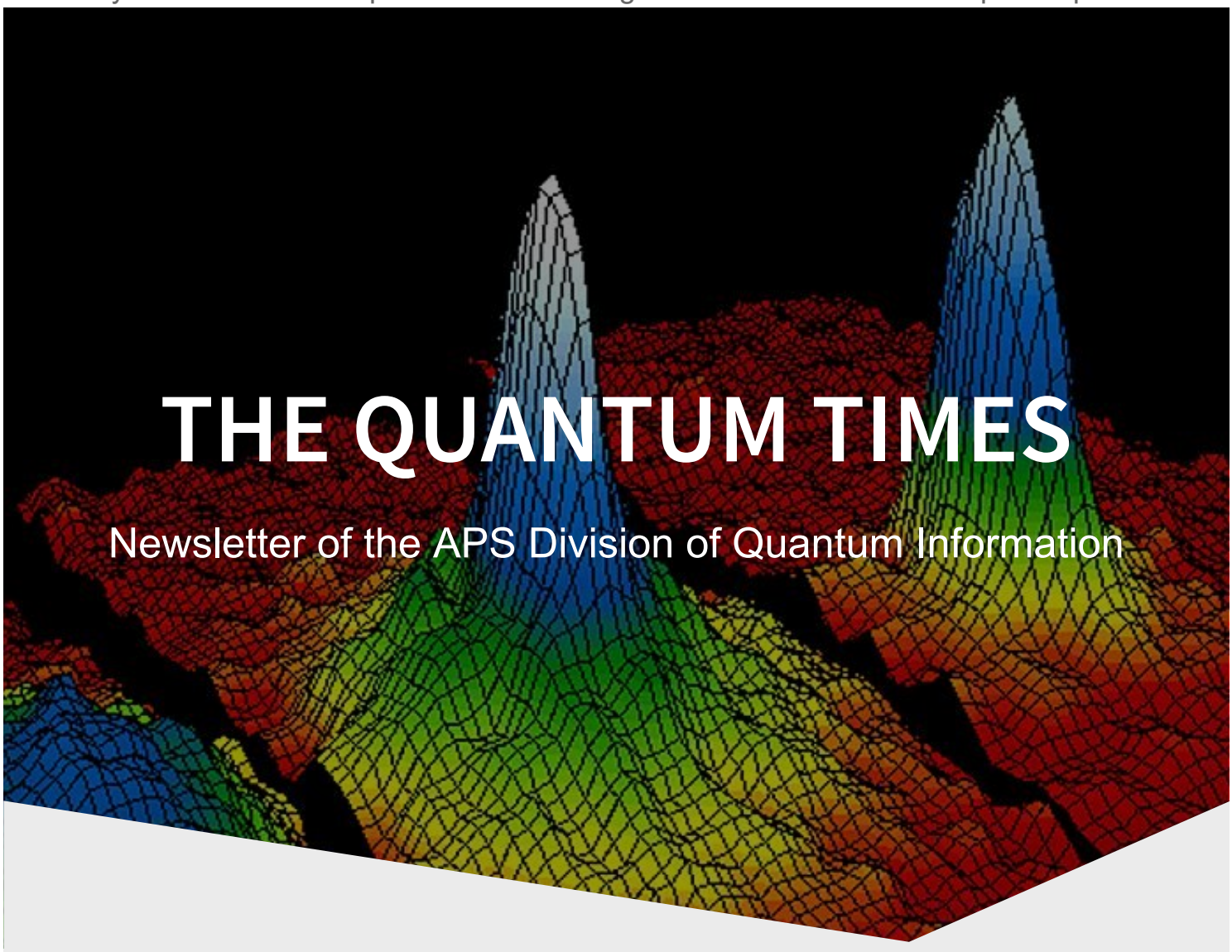

THE QUANTUM TIMES

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Gamifying Quantum Theory

Matthew Leifer March 15, 2017 Articles 0

Over the past few years, the trend of gamification has gradually seeped into quantum research, education and outreach, so that we now have a critical mass of games based on quantum mechanics. I thought the time was right to discuss quantum gamification at the APS March meeting, so I have organized a session on Thursday at 2:30pm on Gamification and other Novel Approaches in Quantum Physics Outreach. If you need a break from superconducting qubits (and I know you do), why not go and learn about this exciting new area.

