BRIEF

Adventures in Quander: A QIS Video Game for Secondary Learners

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The National Quantum Initiative (NQI) Act emphasizes the importance of meeting the demands of the rapidly growing quantum information science (QIS) industry (H.R.6227, 2018). The first priority listed in the act is "to expand the number of researchers, educators, and students with training in quantum information science and technology to develop a workforce pipeline" (H.R.6227, 2018). QIS leverages quantum mechanical effects for applications in computing, sensing, and communication. Quantum mechanical effects are often first introduced in undergraduate physics, computer science, or chemistry courses and requires extensive prerequisite knowledge in those fields.

This can be a barrier for those interested in QIS, which can pose an issue to expanding the QIS workforce with diverse talent as women and people of color are less likely to pursue a higher degree in a STEM field

(National Science Board 2018). With upper-level STEM courses being a gateway into QIS, women and other underrepresented populations in STEM could be left behind just as the field is beginning to take off.

To make QIS more accessible, we developed five connected online games called Quander that introduce foundational QIS concepts without the traditional high-barrier prerequisites. This brief highlights the design choices of Quander, describes one game's QIS connections, and offers recommendations to educators seeking to use the games.

Quander Design

The primary goal of the Quander games is to introduce QIS concepts in a way that is fun and accessible to young learners who may otherwise not have the opportunity to engage with such concepts. The games do not teach players technical physics, mathematics, or computer science, but rather introduce foundational QIS topics on a conceptual level.

We specifically wanted the games to appeal to young girls. Research in game design and gameplay found that girls tend to play puzzle-style games at a higher rate than other styles of games (Bonnano and Kommers 2005) and are more likely to play games that have pleasing aesthetics and a clear narrative (Zheng and Liu 2019). Knowing this, all five games were designed to be puzzle-style games featuring whimsical characters (see Figure 1).

FIGURE 1. CHARACTERS IN QUANDER INCLUDE SUPERNATURAL AND ANIMAL FRIENDS.

QIS in the Quander Games

The Quander games address eight fundamental concepts related to QIS outlined in Key Concepts for Future QIS Learners (see link in References) and listed in Table 1 (Edwards 2020). Instead of being directly explained, the educational content in Quander is integrated into the mechanics of each minigame and the reward system. The rewards appear as collectable cards that explicitly detail the connections between the games and QIS concepts. Each game focuses on a subset of the Key Concepts (see Table 1; *Key Concept 1, a definition of Quantum Information Science, is omitted in Table 1, as all the games were designed to reflect multiple QIS concepts*). One of the games, Qupcakery, is described in greater detail below.

