30 min

6+ years

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 a quantum bit, or qubit, changes when you measure it.

Materials

- ❏ Various flavored Jelly Belly jelly beans (or similar candy)
- ❏ Paper towels or napkins
- ❏ *Measuring Jelly Beans* worksheet
- ❏ *Measurement* worksheet

Preparation

- Print the *Measuring Jelly Beans* and *Measurement* worksheets.

Background Knowledge

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 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. Classical computers store simple values in memory, and the storage devices are able to both measure and retain the value when you read out of memory. Quantum computers, however, have a very complex, fragile state at the molecular level. No measurement device exists that can measure without fundamentally changing what is being stored.

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)

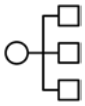
    In these stories, characters measure various items (e.g., the length of a bird's tail in *Inch by Inch*, the strength of buildings in *Three Little Pigs*, and the temperature of porridge in *Goldilocks and The Three Bears*). Ask participants questions to get them thinking about how we measure different 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 some of the jelly beans and tell them that they are going to be able to eat some jelly beans, but not yet. Facilitate a discussion of the question: If someone gave you a jelly bean, how could you measure what flavor a jelly bean it is?
    a. Encourage participants to come up with at least four ways to measure the flavor of a jelly bean.
    b. Have participants share out into the larger group. Some potential responses include: check the package, look at the color, eat it, smell it, break it open and smell, and taste it.
    c. Chart the ideas to refer back to later.
2. Tell the participants that some of the jelly beans are the same color but do not have the same flavor (e.g., lemon and pineapple are both yellow). Facilitate a discussion about which methods would still work to measure the flavor of each jelly bean. Ask questions such as:
    a. Why do you think that method would or would not work?
    b. Does this method have any problems? [Looking at and smelling the jelly beans are not destructive methods, but licking, eating, and cutting open are destructive methods.]
    c. In order to know the flavor of two jelly beans that are the same color, would you need to test both jelly beans? [You might want to tell participants that there can be more or less of each flavor.]

Facilitation Note: Consider recording participants' observations and predictions of flavors on chart paper, a whiteboard, etc.

3. Let participants know that for the remainder of the activity they will use four methods of measurement: (1) looking, (2) smelling, (3) breaking open and smelling, and (4) tasting. Facilitate a discussion of which methods are destructive and which are not destructive.
4. Give each participant a *Measuring Jelly Beans* worksheet and some jelly beans. The worksheet could also be recreated on a whiteboard, chart paper, etc. for the whole class to contribute to.
5. Have each participant test a jelly bean using one method of measurement at a time. Use the measurement methods in the following order: (1) looking, (2) smelling, (3) breaking open and smelling, and (4) tasting.



Differentiation Note: Younger participants might need help breaking open the jelly beans without biting them, so adult help might be required.

   a. After each measurement, have each participant record their thoughts on the worksheet. They should record what they think the flavor is, which might be a change from their previous thought based on the new information they got from the current measurement. Participants should also record why they think the jelly bean is that flavor and indicate how certain they feel. If participants have difficulty predicting which flavor a jelly bean might be, consider showing them the Possible Jelly Bean Flavors chart (located at the end of this guide) or a list of flavors from the jelly bean manufacturer.
   b. After participants have tried all the measurement methods on one jelly bean, they should try them again with a jelly bean of a different color.
   c. Each participant should try all methods with at least 2 jelly beans, depending on time, and record their results. After testing 2 or more jelly beans, have participants respond to the worksheet prompt, “Which method do you think is best for figuring out the flavor of a jelly bean? Why do you think that?”

DISCUSSION

1. Facilitate a discussion of the idea that measuring something about an object can change it but can also give more information than measuring something without changing it. Ask questions such as:
   a. Which method(s) would you use to get an accurate result each time? What are the pros and cons of this method?
   b. How much information did you gain about the jelly beans by using non-destructive methods (looking, smelling)?

c. How much information did you gain about the jelly beans by using destructive methods (breaking open and smelling, tasting)?
d. Can you think of 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), unwrapping a gift to see what's inside (the wrapping is destroyed), and conducting car "crash tests" (the car is damaged or destroyed).*]
e. Do you think it's important to know if the measurement changes the object?