Also, while you are sitting through a typical March meeting talk where the speaker tries to give their usual 30min talk in 10min, rushing through a series of

incomprehensible slides, or when you have gone back to the hotel early with a Subway sandwich having lost all your friends and colleagues in the morass of physicists, why not distract yourself by giving some quantum games a try? Here are some possibilities:

Games to be discussed at the March Meeting:

- Quantum Moves
- qCraft (Minecraft mod)
- MeQanic
- The BIG Bell Test
- Quantum Chess
- Decodoku
- Minecraft PR-Box mod
- Quantum Cats

Other Quantum Games

- Quantum Game with Photons
- MeQuanics

In the rest of this article, I briefly review my top picks for quantum games, bearing in mind that I haven't played all of them. In particular, since I did not have a 12 year old handy, I have not tried any of the Minecraft mods. Also, Quantum Chess is still in private beta, but you can see an interesting talk on it by its creator Chris Cantwell here, and you can watch Stephen Hawking play Quantum Chess with Paul Rudd (Ant Man) here. Following the style of gaming magazines, I will give each of my picks a seemingly arbitrary score out of 10 for their science, their gameplay, and their sound and graphics.

Quantum games broadly fit into four overlapping categories, and I will review my top pick for each one. The categories are:

Crowdsourcing Research: These games aim to use the data generated by humans playing the game to solve research problems in quantum physics. This is the same idea as the well-known FoldIt game, which uses humans to solve protein folding problems.

Building Intuition: The idea of these games is to build intuition for how quantum mechanics works by having a game that is built on the rules of an actual quantum mechanical system, without any equations. The aim is not exactly education, but rather to make the abstract features of quantum theory seem more concrete.

Education: The aim of these games is to actually teach some quantum mechanics. If a student plays through one of these games, then they ought to be better equipped for their modern physics and quantum mechanics classes. These games might also be used as a supplement in such classes.

Outreach: The aim of these games is to get people excited about quantum mechanics by putting some quantum ideas in front of people who might not otherwise see them. If they are educational, then it is only at the popular science level.

Top Pick for Crowdsourcing Research: Quantum Moves

Platform: Windows, Linux, Mac, Android, iOS (basically everything)
Project Lead: Jacob Sherson (Aarhus University)
Science: 9
Gameplay: 6
Graphics and sound: 9
The Science:

The aim of Quantum Moves is to help figure out how to move single atoms/ions around in an ion trap using lasers without changing their quantum state. Computer algorithms exist to optimize this, but apparently better results can be obtained by running human-generated solutions through an optimization algorithm.

This game gets top marks for science because it is the only game I am aware of to have resulted in a Nature Publication. The human generated data has been used to build an efficient heuristic optimization algorithm that outperforms other numerical methods. In fact the Science@Home team behind this game have several publications and preprints based on Quantum Moves, they have several other games in development. The most interesting of these Quantum Minds, which is being used by cognitive scientists to study how humans come up with solutions in games like Quantum Moves.

The Game:

The game itself is quite simple. You are presented with a one dimensional curve, which represents the potential of some physical system. Located somewhere along this curve, usually in a potential dip, will be a “liquid” that has funny properties when you move it around. The “liquid” represents the wavefunction of a single atom. You have a cursor, which you can drag around the screen to move another potential dip, which represents the effect of a laser. The aim is to move the “liquid” to a target area while keeping its shape the same as much as possible, i.e. move the atom while keeping the fidelity with (a translated version of) the initial state as high as possible.
The “liquid” has some very counter-intuitive properties that are unlike anything most players will have encountered. Well, it is, after all, a wavefunction and not a liquid, but “liquid” is the terminology used in the game. If you are a quantum physicist, then you will know a few tricks that will help you through the initial levels. For example, by the adiabatic theorem, you know that moving an isolated potential dip with an atom in it very slowly is probably a good idea, and you know

that when you want to transfer an atom from one dip to another similarly shaped one then you know that making a symmetric double-well will be good for tunneling. Other than that, the behavior of the “liquid” is, to me at least, extremely unintuitive. It sloshes around unpredictably and it is very difficult to figure out what will work well. A few hints are given on the website, e.g. it turns out that shaking the well from side to side a little as you move it helps to maintain the shape of the wavefunction.