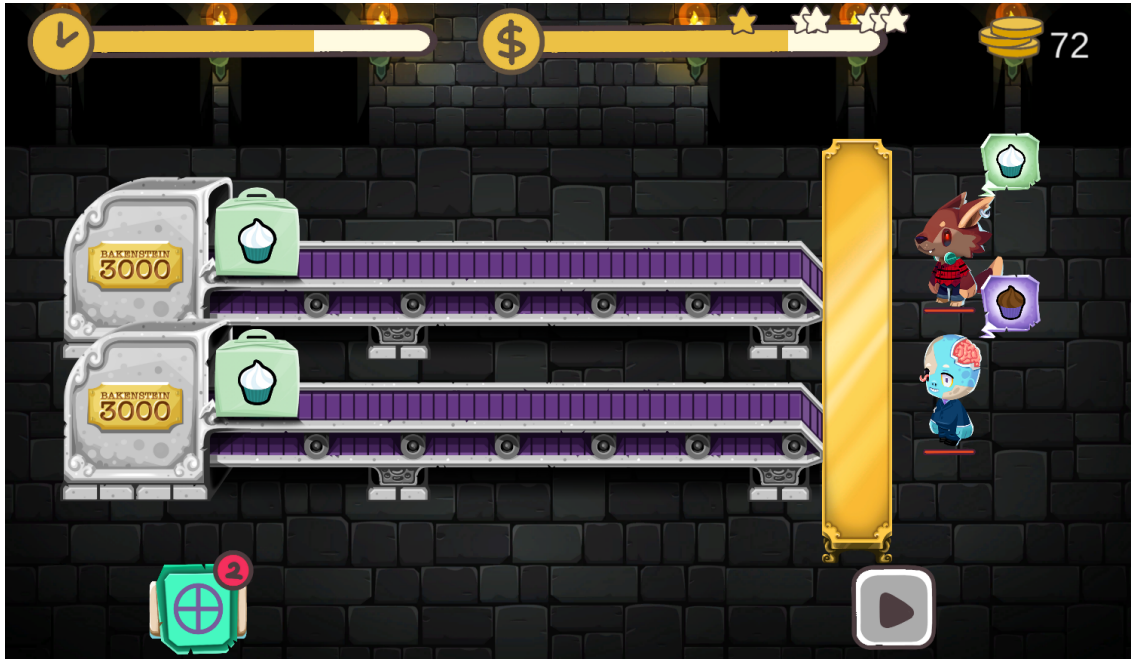
Qupcakery

Qupcakery uses qupcakes (quantum cupcakes) and their flavors as a metaphor for the relationship between qubits and their states and demonstrates how quantum gates affect qubits. In Qupcakery, qupcakes represent *qubits*, the fundamental units of information in a quantum system, much like a bit in a classical computer. While bits are either a "0" or a "1," a qubit exists in a *superposition*, or combination, of both *states* at the same time. When a qubit is *measured*, its state is either only "0" or only "1" and is no longer in superposition. The connection between qupcakes and qubits is made explicit to the player in a reward card (see Figure 2).

FIGURE 2. EDUCATIONAL REWARD CARD CONNECTING QUPCAKERY QUPCAKES TO QUBITS

The goal of Qupcakery is to deliver the correct order to customers. To do this, players place cooking gadgets on conveyor belts to change the flavors of the qupcakes. The cooking gadgets represent quantum gates. *Gates* are operations that are performed on qubits to alter their states. For example, in Figure 3 the werewolf wants a vanilla qupcake and the zombie wants chocolate; however, vanilla qupcakes are heading toward both customers. A NOT gate, which changes the flavor of the qupcake between chocolate and vanilla, can be moved onto the bottom conveyor belt to satisfy the zombie.

FIGURE 3. EXAMPLE QUPCAKERY LEVEL.



Later levels introduce gates that require conditions and create mystery boxes (see Figure 4).

FIGURE 4. COOKING GADGET INTRODUCED IN LEVEL 8 REQUIRES CONDITIONS TO OPERATE CORRECTLY. THE CNOT GATE REQUIRES A CHOCOLATE QUPCAKE ON TOP TO CHANGE THE FLAVOR OF THE QUPCAKE ON THE BOTTOM.

Formal Classroom Connections

Over 100 teachers used the Quander games with facilitation guides in celebration of World Quantum Day 2022. The facilitation guides provide connections to the *Next Generation Science Standards (NGSS)* and *Common Core* mathematics standards. Table 2 connects QIS Key Concepts, *NGSS,* and *Common Core Standards*. Key Concept 2 says, "A quantum state is a mathematical representation of a physical system, such as an atom…." Key Concept 2 relates to CCSS HS.N.VM.1 because quantum states are represented by vectors in an abstract space. Additionally, quantum states represent information about physical systems, like photons, which relates to *NGSS* HS-PS4-3.

TABLE 2. CONNECTIONS BETWEEN KEY CONCEPTS FOR QIS LEARNERS, COMMON CORE MATHEMATICS STANDARDS, AND NEXT GENERATION SCIENCE STANDARDS.

