EPiQC

50-60 min

13+ years

Quantum "Guess Who?"

A game that explores how quantum algorithms work

Learning Goals

Students will:

- Understand that quantum computers are a new type of computer that uses unique features of quantum particles
- Identify differences between classical and quantum algorithms
- Understand how quantum algorithms speed up computations through "quantum parallelism"

Importance in Quantum Computing

Quantum computers are a new type of computer that can solve certain computational problems faster than any classical computer.

Materials

- ❏ Slide Deck
- ❏ Character Sheet
- ❏ Scissors
- ❏ Pencil
- ❏ Optional: Plastic discs (or other classroom objects) that can be placed over characters when eliminated during game play

Preparation

- Print Character Sheet (THREE copies per pair of students)

Background Knowledge

Quantum computers are a new type of computer that works differently than a classical computer (i.e., an ordinary, non-quantum computer). They will have the ability to solve certain computational problems that are too difficult for classical computers, which will lead to applications that impact society in the areas of privacy, medicine, and scientific research. Quantum computers store and process information in the form of quantum bits (or qubits) rather than bits like a classical computer. An important feature of qubits is that they can exist in a **superposition** of two values, 0 and 1, at the same time.

In this hands-on activity, students will play a game that illustrates how quantum algorithms can speed up computations through a process called **quantum parallelism**. A quantum computer can use quantum gates (or operations) to create a superposition (a combination of multiple quantum states) that allows it to ask multiple questions and compute the answers at the same time. For certain problems, the quantum computer can process the resulting superposition of quantum states to arrive at the solution faster than any classical computer.

Facilitating the Activity

ENGAGE

Introduce students to the game Quantum “Guess Who?,” a two-player game in which each player tries to guess the identity of the other player’s character. It is a modified version of the board game *“Guess Who?”*. Begin with the slide deck.

Part 1 : **Introducing quantum computers**

SLIDE 3: Discuss how modern day computers store information using classical bits (0s and 1s).

SLIDE 4: Quantum computers are a new type of device that uses the unique properties of quantum particles to go beyond the limitations of classical computers.

SLIDE 5: Applications of Quantum Computing

Part 2 : **Introduce oracle-based games**

SLIDE 7: Introduce students to oracle-based games (e.g., Battleship, 20 Questions, Mastermind). Players ask an oracle (other player) questions to gather information to help figure out the secret information.

SLIDE 8: ASK: *“* **What kind of questions can you ask the *‘oracle’* in the game 20 Questions**?” *(Students share examples of typical questions and answers for the game 20 Questions.)*

ASK: “**Do you know any other examples of games based on oracles?**” (For each game mentioned, ask students to share examples of typical questions and answers from the oracles in those games.

Explain to students that in oracle-based games, a player uses the answers they receive from the oracle to figure out the secret information.

ASK: “Think about the games *Battleship* and *20 Questions.* **How can players use the oracle’s answers to figure out the secret information (e.g., the secret location or secret word)?”**

Part 3 : **Classical computing vs Quantum computing**

SLIDE 7: Oracles in Computer Science. ASK: “**How many questions do you need to ask the oracle to solve the problem?”**

SLIDE 8: Classical Computing. ASK: “**How are classical computers and oracle-based games alike/different?**” *(Classical computers can only ask one question at a time and then use the answers to figure out the answer.)*

SLIDE 9: Introduce the concept of superposition. Share that Quantum computers are a new type of computer that uses a feature of quantum particles called superposition to ask questions in ‘parallel’.”

ACTIVITY

Tell students that they are going to play a game called *Quantum “Guess Who?”* in two different modes: (1) like a classical computer; (2) like a quantum computer.

Have students form pairs, and distribute THREE Character Sheets to each pair. If using, distribute plastic discs or other classroom object for students to use when eliminating characters.

The game has two modes: CLASSICAL & QUANTUM. Begin by introducing students to the game play. Then, have students play a few rounds of the game in CLASSICAL mode. After a few rounds, introduce and have students play a few rounds in QUANTUM mode.

Object of the game

Guess the secret character.
Ask your partner (the oracle) ONE question each turn. Use the information that you gather about the secret character to eliminate characters.

Get to know the characters

Look at the 24 characters.
Notice the characteristics that make each character unique (e.g., hair color, clothing attributes).

Game setup (The setup is the same for both CLASSICAL & QUANTUM modes.)