The unintuitive behavior of the “liquid” makes for a steep learning curve, and makes the game not especially fun to play, which is why I have only given it 6 for gameplay. Puzzle games can be placed on a spectrum from concrete to abstract. A concrete puzzle game makes use of things that players already have strong correct intuitions for, and the challenge is just to combine these elements in a clever way. An example of a concrete puzzle game is Lemmings, which uses intuitions like, “if a lemming falls a long way it will splat on the ground and die”. In contrast, an abstract puzzle game makes use of elements and rules that seem completely arbitrary when you first encounter them. You have to learn what the rules even mean and build intuition for them as you go. Quantum Moves, and indeed most quantum puzzlers, are on the extreme abstract end of the spectrum. An abstract puzzler can be fun to play, but I think that most players would want considerable help in the early levels as an aid to building intuition. It is not too hard to get high scoring solutions on the first couple of levels, but I quickly struggled to get good scores thereafter. My inability to figure out how to improve my scores turned me off the game fairly rapidly. From a science point of view, you obviously want to present the player with hard problems that we do not know how to solve easily, but if you are trying to compete for distracted players with other more fun games then you are quickly going to lose players to other games like Angry Birds. Players who are more persistent or more fond of arbitrary abstract thinking then I am may enjoy this game more than I did.

The graphics and visuals of this game are very good, comparable to professionally produced games that you might play on your smartphone.

Top Pick for Building Intuition: Decodoku

Platform: Windows, Mac, Web, Android, iOS

Project Lead: James Wootton (University of Basel)

Science: 9

Gameplay: 8

Graphics and sound: 5

The Science:

There is a large overlap between my game categories, and Decodoku is also a crowdsourcing research game, but its style of gameplay is similar to other building intuition games like MeQanic, and it is more fun than the others I have played, so I decided to put it here. I have not read a technical account of the

science behind Decodoku, but from what I can gather it is about correcting errors in a surface code, intended to be used in topological quantum computing.
You are presented with a grid, representing qubits on a torus. From time to time, a syndrome measurement is made and you have to correct the errors. Now, we know how to correct errors in a quantum error correction code, but the idea is to optimize the order in which multiple errors are corrected so that the logical qubits will survive as long as possible. In a toroidal code that means that you do not want an error syndrome that stretches from one end of the grid to the other. The data from this game will be used to optimize the order of error correction in actual algorithms in some way, but, as I said, I have not seen a technical discussion of this yet.
The Game:

The game is a puzzle game involving combining numbers, in some ways similar to the viral hit 2048. From time to time, numbers in different colors will appear on a grid. You can combine to numbers of the same color that are next to each other and they will add together forming a single number. When they reach a multiple of ten they disappear. The objective is to keep going for as long as possible until you get a string of numbers that goes from one edge of the grid to another.
If you were a 2048 addict, you will probably find this game only marginally less addictive (the lack of sliding blocks is slightly less satisfying). You really do not need to know the quantum mechanics behind the puzzle, and, unlike in Quantum Moves, I doubt it will help you. You just need to know how numbers add to multiples of ten. I can see myself playing this game in the same sorts of situations I played 2048, i.e. when I have five or ten minutes of waiting time so it is not worth starting something that would take a long time. I feel a bit better about playing Decodoku than 2048, knowing that it could actually contribute to science in some way.
The graphics look like they were programmed on a Commodore 64 in the 1980's. I assume that is because James is not a professional game developer rather than being deliberately retro, but in any case, graphics are not a major factor in the playability of this kind of game.

