Quantum games aim to demystify heady science

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In a video game called Quantum Moves, the players' goal is straightforward: Move an atom from one place to another as quickly and efficiently as possible while a timer counts down the seconds. Atoms in the game aren't represented as mini solar systems with electron "planets" moving around them, like those you see in a middle-school textbook. Rather, they're liquid-like waves sloshing in a roughly U-shaped curve. To move the atoms, players have to move the curve.

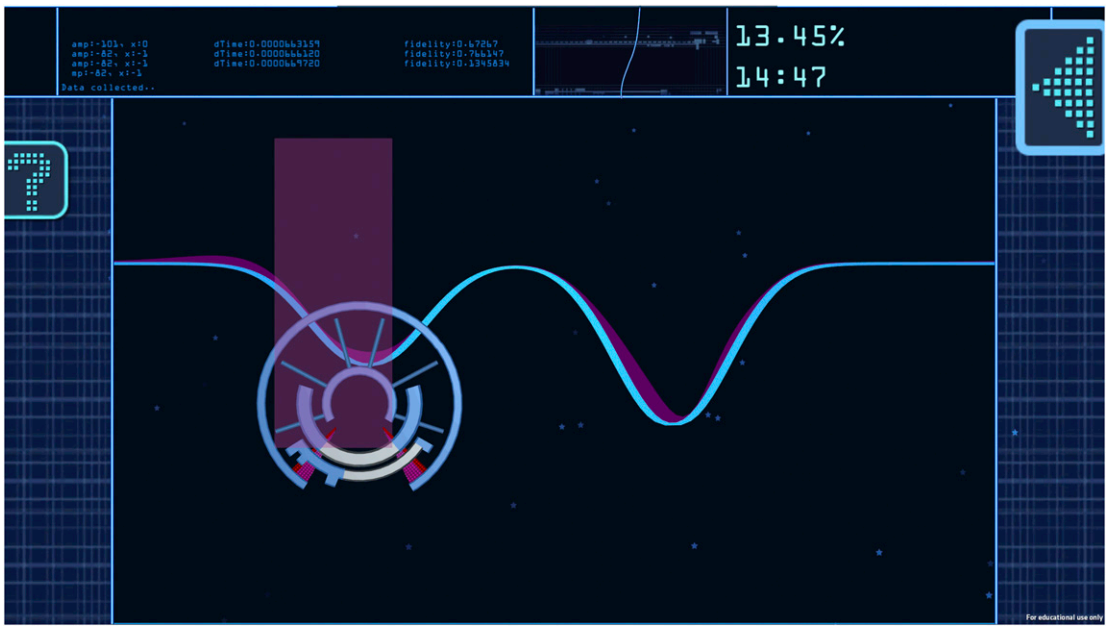
The antagonists in video games tend to be monsters or zombies, but Quantum Moves pits players against the fundamental laws of nature. The waves represent the changing probability distribution of the atom's location, showing where it's most likely to be measured. Players get points when they shuffle the waves into a designated location, and the more waves that get there, the more points players earn. But that's tricky. The atom-waves slosh around, often high enough to splash out of the curve and disappear.

As levels advance, the atomic waves become less predictable: It's harder to tell where they'll move. Other quantum phenomena come into play, such as tunneling, which is the probability that a particle will pass through a solid barrier. On screen, that means the waves might vanish from one curve—and show up in another.

Quantum mechanics may be among the strangest and most abstruse subject matters in science. Its fundamental ideas are fussy, counterintuitive, and difficult to explain to the uninitiated. But Quantum Moves suggests there's a way for amateurs to learn about those big ideas without struggling through years of formalism and equations. And it's far from the only game with an ambitious outreach agenda.

Strange Games

Jacob Sherson, the quantum physicist behind Quantum Moves, was inspired to create the game while



In one level of the game Quantum Moves, called "Bring Home Water," players must use a laser (round marker on the left) to pick up atoms (light purple areas inside the valleys) and deposit them in the trap (vertical purple strip). Users drag the valleys toward the trap and deposit as much of the atom as possible. Image courtesy of Scienceathome.org.

Students at Aarhus Tech, a technical secondary and vocational school in Denmark, test the game Quantum Moves during class in 2015. Image courtesy of Scienceathome.org.

riding his bike to work at Aarhus University, in Denmark, where he works on quantum computers. Like his commute, the game's problem hinges on optimizing the best route from point A to point B. The problem of moving atoms has implications for Sherson's work, because the machines need to shuttle atoms without disrupting their fragile quantum states. Sherson sees his own work as a sort of game in which the goal is to unlock the secrets of particle behavior. Why shouldn't everyone else?

Quantum Moves has two purposes, he says: It introduces players to the strangeness of the quantum realm without any brutal equations, and it provides a way to crowd source novel strategies for moving atoms around based on how the atoms moved in the most successful game plays. Sherson says computer algorithms that optimize these processes often miss some of the strategies that human players use.

After studying the strategies of about 12,000 game plays, executed by 300 players, Sherson reported that the human atom-moving trajectories were at least as efficient as those generated by numerical methods, which analyzed 100,000 times more game plays. Sherson and his team were then inspired to develop a computer–human hybrid algorithm that used the top 70% of player solutions as a starting point. That strategy revealed new, even more efficient approaches to optimization (1). Sherson calls his game development approach "research-enabling, game-based education."

