Quander Games: Qupcakery

Deliver the correct qupcake order by using quantum gates!

1 Player

Ages 10+

2 hours

Learning Goals

Understand that quantum gates can do operations on qubits.

Understand how to use quantum gates to do quantum operations.

Quantum Computing Connection

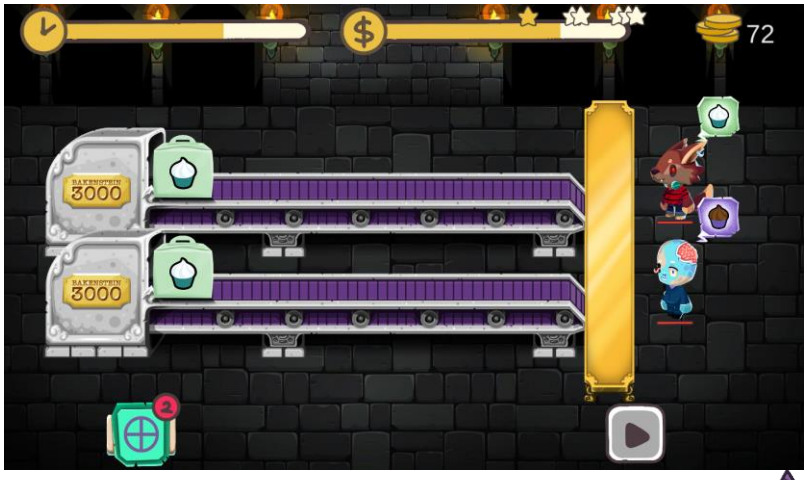
Current quantum computers perform operations on quantum bits (qubits). A quantum gate, also s a quantum operation, changes the state of one or more qubits. These operations are similar to more familiar arithmetic operations (+, -, × ,÷).

Game Overview

In Qupcakery, the player is tasked with helping a forgetful chef deliver customers their correct order. Players accomplish this by placing quantum cooking gadgets on conveyor belts, which manipulate the flavor of qupcakes (quantum cupcakes) before they reach the customer.

Qupcakery uses qupcake flavors to symbolize the different possible **states** of a qubit. Each cooking gadget represents a type of **quantum operation**. Students combine the gadgets to create the customer's order. The orders come in boxes whose labels indicate the possible flavor inside.

In Qupcakery, a qupcake's box represents a **qubit** inside of a quantum computer. Qubits are the fundamental units of information in a quantum system, analogous to a bit in a classical computer. While bits are either "0" or "1", qubits can exist in a **superposition**, or combination of both values at the same time. When a qubit is measured, its state is either only "0" or only "1" and is no longer in superposition. In the game, **measurement** is represented by the customers opening the qupcake box.



Background Knowledge for Facilitators

Operations/Gates: Classical computers are built to mimic how humans perform arithmetic calculations. Quantum computers are designed to use quantum properties like superposition and entanglement. They are more powerful than classical computers when performing certain tasks. However, they are unsuitable for most tasks. In order to understand how superposition and entanglement are used in quantum computers, we must first understand the basic operations in quantum computing: NOT, SWAP, CNOT, H, Z (see page 8-10).

Note: Quantum operations are often called “gates”

Molly’s Challenge:

What does Molly have to do to help Chef Scatter make enough money so that he can purchase his own quantum computer parts and return the parts he is using to Tangle?

Guiding Question:

How do quantum operations, superposition, measurement, and entanglement affect the flavor of the qupcakes in the game?

Engage

1. Begin by telling your students that they will be playing a game that introduces concepts critical to quantum computing, like **operations**, **qubits, measurement**, **superposition**, and **entanglement.**
2. Start by asking students questions about the following concepts:
    a. Has anyone heard of the term qubit?
    b. What comes to your mind when you hear the word qubit?
    c. What do you think operation means?
    d. Have you heard of the order of operation in math class? What do operations do to numbers?

