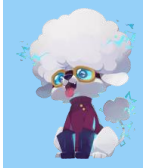
Quander Games: QueueBits

A Connect-4 Style game with a Quantum Twist!



1 Player

Ages 10+

45-60 minutes

Learning Goals

- Understand that working with data in superposition affects strategy.
- Understand that the timing of measurement affects strategy.

Quantum Computing Connection

Quantum computers rely on qubits that are in a superposition of multiple states. Each State has a probability of being measured. You don't know ahead of time which state you will get upon measurement. This affects how quantum programs are designed.

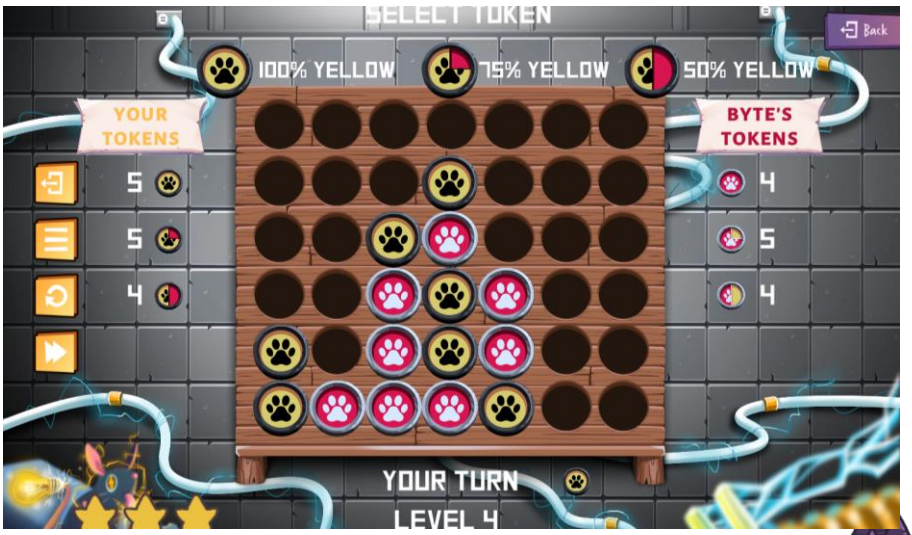
Game Overview

In QueueBits, players explore **probability**, **superposition**, and **measurement**. Players will compete against a computer in a Connect 4-style game that gradually introduces quantum twists.

Players choose from their set of tokens, which have differing probabilities of being measured as yellow: 100%, 75%, or 50%.

Measuring the token "collapses" the token's superposition, meaning that the token goes from having a certain probability of being yellow, to fully being either yellow or red (the opponent's color). Measurement occurs at different points in the game play depending on the level. The options are either automatically when the token is placed, automatically in the order they were placed once the whole board is filled, or manually one at a time when the whole board is filled.

In this game, the tokens represent **qubits**, while the token's color represents the **state** of the qubit. How and when the tokens are **measured** changes the strategy of the game.



Background Knowledge for Facilitators

Superposition: Quantum objects can exhibit superposition, where they can be more than one thing at once. In quantum computing, quantum bits (qubits) can exist in multiple states at the same time. In classical computing, bits have one of two values, either “0” or “1”. A qubit, however, can exist as a combination of both “0 “and “1”.

Measurement: Usually when something is measured, it is the same before and after we measure it. If you measure the length of a book using a ruler, the book is the same before and after measurement. Sometimes, however, measurement can affect the thing we are measuring. For example, we might want to know how many licks it takes to get to the center of a Tootsie Pop; licking the Tootsie Pop until you get to the center means the Tootsie Pop changes as we measure it. Similarly, measurement affects qubits. When you measure a qubit, it changes from being a superposition of “0 “and “1” to being only “0” or only “1” like a classical bit.

Molly’s Challenge:

What does Molly have to do to retrieve all of Tangle’s quantum computer parts back from the Quander villagers?

Guiding Question:

How do probability and measurement affect the outcome of Molly and Tangle winning a QueueBits tournament against Byte?

Engage

1. Begin by telling your students that they will be playing a game that introduces concepts critical to quantum computing, like **superposition** and **measurement**.
2. Start by asking students questions about the following concepts:
    a. Has anyone heard of the term superposition?
    b. What comes to your mind when you hear the word superposition?
    c. What do you think measurement means?
    d. What are some things you have measured? How did you measure it?

Engage cont.