The counter-intuitive nature of quantum mechanics has spurred games in the classroom as well. One, called Particle in a Box, developed by an interdisciplinary team at the Georgia Institute of Technology, in Atlanta, GA, aims to elucidate the formal quantum mechanics equations undergraduates study in class. The video game has players scramble through a miniaturized obstacle course governed by quantum rules rather than classical ones. To avoid being hit by particles, for example, players have to use the probability wave function to anticipate where the particles are likely to be found. In another online game, called Quantum Minigolf, players try to hit a ball in a hole, but the ball follows quantum rules. Multiple copies of the ball may appear at the same time, or it might vanish in one place and appear in another. Yet another online game, called "The Quantum Game with Photons," was developed by Piotr Migdał, a data scientist in Warsaw, Poland. It has individual players solve puzzles by assembling arrays of single-photon sources, mirrors, interferometers, and beam splitters in virtual experiments that reveal the probabilistic nature of fundamental particles. The object is to guide photons to a sensor—but that becomes increasingly difficult because more obstacles appear and the particles may change their behavior.

Designer Difficulties

Sometimes the physics is the easy part. Sherson says he found the game design more difficult than the science behind it. And if no one plays a game, what's the point? His first attempt at Quantum Moves was a disaster. "I thought people would be happy to help out with the development process, and crowds would be happy to play non-engaging games," he says. He'd seen people play popular computer versions of solitaire, where players only had to click a button and all the cards would fly to the right piles. It required little work or thought on the players' part. And he didn't worry too much about his game's appearance.

Sherson enlisted a few dozen people to try the game. Only about 10% could even open the custom software package, he says. Of those, only a few even tried. No one finished. "It was failing miserably," he says. The game proved to be as inscrutable as the ideas it was trying to present. So Sherson enlisted professional game designers, who helped him change Quantum Moves into a game that people wanted to play. They taught him about what he calls "the art of the puzzle" and the difficulty of coding fun. They added high scores and increasing difficulty; those scores and levels became a kind of epic mission for players. The formalism of quantum mechanics, he learned, was less important than emphasizing the most astonishing implications.

"You have to create a sort of atmosphere of personal gratification and reward that keeps them engaged in the process as long as possible," he says. Now, hundreds of thousands of people have played Quantum Moves. Players often tell him about their novel solutions to the most difficult puzzles. In 2016, he heard from a German taxi driver with a ninth-grade science education. "He had reformulated the whole process of quantum tunneling," Sherson says, but using words and processes he could understand, rather than quantum theory jargon.

Recruiting Players

Any game has to reach its audience—and some have found innovative ways to make that happen. In 2015 during a break from a conference in Lausanne, Switzerland, physicist Paul Kwiat found game-making inspiration while participating in an escape room—a type of interactive physical game in which participants are locked in a room and work together to solve a mystery and escape. They find hidden clues and solve difficult puzzles. The storyline for the one in Lausanne went like this: Sherlock Holmes had been captured by his arch-nemesis, Moriarty, and Kwiat and his team, assigned the roles of criminal investigators, had 1 hour to get out alive. "I immediately had the sense that we could do a fun one based on physics phenomena," says Kwiat, who studies quantum optics at the University of Illinois at Urbana-Champaign.

So Kwiat did: With help from fellow physicists and undergraduates, Kwiat hatched a physics-themed life-size escape room. Participants would have to figure out what happened to Professor Schrödenberg, a fictional physicist who disappeared while researching a quantum computer that worked at room temperature. (Most approaches to quantum computing require a computing environment near absolute zero.) Also, the computer could break any digital encryption code. The subject is close to Kwiat's own interests: He works on ways to manipulate entangled photons, which could be used to develop unbreakable digital encryption schemes and quantum networks (2).

Some of the puzzles in LabEscape, which opened at Lincoln Square Mall in Urbana, IL, in January 2017, rely on physics ideas. The solutions hinge on participants' use of diffraction gratings, infrared sensors, and other tools they have to read "found" documents to learn about refraction indices and the ability of smartphones to image things the eyes can't see. However, simplified directions for using those tools, and where to find the information, are also built into the room as notes from the physicist. Participants are led through experiments as the story progresses.

Although aimed at a general audience, participants can't escape without interacting with the physics in some way. The idea, Kwiat says, "was to have people exposed to general ideas about quantum computing and quantum information." During a briefing after the game, the scientists lead the participants through a lesson of the real physics behind the escape room. "I do suspect we're getting them interested," Kwiat says.

Beyond Quantum

Quantum mechanics may be a prime candidate for educational gaming. But games can serve to teach difficult ideas in an array of science fields.

Microbiologist David Coil, at the University of California, Davis, spent 2 years creating Gut Check: The Microbiome Game, which was released in September 2016. Players move along an intestine-shaped path on the game board, giving bacterial and fungal infections to each other—including botulism and the plague—and guarding against incoming infections with protective germs. Antibiotics wipe out good and bad bacteria alike; the "fecal transplant" card can wipe out a *Clostridium difficile* infection, but it also results in the loss of general health.

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> **—David Coil**

"As someone who plays a lot of games, I envisioned that people might be willing and interested to play a game and also learn from it," Coil says. He'd hoped it would appeal to gamers who might learn some microbiology; instead, it's mostly become an educational tool by biologists and teachers who use it in their classrooms.

A game doesn't have to be only a teaching tool; Sherson says games offer a way to explore a new way of thinking. "Quantum Moves doesn't focus on increasing a person's understanding of the details of quantum physics," he says. Instead, they learn the process of thinking about quantum oddities. "They merge their everyday experience and intuition with these small, strange quantum effects."

1 Sørensen JJ, et al. (2016) Exploring the quantum speed limit with computer games. *Nature* 532:210–213.
2 Ornes S (2017) News Feature: Code wars. *Proc Natl Acad Sci USA* 114:2784–2787.