Explore

1. Give the students ~5 minutes to play Levels 1 and 2 of Qupcakery.
    a. Once the timer is up, give students 5 minutes to discuss the following questions:
        i. How often did you give the customers the correct order?
            (Student answers may vary)
        ii. What did you notice about the levels? (flavors, gadgets, and patterns)
            (Student answers may vary)
        iii. **(Referencing the Terms; See page 7)** Describe the operation that the Flavor Inverter does to qupcakes.
            (Answer: changes cupcake flavors between chocolate and vanilla; See page 9)
        iv. **(Referencing the Terms)** What do you think the qupcakes in boxes represent?
            (Answer: Qubits)
        v. **(Referencing the Terms)** What do you think the flavor of the qupcakes represent?
            (Answer: Quantum states)
2. Next, give the students ~10 minutes to play Levels 3-7.
    a. Once the timer is up, give students 5 minutes to discuss the following questions:
        i. Which levels did you get 3 stars on? 2 stars? 1 star?
            (Student answers may vary)
        ii. Were these levels more challenging than previous levels? How so?
            (Student answers may vary)
        iii. (**Referencing the Terms)** Describe the operation that the Flavor Swapper does to qupcakes.
            (Answer: swaps the flavor of cupcakes on two adjacent belts; See page 9)

Explore cont.

3. Next, give the students ~10 minutes to play Levels 8-12.
    a. Once the timer is up, give students 5 minutes to discuss the following questions:
        i. Which levels did you get 3 stars on? 2 stars? 1 star?
            (Student answers may vary)
        ii. Were these levels more challenging than previous levels? How so?
            (Student answers may vary)
        iii. **(Referencing the terms)** Describe the operation that the Chocolate-Powered Flavor Inverter does to qupcakes?
            (Answer: If the qupcake that passes through the dot side of the Chocolate-Powered Flavor Inverter is chocolate, then the qupcake that passes through the x side of the gadget is inverted; See page 9)
4. Next, give the students ~5 minutes to play Levels 13-15.
    a. Once the timer is up, give students 10 minutes to discuss the following questions:
        i. Which levels did you get 3 stars on? 2 stars? 1 star?
            (Student answers may vary)
        ii. Were these levels more challenging than previous levels? How so?
            (Student answers may vary)
        iii. **(Referencing the Terms)** Describe the operation the Mystery Wrapper does to qupcakes.
            (Answer: changes a regular qupcake box into a box that has a 50-50 chance of being either flavor; See page 10)
        iv. **(Referencing the Terms)** Where do you think superposition is being represented in the game?
            (Answer: when the boxes go through the Mystery Inverter they are put in a superposition state of both chocolate and vanilla)

Explore cont.

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

(Answer: when you open a qupcake box it is like measuring a qubit)

5. Next, give the students ~10 minutes to play Levels 16-22.
   a. Once the timer is up, give students 10 minutes to discuss the following questions:
      i. Which levels did you get 3 stars on? 2 stars? 1 star?

      (Student answers may vary)

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

      (Student answers may vary)

      iii. **(Referencing the Terms)** Describe the operation that the Mystery Inverter does?

      (Answer: changes a Mystery Box between having a green wrapper and having a purple wrapper; See page 10)

6. Next, give the students ~10 minutes to play Levels 23-27.
   a. Once the timer is up, give students 10 minutes to discuss the following questions:
      i. Which levels did you get 3 stars on? 2 stars? 1 star?

      (Student answers may vary)

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

      (Student answers may vary)

      iii. **(Referencing the Terms)** Describe the operation that the Chocolate-Powered Flavor Inverter does to Mystery Boxes.

      (Answer: When mystery boxes go through the Chocolate Powered Flavor Inverter it creates mystery box pairs; See page 11)

Explore cont.

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

(Answer: When you create a pair of Mystery Boxes the pair of boxes represents a pair of entangled qubits.)