3. Then, ask students if they have ever played the game Connect-4
    a. Review the rules of Connect-4
        i. Two players compete against each other
        ii. Player take turns dropping a colored token into a grid
        iii. The first player who gets 4 tokens in a row, column, or diagonal wins

Explore

1. Give the students ~5 minutes to play Levels 1 and 2 of Queuebits.
    a. Once the timer is up, give students 5 minutes to discuss the following questions:
        i. Did you win your match?
            (Student answers may vary)
        ii. Did you think the levels were difficult?
            (Student answers may vary)
        iii. What did you notice about the levels? (tokens and patterns)
            (Student answers may vary)
2. Next, give the students ~10 minutes to play Levels 3-5.
    a. Once the timer is up, give students 10 minutes to discuss the following questions:
        i. Which levels did you win? Which levels did you lose?
            (Student answers may vary)
        ii. Were these levels more challenging than previous levels? How so?
            (Student answers may vary)
        iii. **(Referencing the Terms; page 6)** What do you think the tokens represent?
            (Answer: Qubits)
        iv. **(Referencing the Terms)** What were the token probabilities in Levels 3, 4, and 5? How did these tokens change the game?
            (See page 12; Student answers may vary)

Explore cont.

v. **(Referencing the Terms)** Where do you think superposition is being represented in the game?

(Answer: The tokens being a combination of red and yellow)

vi. **(Referencing the Terms)** What do you think is being measured? When is it being measured?

(Answer: Tokens are being measured when they are placed in the grid)

3. Next, give students ~10 minutes to play Levels 6-10.
   a. Once the timer is up, give students 5 minutes to discuss the following questions:
      i. Which levels did you win? Which did you lose?

      (Student answers may vary)

      ii. Were these levels more challenging than previous levels? How so?

      (Student answers may vary)

      iii. **(Referencing the Terms)** What do you think is being measured? When is it being measured?

      (Tokens are being measured at the end of the level when the board is full. Tokens are measured one at a time in the order they were placed).

4. Next, give students 1~10 minutes to play Levels 11-15.
   a. Once the timer is up, give students 5 minutes to discus the following questions:

      i. Which levels did you win? Which did you lose?

      (Student answers may vary)

      ii. Were these levels more challenging than previous levels? How so?

      (Student answers may vary)

      iii. **(Referencing the Terms)** When are the tokens being measured?

      (Tokens are being measured at the end of the level when the board is full. Tokens are measured one at a time by clicking on them).

