

Superposition

Explore how something can be two things at once

Big Ideas

1. Some objects exist in a state called superposition, which means they can be in multiple states at the same time.
2. When you measure an object in superposition, you can measure only one state.

Importance in Quantum Computing

Quantum computers use quantum bits (or qubits) that exist in a state of superposition, such that they are both 0 and 1.



Materials

- “Superposition Examples” slides
- Speakers
- Chart paper
- Sticky notes or index cards
- Sporks* worksheet
- Opaque bag or other opaque container
- 8 Pompoms, marbles, or other small objects, in two colors
- Quarters, 1 per participant
- Modeling clay or play dough

Preparation

- Make sure you can project the slides.
- Make sure you are able to play the audio clips.



Background Knowledge

Objects exist in a state of superposition when they can be more than one thing at once. In the quantum realm, this means that a unit of light, a photon, can behave both as a wave and as a particle. In quantum computing, quantum bits (“qubits”) can exist in multiple states at the same time. The different states can add together and interfere with each other to define the overall state of the qubit. In classical computing, bits have one of two values (zero or one). A qubit, however, can be zero or one or anywhere in between. The real power of superposition arises when more than one qubit is involved because the number of possible combinations grows exponentially, rather than linearly. This is often referred to as the quantum advantage.

Engage



Literacy
Connection

1. Consider reading or having available one or more of the following:
 - a. *Duck! Rabbit!* by Amy Krouse Rosenthal
 - b. *Another* by Christian Robinson:
 - c. *Battle Bunny* by Jon Scieszka

In these books, readers are exposed to the idea that something can be two things at once.
2. Introduce the idea of superposition via the first 3 examples included in the “Superposition Examples” slides (duck/rabbit, vase/faces, and old/young woman).
 - a. Ask participants what they see in each image. Encourage them to discuss the different things they see.
 - b. Introduce the term **superposition**. Something exists in a state of superposition when it can be in multiple states at once.
3. Introduce the idea that when we look at or listen to something, we are **measuring** it.
 - a. For the “Superposition Examples”, when you looked at the image your eyes measured it. Ask: *How is this idea of measurement different than how we usually think about measuring things?* [We usually measure things with a tool and with units, like using a ruler to measure inches. In this kind of measurement, we’re determining what state an object is in.]
 - b. For an object in superposition, we determine the state it is in each time we measure it.
 - c. Different people might have different measurements (i.e., see different things). One person might get different measurements (i.e., see different things) at different times.
4. Introduce homographs, words that are spelled the same but might be pronounced differently and/or have different meanings. Show the three examples of homographs in the “Superposition Examples” slides and ask participants for their different pronunciations and/or meanings (as applicable).
 - a. Different pronunciation, different meaning: Bow as in bow tie, bow as in bow for the audience.
 - b. Different pronunciation, different meaning: Live as in live your life, live as in live TV broadcast.
 - c. Same pronunciation, different meaning: Jam as in traffic jam, jam as in put jam on your toast.



Facilitation Tip: Continue to use the words “measurement” and “measuring” throughout the activity.

Activity

5. Let participants know that you have more examples of superposition that you want them to experience. They are not all things you can see. Ask: *How else might we measure the state, if we can't see it?* [We can use other senses, like hearing.]
6. Tell participants that you are going to say a word and you want them to think of the meaning of that word. Say aloud one or more of the following homophones (words that are pronounced the same, but are spelled differently and have different meanings). After saying a word, give participants time to think of a meaning and then ask participants to share. Alternatively, have participants write down the word they think you said. Did they all think of the same word and definition? If so, what is another spelling and definition it could have been?
 - a. Two/To/Too
 - b. Their/They're/There
 - c. Break/Brake
 - d. Write/Right
 - e. Male/Mail
 - f. Steel/Steal
 - g. Deer/Dear
 - h. Eight/Ate
 - i. See/Sea
 - j. Flower/Flour
7. Play the “Yanny/Laurel” audio clip and ask participants to share their measurement of state with the group.
 - a. Ask: *What are the states?* [The recording sounds like either “laurel” or “yanny.”]
 - b. Ask participants to record their measurement of state on the chart paper.
Consider keeping a running tally throughout the time you run the activity. Is one measurement more common than the other? Why might that be?
8. Explain that quantum computers are a kind of computer that use something called quantum bits, or **qubits**. Qubits exist in a state of superposition. For something to be used as a qubit, you also have to be able to change the chances of measuring a certain state.
9. Ask: *What do you think it means to be able to change the chances of measuring one state or the other?* [Accept all answers at this point.]
10. Tell participants that now they will explore ways to change the chances of measuring one state or the other. Return to the sound example from the “Superpositions Examples” slide. Explain that it’s possible to change the probability that we measure (i.e., hear) either “yanny” or “laurel” by changing some properties of the sound files. Listen to manipulated recordings on slide 7 in “Superposition Examples” and record on a chart how many participants measured each state. Compare these data to those you collected earlier in the session. Discuss if the chances of measuring one state or the other changed. *Did we change the chance of measuring one state?* [Yes.] *What is your evidence?* [The evidence is that we measured more of one sound than the other.] *Could*