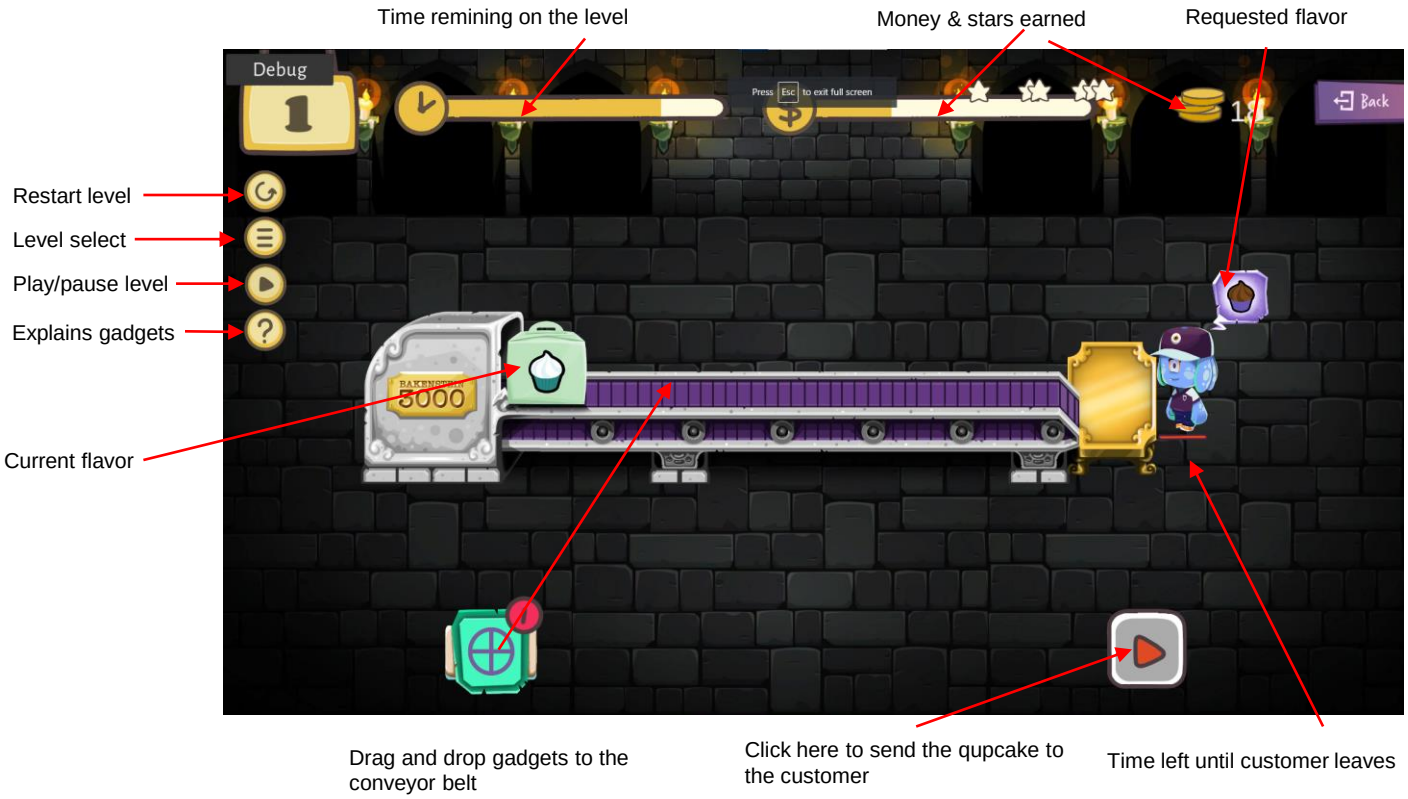
Explain

1. Give students ~5 minutes to explore the Reward Area (See page 8) 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 quantum operations, superposition, measurement, and entanglement affect the flavor of the qupcakes in the game?
    b. Word Bank for students to use in their responses: Qubits, Entanglement, Molly, Chef, Customers, Operations, Boxes, Qupcakes, Gadgets, Measurement.

Quantum Information Science Connections

Concept	Definition	In-Game Representation
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.	Qupcake box designs (vanilla or chocolate) represent quantum states (0 or 1).
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.	Opening the qupcake box to reveal the flavor represents measuring a qubit to determine its state.
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.	Qupcake boxes represent qubits.
Quantum Operations	Quantum operations manipulate qubits to increase the probability of measuring a certain result.	Quantum cooking gadgets represent quantum gates.
Entanglement	Entangled particles share a relationship. Measuring one particle's properties affects the outcome of measurements of the other	A pair of mystery boxes represents two entangled qubits

How To Play



Characters & World

Molly: The main character of the Quander games. In Qupcakery she helps the chef.

Tangle: Molly's best friend and cat. Caused an explosion while building a quantum computer.