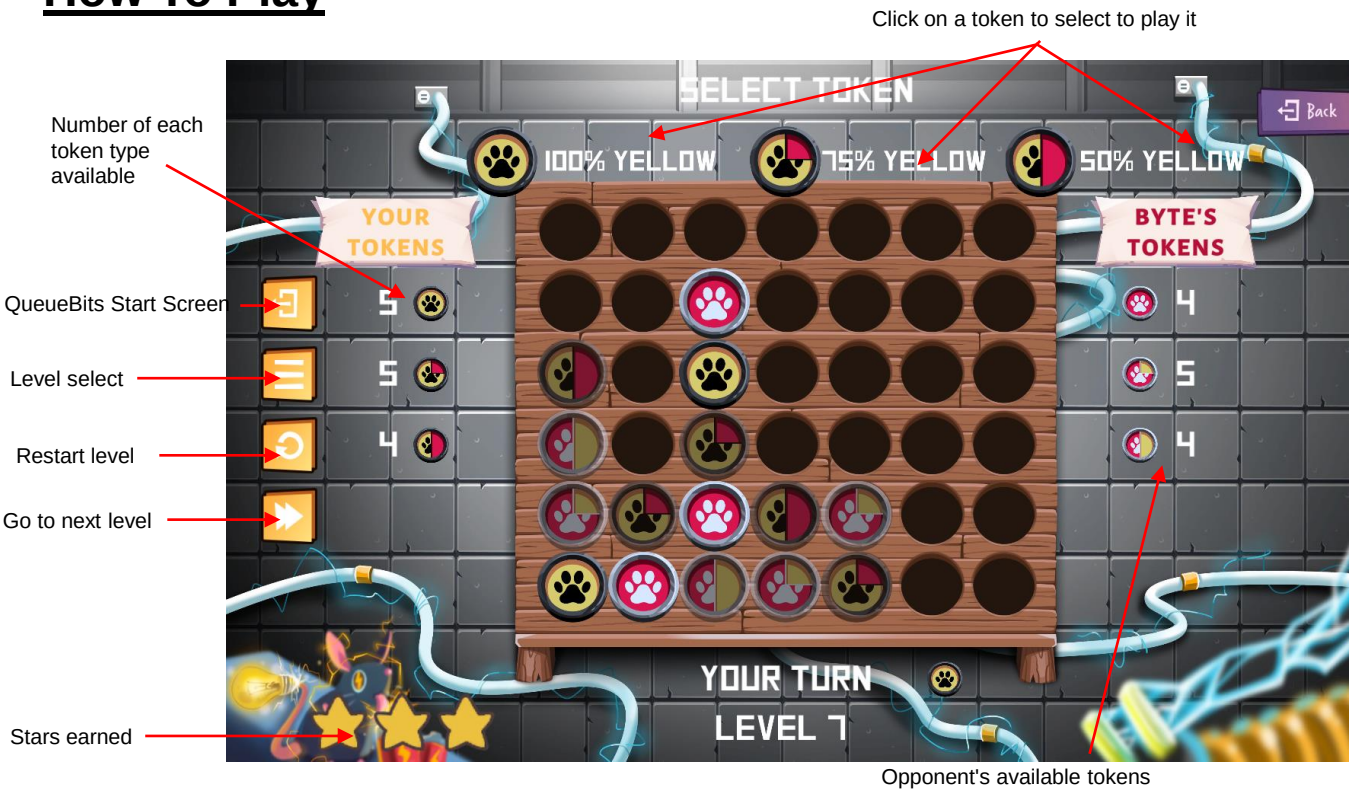
Explain

1. Give students ~5 minutes to explore the Reward Area (See page 6) and review the reward cards they earned while playing the game.
    a. Cards are double-sided. Students must click on the enlarged card (displayed on the right side of the screen to flip it).
2. Have students write a 3-5 sentence response to the guiding question:
    a. Guiding Question: How do probability and measurement affect the outcome of Molly and Tangle winning a QueueBits tournament against Byte?
    b. Word Bank for students to use in their responses: Qubits, Tokens, Probability, Superposition, Measurement, Byte, Molly, Tangle.

Quantum Information Science Connections

Concept	Definition	In-Game Representation
Probability	Probability lets us make predictions. So, if you flip a coin, there is a 50% probability it will land on either heads or tails. In quantum, you can predict the likelihood of something happening, but can't know for certain until you measure it	Players choose from their set of tokens which includes tokens that have 100%, 75%, or 50% probability of being measured as yellow.
Superposition	Objects exist in a state of superposition when they can be more than one thing at once. The quantum information can be a combination of both a 0 and a 1 at the same time, but also neither 0 nor 1 at the same time.	The tokens are solid yellow for the player and red for Byte. Tokens can exist in a superposition, or combination that represents both colors.
Quantum Bit	The quantum bit, or qubit, is the fundamental unit of quantum information and is encoded in a physical system, such as polarization states of light, energy states of an atom, or spin states of an electron.	Unmeasured tokens represent qubits in superposition.
Measurement	Quantum applications are designed to carefully manipulate fragile quantum systems without observation to increase the probability that the final measurement will provide the intended result.	How and when the token color is decided represents measurement.
Quantum State	A quantum state is a mathematical representation of a physical system, such as an atom, and provides the basis for processing quantum information.	The color of the token represents the quantum state.

How To Play



Characters & World

Molly: The main character of the Quander games. In QueueBits she helps the Tangle play against Byte.

Tangle: Molly's best friend and cat. She keeps falling asleep while playing QueueBits.

Byte: Tangle's neighbor and arch nemesis.

QueueBits game circled in red
Reward Area circled in white

QueueBits Symbols Reference Sheet

100% Yellow Token

This token will always be yellow and does not need to be measured.

75% Yellow Token

This token will be measured as yellow 75% of the time.

50% Yellow Token

This token will be measured as yellow 50% of the time.

100% Red Token

This token will always be red and does not need to be measured.

75% Red Token

This token will be measured as red 75% of the time.

50% Red Token

This token will be measured as red 50% of the time.

Note: Tokens shaded in gray have not been measured yet. Grayed-out tokens are still in superposition. They will be measured once the board is full.