this be used for quantum superposition? [Yes, because we can make one state more likely to be measured.]

11. Engage participants in one or both of the following. Explain that quantum computing is complicated and the measurement doesn't measure what's truly there. In these activities, we'll try some things in which the measurement is imperfect, because we're choosing between a set of things, but it will help us get a better understanding of probability.
 - a. Show a quarter and demonstrate spinning it. Ask: *What are the 2 states?* [Heads and tails.] *What are the chances of measuring each state?* [They should be the same, 50%.] *What ideas do you have about how to change the chance of measuring tails instead of heads?* [Accept all ideas.] Give each participant a quarter and a piece of modeling clay about the size of a large pea. Have them press the modeling clay onto the tails side of the quarter, without spreading it out too much. Each participant should then spin their quarter 10 times, and record their measurement of each spin. Have participants share their data. Ask: *Did we change the chance of measuring tails?* [Yes.] *What is your evidence?* [The evidence is that we measured more tails than heads.] *Could this be used for quantum superposition?* [Yes, because we can make one state more likely to be measured.]



Differentiation Note: Depending on participants' ages, you might need to show them how to spin a quarter. Also consider doing this activity in pairs rather than individually.

- b. Show your opaque container and put in 4 of your objects - 2 of each color. Ask: *What are the 2 states?* [The two colors.] *What are the chances of measuring each state?* [They are the same, 50%.] *What ideas do you have about how to change the chance of measuring tails instead of heads?* [Accept all ideas.] Remove one of the objects and replace it with one of the opposite color, so you have 3 of one color and 1 of the other. Give each participant a chance to remove one of the objects, then return it to the container before the next participant's turn. Each participant should record the color they selected on a chart that all can see. When you have enough data, ask: *Did we change the chance of measuring one color?* [Yes.] *What is your evidence?* [The evidence is that we measured more of one color.] *Could this be used for quantum superposition?* [Yes, because we can make one state more likely to be measured.]

Discussion

12. Return to some of the other "Superpositions Examples" slides. For each, ask: *What are the states? How do we measure the state? What ideas do you have to change this, to make it more likely that you'll measure one state instead of the other? Could we use for quantum superposition?*
13. Use one or both of the following to gauge participant's understanding of superposition.

- a. Ask participants to talk in small groups about ideas on additional examples of things that exist in a state of superposition. They can record their ideas on sticky notes or index cards to share with the whole group. For any examples they share, ask: *What are the states? How do we measure the state? Can make it so one is more likely to be measured than the other? Could we use it for quantum superposition?*
 - i. If participants have difficulty getting started, ask if they can think of other examples of homophones or homographs. One example is the written word “read” that has 2 different pronunciations--reed and red. Pear, pare, and pair are all pronounced the same way, even though they have different spellings and meanings.
 - ii. You might suggest participants consider everyday items around the room. Could any of them be considered two things at once? For example, a standard #2 pencil can be used to both write and erase.
- b. Have participants complete the *Sporks* worksheet. Discuss their answers and their reasoning as a group.

Connections to Standards

Next Generation Science Standards*

Science and Engineering Practices: Using Mathematics and Computational Thinking

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I am in grade _____

Sporks

Keira and Amaria have been learning about superposition. They are talking about different things that might be in a state of superposition.