2. Tell participants that in quantum computers, the qubits have complex state, including being both a 0 and 1 at once. However, there exists no non-destructive measurement device - the devices are destructive and only measure whether it's 0 or 1. As soon we try to measure something on the quantum level, the very event/entity we're trying to measure changes.
3. 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

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Possible Jelly Bean Flavors

Color	Possible Flavors				
Red	 Cinnamon	 Cherry	 Red apple	 Strawberry	 Raspberry
Orange	 Orange	 Peach	 Cantaloupe	 Grapefruit	
Yellow	 Lemon	 Pineapple	 Popcorn		
Green	 Green apple	 Kiwi	 Lime	 Watermelon	

I am in grade _____

Measuring Jelly Beans

Jelly bean #1
Color: _____

Non-destructive Measurement Methods

Method	**What flavor do you think it is?**	**Why do you think that?**	**How sure are you?**
Look			
Smell			

Destructive Measurement Methods

Method	**What flavor do you think it is?**	**Why do you think that?**	**How sure are you?**
Break open and smell			
Eat			

After all the measurements, I think the jelly bean flavor is _____

I am in grade _____
Jelly bean #2
Color: _____

Non-destructive Measurement Methods

Method	**What flavor do you think it is?**	**Why do you think that?**	**How sure are you?**
Look			
Smell			

Destructive Measurement Methods

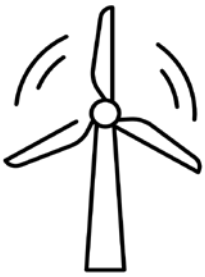
Method	**What flavor do you think it is?**	**Why do you think that?**	**How sure are you?**
Break open and smell			
Eat			

After all the measurements, I think the jelly bean flavor is _____

Which method do you think is best for figuring out the flavor of a jelly bean? Why do you think that?

I am in grade _____

Measurement

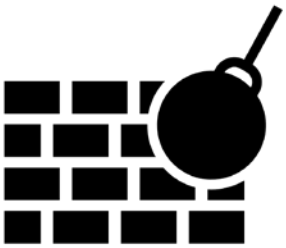


Nevaeh's class is learning about windmills. She and her partner designed blades for a windmill and then attached them to the windmill. They will test their blades by measuring how fast the windmill turns in the wind. They will record how many times the blades turn in 1 minute. Nevaeh will use her eyes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

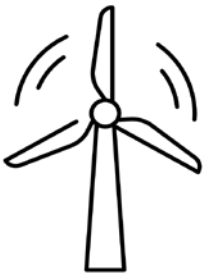


Marisol's class has been learning about how walls are built. They designed a mortar made out of sand, clay, and water to hold the bricks together. Now they will test the strength of their mortar by hitting the wall with a wrecking ball. They will use their eyes to look at the wall after the wrecking 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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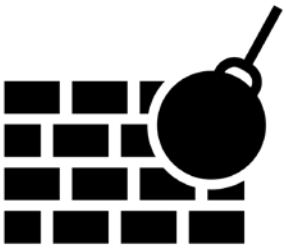
Will this measurement change the state of the windmill blades? Explain your thinking.

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.

I am in grade _____

Measurement



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

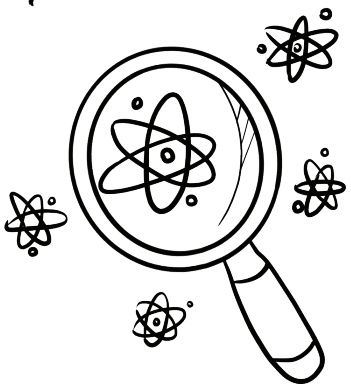
Answers will vary, but look for thinking related to how the mortar (or the wall as a whole) is likely to change because it will break when the wall falls down.

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?

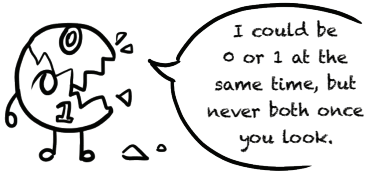
Quantum and Measurement



Quantum Bits "Qubits"

You cannot measure them because...

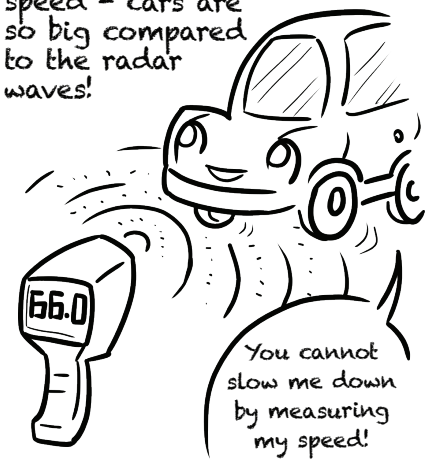
- They are fragile.



- 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

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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AN NSF EXPEDITION IN COMPUTING

EPiQC

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