1. Students cut out character cards, if not already cut out.
2. Each pair of students should have THREE Character Sheets:
   - **Secret Character Deck** (one per pair): Cut out one set of character cards; shuffle the cards and place them face down.
   - **Character Grids** (one per student): If using plastic discs to eliminate characters, then a full Character Sheet can be used as a Character Grid. Otherwise, students flip over individual characters to eliminate them during game play. In this case, each student must cut out the characters to form a Character Grid.
3. To begin, each player selects a random card from the Secret Character Deck. This character should be kept secret from the other player.

Game play: CLASSICAL

Players take turns asking questions to the other player (acting as an oracle) to gather information about their partner’s secret character. Players should keep track of how many turns it takes for them to correctly guess their partner’s secret character. For each turn, players can **ASK A QUESTION** or **GUESS THE CHARACTER**:

ASK A QUESTION

1. Ask a “yes/no” question about the other player’s secret character
2. The other player (acting as an oracle) answers with only a “yes” or “no”
3. Based on the oracle’s answer, eliminate characters from the Character Grid by flipping them over or placing a disc over the character.

GUESS THE CHARACTER

1. Guess the secret character.
2. If you guess correctly, then you win the game! If you guess incorrectly, you lose.

Game Play: QUANTUM

Quantum mode changes the way that questions about the secret character are asked and answered by the players. Player 1 starts. Players take turns asking questions to the other player. Players should keep track of how many turns it takes for them to correctly guess their partner’s secret character. For each turn, players can **ASK A QUESTION** or **GUESS THE CHARACTER**:

ASK TWO QUESTIONS

1. Ask TWO “yes/no” questions about the other player’s secret character.

   For example, “Is your character wearing a hat?” and “Is your character facing to the left?”

NOTE: *This is like a quantum computer using quantum gates to create a superposition of two inputs.*

2. The oracle player answers with one of the following replies (depending on how many “yes” answers there are to the two questions):
   - There are 0 “yes” answers.
   - There is 1 “yes” answer.
   - There are 2 “yes” answers.

← ***NOTE:*** *In QUANTUM mode, the oracle does not directly answer each question. Rather, you must think about how to use the information you receive. The oracle only tells the number of “yes” answers. No other information is shared.*

NOTE: *This is like figuring out a way to program a quantum computer to process the output of the oracle.*

3. Use the oracle’s answer to eliminate characters from the character grid by flipping them over or placing a disc over the character.

GUESS THE CHARACTER

1. Guess the secret character.
2. If you guess correctly, then you win the game! If you guess incorrectly, you lose.

DISCUSSION

After the students have played the game in both CLASSICAL & QUANTUM modes a few times, bring the class back together for a discussion.

SLIDE 16: Revisiting CLASSICAL mode:

ASK: “What strategies did you develop to help you to identify the characters more efficiently and win the game in CLASSICAL mode?”

SLIDE 17: Revisiting QUANTUM mode:

ASK: “How did you use the oracle’s answers to figure out the secret character?”
ASK: “What did you do if the oracle said ‘0’ or ‘2’?”
ASK: “What did you do if the oracle said ‘1’?”

SLIDE 18: Compare the two versions of the game:

ASK: “How many turns did it take to win the game in CLASSICAL mode?”
ASK: “How many turns did it take to win the game in QUANTUM mode?”

If students are able to make good use of the oracle’s replies in QUANTUM mode, then winning the game in QUANTUM mode should be faster than in CLASSICAL mode. Explain that this is like using the unique features of quantum computers (e.g., superposition) to solve a problem faster than a classical computer.

SLIDE 18: Connection to Quantum Computing:

Explain that quantum computers use *quantum gates* to create a *superposition,* and this makes it possible for quantum computers to “ask” questions of the oracle in “parallel.” Quantum computers also use *quantum gates* to process the oracle’s replies to figure out the secret information.

Connections to Standards

Next Generation Science Standards

- Crosscutting Concepts: Patterns; Cause & Effect
- Science and Engineering Practices: Using Mathematics & Computational Thinking, Constructing Explanations, Engaging in Argument from Evidence

QIS K-12 Key Concepts

4. 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.

    (4.a) Unlike a classical bit, each qubit can represent information in a **superposition**, or vector sum that incorporates two mutually exclusive quantum states.

7. **Quantum computers**, which use qubits and quantum operations, will solve certain complex computational problems more efficiently than classical computers.

    (7.b) Quantum data can be kept in a superposition of exponentially many classical states during processing, giving quantum computers a significant speed advantage for certain computations such as factoring large numbers (exponential speed-up) and performing searches (quadratic speed- up). However, there is no speed advantage for many other types of computations.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 1730088 and No. 1730449. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Guest designer: Mickey Claffey