Keira says, “I think a spork is in a state of superposition. It is a spoon and a fork at the same time!”

Amaria says, “I think a spork is not in superposition because it is not a spoon or a fork. It’s a spork!”

Who do you agree with more: Keira or Amaria? Explain why.

I agree more with...

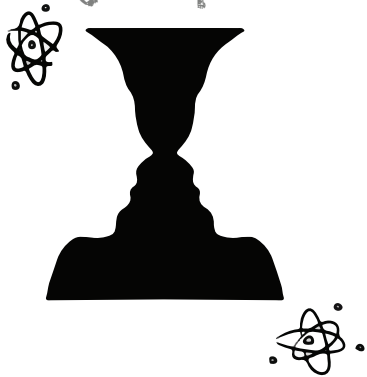
because...

What information would help Amaria and Keira agree?

A PEEK INTO...

Quantum Superposition

Quantum Superposition



SUPERPOSITION OF IMAGES

LOOK AT THIS PICTURE:



WHAT DO YOU SEE?
A DUCK? A RABBIT?
CAN YOU SEE BOTH?

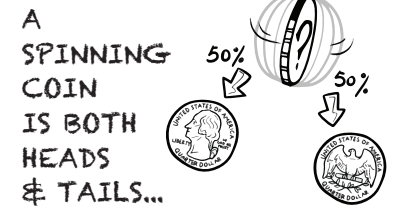
A PIECE OF ART CAN HOLD TWO IMAGES AT THE SAME TIME



DO YOU SEE
AN OLD WOMAN?
A YOUNG WOMAN?

HEADS? TAILS? (OR BOTH!?)

SOME THINGS HOLD TWO VALUES AT THE SAME TIME

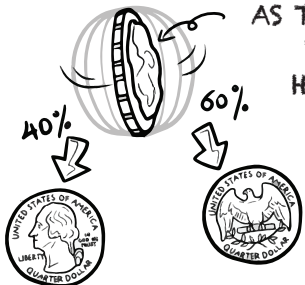


UNTIL IT STOPS... AND IS MEASURED!

THAT'S UNFAIR!

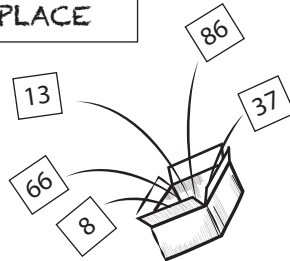
SOMETIMES, THE PROBABILITY OF A RESULT CAN BE ADJUSTED

THIS UNFAIR COIN IS MORE LIKELY TO BE MEASURED AS TAILS THAN HEADS



SUPERPOSITION IN QUANTUM COMPUTING

HOLDS MANY VALUES IN THE SAME PLACE

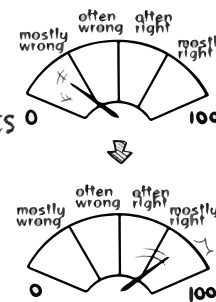


CAN UPDATE ALL VALUES WITH ONE OPERATION

MANIPULATES PROBABILITIES (SO DESIRED OUTCOMES ARE MORE LIKELY)

QUANTUM COMPUTATION

OPERATIONS CAN GRADUALLY REFINE PROBABILITIES UNTIL CORRECT OUTCOMES ARE (MORE) LIKELY



ONCE MEASURED, SUPERPOSITION COLLAPSES & ONLY THE MEASURED VALUE REMAINS

FIND MORE QUANTUM COMPUTING ZINES HERE:

<https://www.epiqc.cs.uchicago.edu/resources/>

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Share what you've learned about superposition!

- Explain to someone else what it means for an object to be in a state of superposition.
- Look for new examples of superposition and discuss them.
 - What are the two states of the object?
 - How do you measure the state of the object?
 - Are both states obvious to everyone?
- Explore how to change probabilities.
 - Put two or more objects of different colors or shapes into a paper bag. Close the bag, shake it up, and pull out one of the objects. Record your results in a chart.
 - How often do you pick each object? How could you change your set-up so that you're more likely to pick a certain one?