

Measurement Perturbs State

Explore how measuring something can change it

Learning Goals

- Understand that measurement methods can change the thing being measured

Importance in Quantum Computing

The state of quantum bits, or qubits, changes when you measure it.



Materials

- Ice cubes (same sized)
- Warm water
- Room temperature water
- 2 identical bowls
- Measurement worksheets

Preparation

- Fill one bowl with warm water and one bowl with room temperature water.



Background Knowledge

Usually when we measure something, the thing we measured 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 length when you were done measuring. Sometimes, however, our measurements change 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. In science, it is often important that the method of measurement does not “intrude” on what you are measuring. Otherwise, the process of measuring will introduce errors to your measurement. In classical computers, bits can only exist in one of two definite states (on or off; 0 or 1) and measuring the state does not change the bit. In quantum computers, the quantum bits (qubits) exist in can exist in combinations of these two states. The property of being in two states at once is called superposition. The act of measuring a qubit actually changes its state.

Facilitating the Activity

ENGAGE



1. Consider reading or having available one or more of the following:
 - a. *Inch by Inch* by Leo Lionni
 - b. *The Three Little Pigs* (choose your favorite version)
 - c. *Goldilocks and The Three Bears* (choose your favorite version)

In these stories, characters measure various items (e.g., the length of a bird's tail in *Inch by Inch*, the strength of buildings in *Three Little Pigs*, and the temperature of porridge in *Goldilocks and The Three Bears*). Ask participants questions to get them thinking about how we measure different things: What were they measuring? How did they measure it? Why did they measure it that way? Did it change at all when they measured it?

ACTIVITY

1. Show participants the two bowls you have prepared. Tell the participants that we need to figure out the temperature of the water in each bowl, but the only thing we have is ice cubes. Ask: What ideas do you have about how we could figure out the temperature of the water in the bowls?



Facilitation Note: If participants suggest touching the water to see how warm or cold it is, tell them we can't touch it for safety reasons.

2. As participants share their ideas, ask open-ended questions such as:
 - a. What do you think will happen when you do that?
 - b. How will that help you determine the temperature of the water?
3. If it hasn't come up already, explain that measuring how quickly an ice cube melts will tell you something about the water's temperature. If needed, ask for ideas on how to set up an investigation using this idea.
 - a. Drop one ice cube into the room temperature water and one in the warm water.
 - b. Measure how long it takes each ice cube to melt.
4. Ask participants to share what they notice after you start the investigation. Ask questions such as:
 - a. How do your observations help you figure out the temperature of the water?
 - b. Which bowl do you think has a higher/lower temperature? Why do you think that?
 - c. What changed during this investigation?

- d. Do you think the temperature of the water is the same as it was before we put the ice in it?

DISCUSSION

1. If it hasn't come up, tell participants that putting the ice in the water helped us tell the temperature but it also changed, or perturbed, the temperature. As the ice melted, it lowered the temperature of the water. In other words, the measurement changed (or perturbed) the state of what we were measuring.
2. Facilitate a discussion of the idea that measuring something about an object can change it. Ask questions such as:
 - a. Can you think of any other times when we measure something and it changes what we are measuring? [*Some examples include testing foods to see if they are done cooking (you eat some of the food), checking the air pressure of tires (some air escapes), and conducting car "crash tests" (the car is damaged or destroyed).*]
 - b. Do you think it's important to know if the measurement changes the object?
3. Tell participants that in quantum computers, the qubits can be in two states at once. When we try to measure the state of a qubit, it changes the qubit so that it is forced into one of the two possible states. On the quantum level, current measurement methods interfere with the values we are attempting to measure. As soon we try to measure something on the quantum level, the very event/entity we're trying to measure changes.
4. Ask participants to complete the *Measurement* worksheet. Consider facilitating a discussion so that participants can share their thoughts, once they have finished.