Top Pick for Education: Quantum Game with Photons

Platform: Web
Project Lead: Piotr Migdal (Freelance)
Science: 8
Gameplay: 8
Graphics and sound: 8

The Science:

This game is about linear optics, and it basically explores what you can do with photons on an optical table. You can place objects like beamsplitters, mirrors, etc.

on a grid, then fire the lasers and see which detectors fire.
The idea of this is to allow people to play around with quantum optics freestyle, as well as solving puzzles. Most of the puzzles involve single-photon interference, although there is some entanglement on later levels.
I think that introducing quantum theory via photon interferometry is a great idea, as it allows you to get to the mathematics of a qubit quickly for students who have studied some classical optics. I can see myself using this game in sandbox mode as a demonstration tool in the classroom, as well as having the students solve some of the puzzles.
The Game:

You can play the game in a sandbox mode, or solve a series of puzzles where certain elements are fixed and you have to place a limited number of other elements to get certain detectors to click. Many of these puzzles are based on well-known experiments like the Mach-Zehnder interferometer or the Elitzur-Vaidman bomb. However, some of them are challenging even for a physicist experienced in the theory of weird and wonderful interferometers, e.g. they involve putting beamsplitters in unusual places that you would not immediately think of. The learning curve is well-judged and the game is fun to play, at least if you are someone who already likes to think about physics. I don't know how well it would do as a tool for drawing people into physics.

This game is browser based and the web design is very slick and pretty. The game board itself is just a minimalist white grid, with symbols for the various elements. It could be prettier, but it is perfectly functional.

Top Pick for Outreach: The BIG Bell Test
Platform: Web
Project Lead: Morgan Mitchell (ICFO, Barcelona)
Science: 8
Gameplay: 7
Graphics and sound: 10
The Science:

On November 30, 2016, several labs around the world participated in the BIG Bell Test, which aimed to close the free will loophole in Bell's theorem by using randomness generated by human "free will" to choose the measurement settings. Now, if you believe that human choice is genuinely free, and uncorrelated with anything else in the universe, then this really does close a relatively minor loophole in Bell's theorem. On the other hand, there is reason to doubt that genuine free will exists, and there are also other ways of getting the same sort of

loophole, such as retrocausality (the future affects the past) that this experiment does not address.

However, the BIG Bell Test was great for outreach, as the website, games, and videos were very slickly done and it did genuinely make you feel like you were contributing to science in a fun and simple way. It probably introduced Bell's theorem to many people who would not have known about it otherwise.

The Game:

You can still play the BIG Bell Test games online, although there is little point as the experiments are now over. The basic idea is to get participants to mash on the 0 and 1 keys in order to extract random numbers to be used in the experiments. On the face of it, this task would be pretty boring, and we know that humans are not very good at generating random sequences anyway, so the game has to address these two issues.

To address the boredom issue, the generation process is divided into a number of short subgames that have different themes. For example, in the first game your randomness propels you forward along a road in a village, and you have to collect atoms along the way. In the second game, an oracle attempts to predict which key you will press next, and your objective is to outsmart the oracle by being unpredictable.

To address the randomness issue, some statistical tests are run in the background. The player is given feedback on how well they are doing, and is encouraged to be "more random" if necessary. You are scored on each game based on how random you are, and there is a target level of randomness to achieve in each game. I am not sure how all this works on the mathematical level. I presume the game is not computing Kolmogorov complexity, as this is uncomputable in general, but rather some simpler statistical tests that have been found to work well in practice. I also assume that randomness extraction is run on the resulting data. In any case, on November 30, at the end of the game you were told how many bits of randomness you generated, and in which lab they were used, which is a nice touch.

One of the most compelling aspects of the game is the visuals, which are done in a monochrome style that looks hand-drawn and cartoon-like. This really helps to draw the player in, as you want to see what graphics are coming up in the next game. The only complaint I have is that the 0's and 1's that you generate are represented by halves of a yin-yang symbol. To put it bluntly, to me, these look like sperm. For me, this just added to the quirky charm of the graphics, but I imagine it might be distracting for some players.

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