Rewards Cards (Levels 1-6)

Card: Measured Token

Type: Visual Representation

Level Earned: 3

Card: DeeCee Ratton

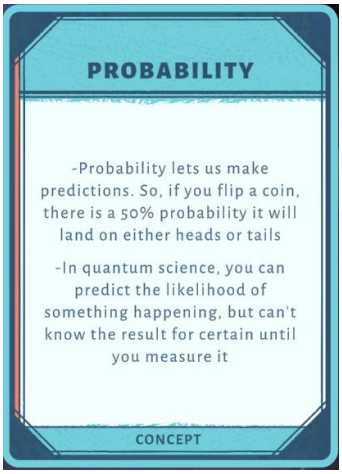
Type: Character

Level Earned: 5

Card: Probability

Type: Character

Level Earned: 6

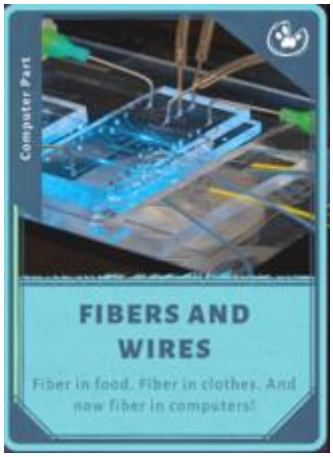


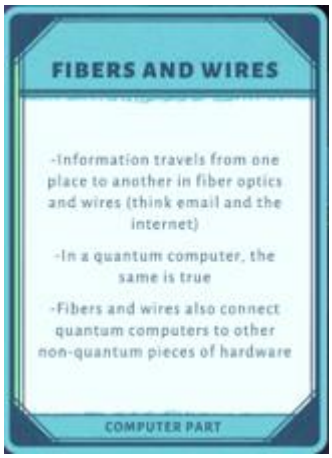
Rewards Cards (Levels 7-12)

Card: Fibers and Wires

Type: Computer Part

Level Earned: 8





Card: Superposition Token

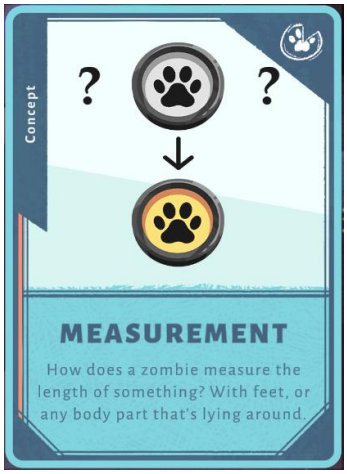
Type: Visual Representation

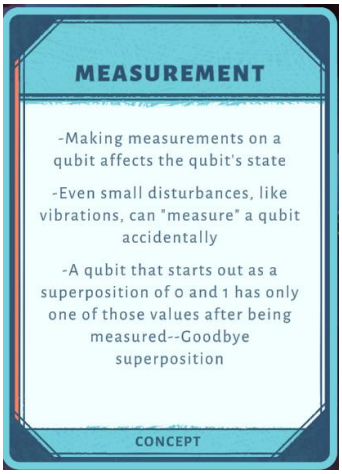
Level Earned: 9

Card: Measurement

Type: Concept

Level Earned: 11





Rewards Cards (Levels 13-15)

Card: Byte

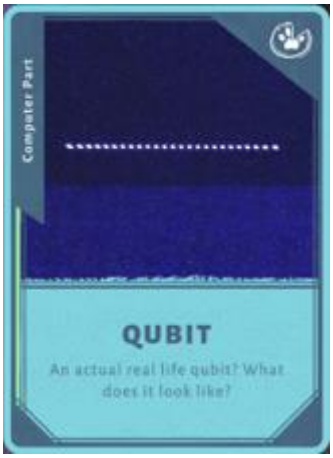
Type: Character

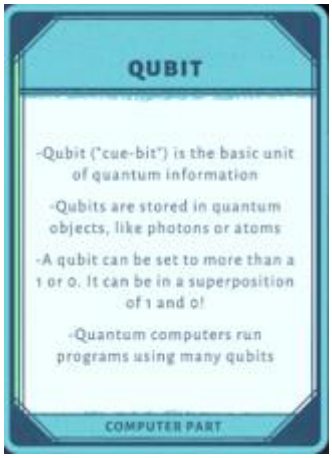
Level Earned: 13

Card: Qubit

Type: Computer Part

Level Earned: 15





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Level Summary

Level	Board Condition	Measurement happens	100%	75%	50%
1	Empty	N/A	21	0	0
2	Empty	N/A	21	0	0
3	Partially filled	Upon placement	7	7	0
4	Partially filled	Upon placement	5	5	4
5	Partially filled	Upon placement	4	4	6
6	Partially filled	Automatically at end	7	7	0
7	Partially filled	Automatically at end	5	5	4
8	Partially filled	Automatically at end	4	6	4
9	Partially filled	Automatically at end	4	4	6
10	Partially filled	Automatically at end	2	6	6
11	Partially filled	Manually at end	7	7	0
12	Partially filled	Manually at end	5	5	4
13	Partially filled	Manually at end	4	5	4
14	Partially filled	Manually at end	4	4	6
15	Partially filled	Manually at end	2	6	6