QIS Key Concepts	Common Core Mathematics Standards	Next Generation Science Standards
1: Quantum Information Science		
2: Quantum State	HS.N.VM.1 HS.N.VM.5 HS.N.VM.5.b HS.S.MD.3 HS.S.CP.2 HS.N.VM.11 HS.N.CN.1 HS.N.CN.2	HS-PS1-1 HS-PS1-2 HS-PS1-3 HS-PS1-4 HS-PS1-5 HS-PS4-3
3: Measurement	7.SP.6 HS.S.IC	1-PS4-3 HS-PS2-2 HS-PS2-5 HS-PS2-6 HS-PS4-1 HS-PS4-3
4: Quantum Bit (Qubit)	7.SP.5 HS.S.CP.8 HS.S.CP.9 HS.S.CP.2	1-PS4-3 HS-PS1-1 HS-PS1-4 HS-PS2-5 HS-PS2-6 HS-PS4-2
5: Entanglement		
6: Coherence		HS-PS1-5 HS-PS4-3
7: Quantum Computers	HS.S.CP.9 HS.F.LE.3 HS.F.LE.3	HS-PS1-1 HS-PS1-4 HS-PS2-6
8: Quantum Communication		
9: Quantum Sensing		

Informal Applications

A summer camp for students 12–14 years old that focused on QIS topics used Quander games to prompt discussions about QIS fundamentals. Many students commented that Quander was their favorite part of the camp. In playtesting with older students, participants reported that “the games and cards are so adorable,” which was a motivating factor to continue engaging with QIS. The games have also been used as an attraction at science festivals and county fairs. Visitors at these events spend time interacting with the games and facilitators who help scaffold QIS learning.

Advice for educators seeking to bring QIS learning experiences to their students

For educators wishing to bring QIS learning to their students through the Quander games, we offer the following advice:

1. Exposure to QIS is more important than teaching the intricacies of QIS. Students will not develop a detailed understanding of quantum computing through playing. However, being familiar with quantum ideas will help them become a more quantum-literate consumer as information about quantum technologies becomes more prevalent in media.
2. You don't need to know everything about quantum to start a conversation with your students. Quantum computing is a complex and evolving field.
3. The most important part of playing the games is to have fun! If the QIS industry is going to grow, we need passionate young learners leading the way.

Conclusion

With Quander, students are exposed to concepts that can build curiosity in QIS in a playful way. The potential that the Quander games provide can develop opportunities for students to meaningfully explore the rapidly expanding field. The Quander games and educator guides can be found online at https://q12education.org/quantime and https://www.canonlab.org/quander to be used in celebration of World Quantum Day on April 14, 2023.

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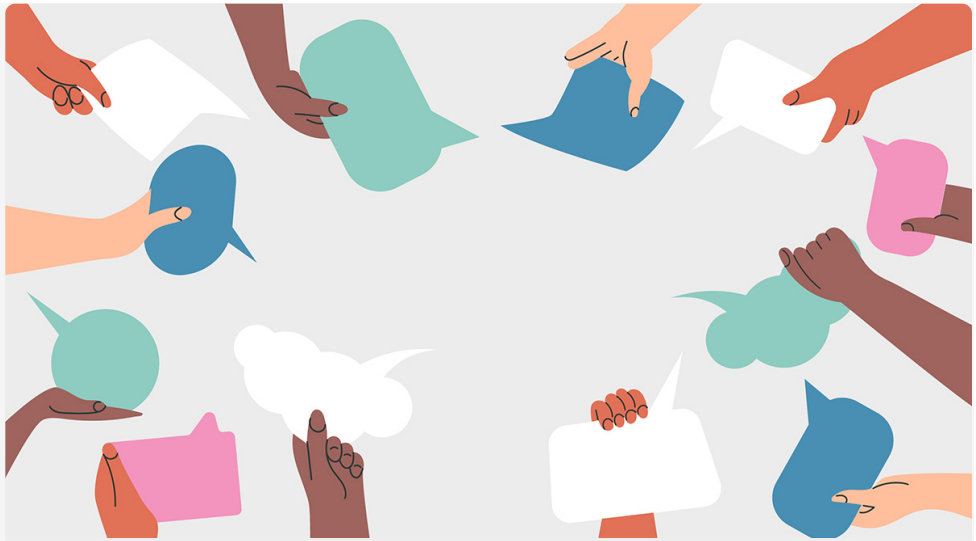

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