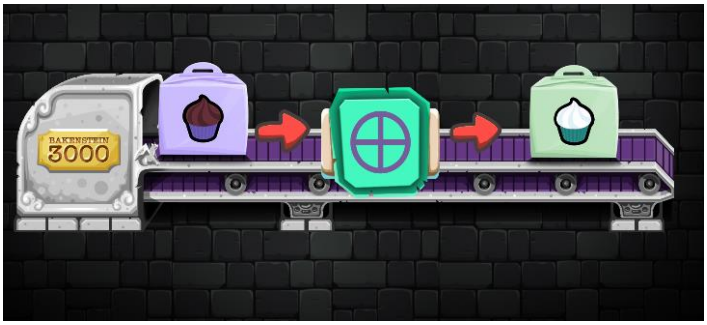
Chef Scatter: A talented but forgetful baker. He uses quantum operations to fix wrong orders.

Qupcakery game circled in red
Reward Area circled in white

Cooking Gadget Reference Sheet

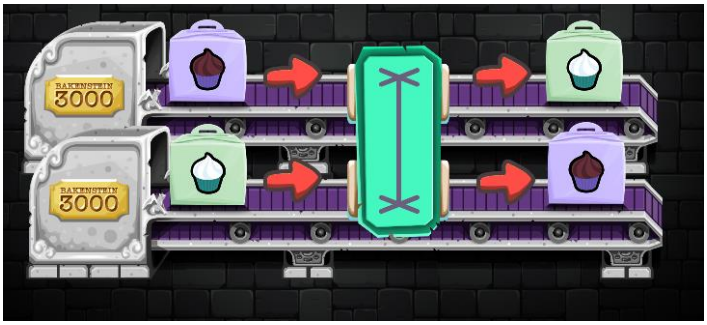
Flavor Inverter/ NOT Gate

Changes chocolate to vanilla OR
Vanilla to chocolate



Flavor Swapper/SWAP Gate

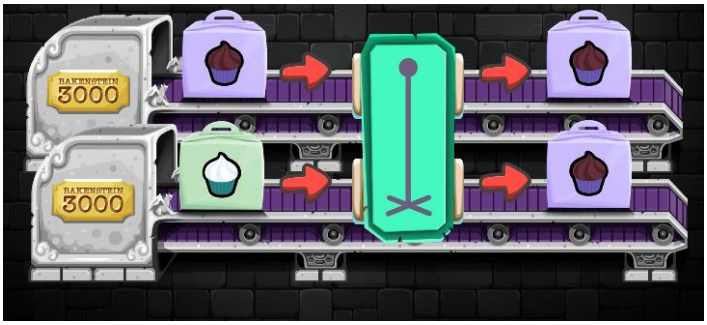
Swaps the flavor of two cupcakes on adjacent conveyor belts

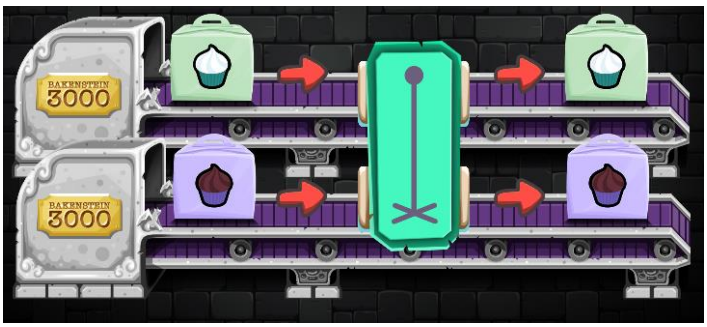


Chocolate-Powered Flavor Inverter/ CNOT Gate

If a chocolate cupcake passes through the side of the gate that has the dot, then the cupcake that passes through the x inverts its flavor.

CNOT stands for “controlled NOT”.
If the control cupcake is chocolate, the other cupcake undergoes the NOT operation.