Connections to Standards

Next Generation Science Standards*

Crosscutting Concepts: Cause and Effect, Stability and Change
Science and Engineering Practices: Planning and Carrying Out Investigations, Using
Mathematics and Computational Thinking

Common Core State Standards

Standards for Mathematical Practice: Construct Viable Arguments and Critique the Reasoning of
Others, Use Appropriate Tools Strategically

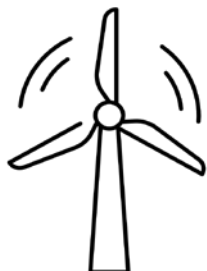
Acknowledgements

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I am in grade _____

Measurement

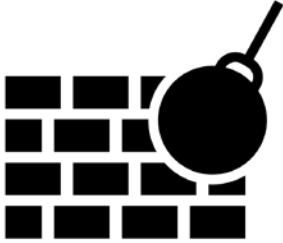


Nevaeh's class is learning about windmills. She and her partner designed blades for a windmill and then attached them to the windmill. They will test their blades by measuring how fast the windmill turns in the wind. They will record how many times the blades turn in 1 minute. Nevaeh will use her eyes to count the number of turns and her partner will use a stopwatch to time 1 minute.

Will this measurement change the state of the windmill blades?
Explain your thinking.

I am in grade _____

Measurement

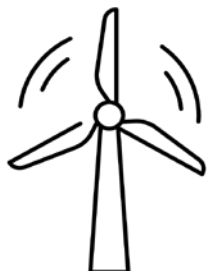


Marisol's class has been learning about how walls are built. They designed a mortar made out of sand, clay, and water to hold the bricks together. Now they will test the strength of their mortar by hitting the wall with a wrecking ball. They will use their eyes to look at the wall after the wrecking ball hits it. They will count how many times the wrecking ball hits the wall before it falls down.

Will this measurement change the state of the mortar?
Explain your thinking.

I am in grade _____

Measurement

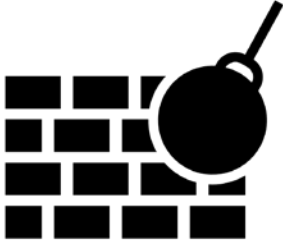


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Will this measurement change the state of the windmill blades?
Explain your thinking.

Answers will vary, but look for thinking related to how the windmill blades (or the windmill as a whole) should stay the same during the measurement.

Measurement



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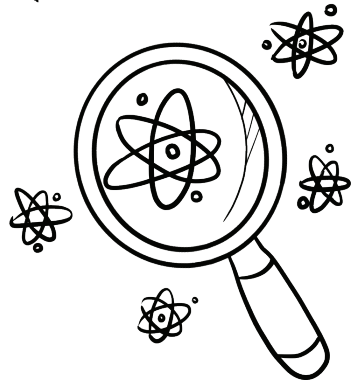
Will this measurement change the state of the mortar?
Explain your thinking.

Answers will vary, but look for thinking related to how the mortar (or the wall as a whole) is likely to change because it will break when the wall falls down.

Share what you've learned about how measuring something can change it!

- Explain to someone else what it means for a measurement to change the thing that you are measuring.
- Notice when you change things by measuring them in your everyday life. Discuss your experiences with others.
 - What were you measuring?
 - How were you measuring it?
 - What changed when you measured it?

Quantum and Measurement



Quantum Bits "Qubits"



You cannot measure them because...

- They are fragile.

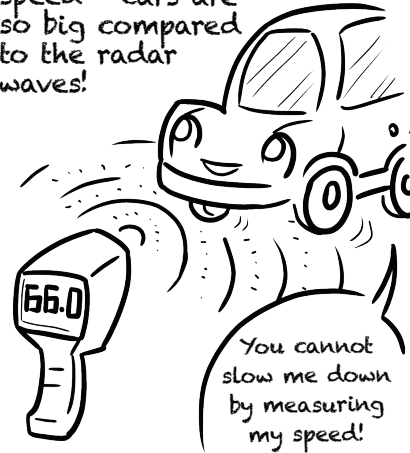


I could be 0 or 1 at the same time, but never both once you look.

- Measurement methods cause problems.

Measurements: Non-intrusive?

Police radar guns do not affect a car's speed - cars are so big compared to the radar waves!



Measurements: Side Effects

Some measurements do not affect what is being measured... but they do something else!



X-rays are commonly used in hospitals to produce photographs for checking bone fractures.

But... They could potentially cause cancer when people are exposed unprotected!



If you time how long you can hold your breath...



You would do just fine the first time, but...

You cannot hold your breath as long the second time, without resting in-between.



This is caused by the side effects of such measurements

Measurements: Disturb Aspects Measured

For the carnival game...



Putting together Quantum and Measurement

The measurement of a 0 or 1 of a qubit disturbs the state of the qubit that you are trying to measure.



And quantum states - states of the minimal amount of physical entity - are so small that a single photon may alter it.



Find more Quantum Computing zines here:

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

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