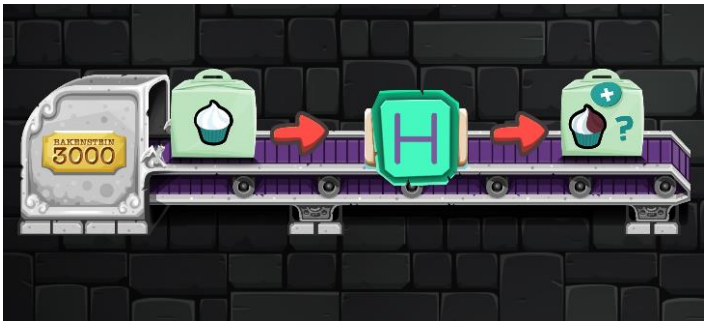
Note: The chocolate-powered flavor inverter can be flipped so the dot is on the bottom by clicking on it after it is placed on a conveyor belt.

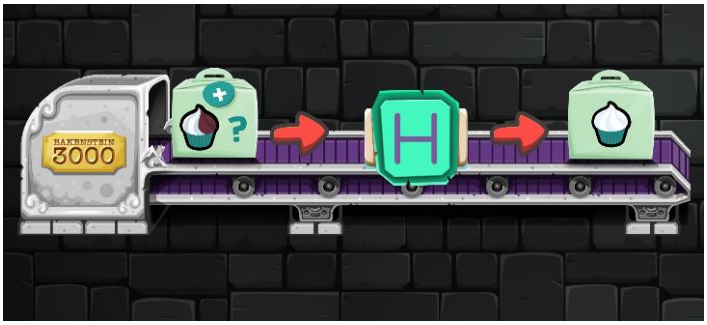
Cooking Gadget Reference Sheet Cont.

Mystery Wrapper/ H Gate

Changes regular cupcake boxes to mystery boxes OR
Changes mystery boxes into regular cupcake boxes

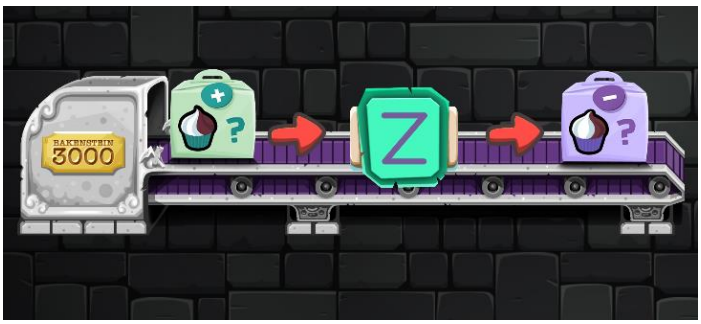
Note: H stands for Hadamard





Mystery Inverter/ Z Gate

Changes chocolate mystery boxes to vanilla mystery boxes OR
Changes vanilla mystery boxes to chocolate mystery boxes



Standard qupcake boxes

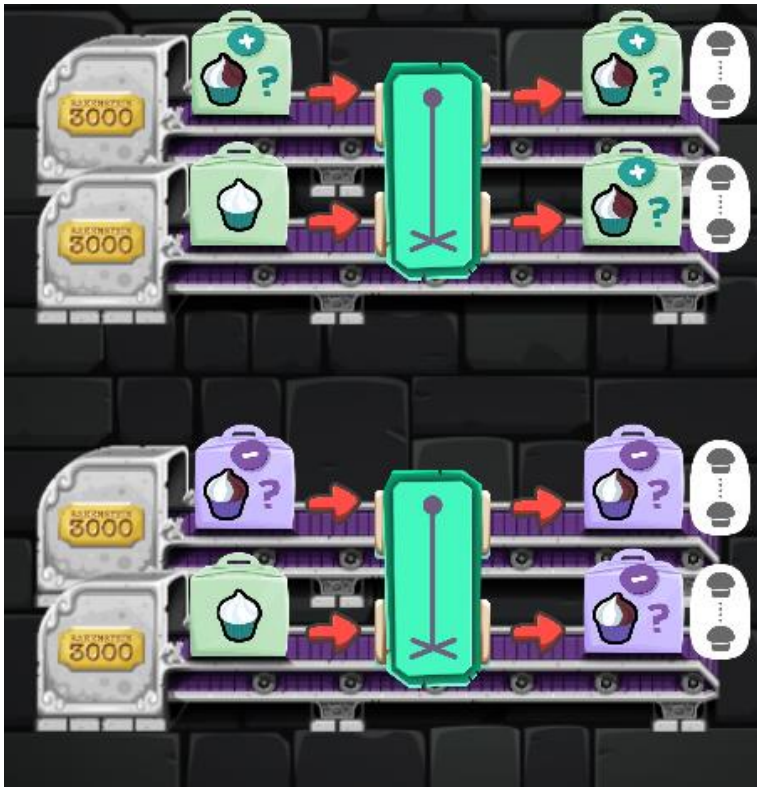
Mystery qupcake boxes (in superposition)

Cooking Gadget Reference Sheet Cont.

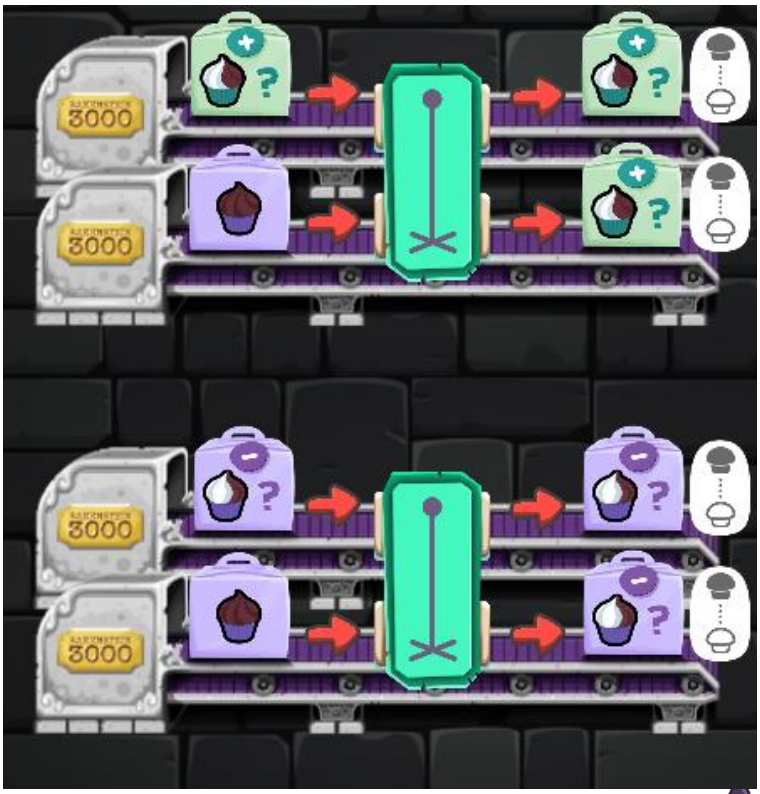
Chocolate-Powered Flavor Inverter with Mystery Boxes

Using the chocolate-powered flavor inverter on a mystery box will create a pair of mystery boxes.

If the mystery boxes are the same color after going through the chocolate-powered flavor inverter, then the pair of mystery boxes will have the same flavor qupcake inside. This is denoted by two linked gray cupcakes.



If the mystery boxes are different colors after going through the chocolate-powered flavor inverter, then the pair of mystery boxes will have one of each flavor qupcake inside. This is denoted by one gray cupcake and one white cupcake linked.

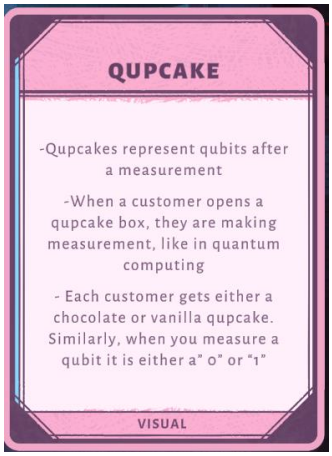


Rewards Cards (Levels 1-9)

Card: Qupcake

Type: Visual Representation

Level Earned: 2



Card: Chef Riley Scatter

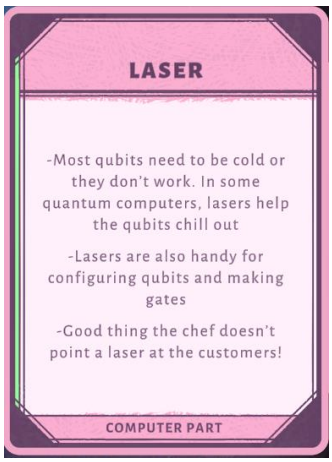
Type: Character

Level Earned: 5

Card: Laser

Type: Computer Part

Level Earned: 9

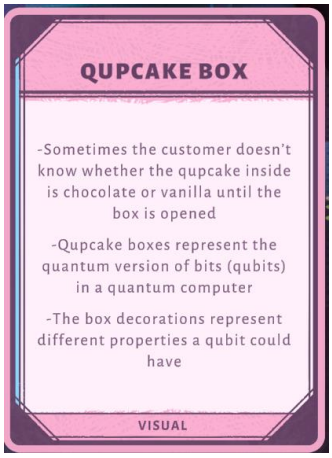


Rewards Cards (Levels 10- 20)

Card: Qupcake Box

Type: Visual Representation

Level Earned: 13



Card: Superposition

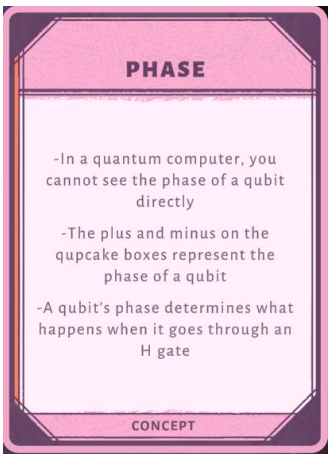
Type: Concept

Level Earned: 15

Card: Phase

Type: Concept

Level Earned: 20



Rewards Cards (Levels 21-27)

Card: Molly Cule

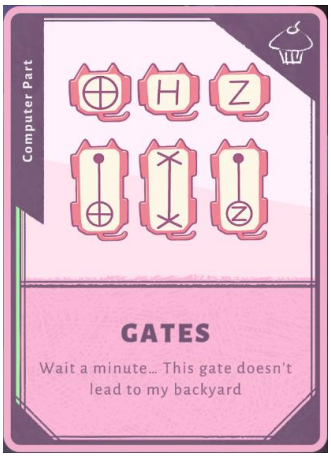
Type: Character

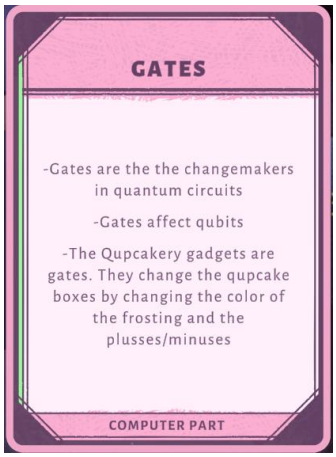
Level Earned: 23

Card: Gates

Type: Computer Part

Level Earned: 27





Level Summary (1-18)

Level	Belts	Gates Available
1	1	NOT x1
2	2	NOT x2
3	2	NOT x2, SWAP x1
4	3	NOT x1, SWAP x1
5	3	NOT x 2, SWAP x1
6	3	NOT x1, SWAP x1
7	3	SWAP x2
8	2	CNOT x1
9	2	CNOT x1
10	2	CNOT x1, SWAP x1
11	3	NOT x1, CNOT x1, SWAP x2
12	3	CNOT x2, SWAP x1
13	1	H x1
14	2	SWAP x1, H x2
15	2	SWAP x1, H x2
16	1	H x1, Z x1
17	2	NOT x1, H x2, Z x2
18	3	SWAP x1, H x3, Z x2

*Only levels 1-13 available for Quantime participants

Level Summary (19-27)

Level	Belts	Gates Available
19	2	SWAP x1, H x2, Z x2
20	2	H x3, Z x2
21	3	NOT x2, H x3, Z x2
22	3	SWAP x1. H x2, Z x1
23	2	NOT x1, CNOT x1, H x1
24	2	NOT x1, CNOT x1, H x1
25	2	NOT x1, CNOT x1, H x1
26	3	NOT x2, CNOT x1, SWAP x1, H x1
27	3	NOT x1, CNOT x1, SWAP x1, H x1, Z x1

*Only levels 1-13 available for Quantime participants

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