20-30 min

6+ years

Up to 5

Reversibility

Exploring what makes something reversible

Learning Goals

- Understand what it means to be able to reverse an action or a mathematical operation.
- Explain why particular actions or mathematical operations are reversible or irreversible.

Importance in Quantum Computing

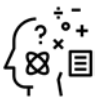
This activity introduces participants to the concept of reversibility, which is a key theme in quantum computing. Because of quantum physics, all quantum computations must be reversible.

Materials

- ❏ *Reversibility with Paper* sheets
- ❏ Reversibility Cards (1 set)
- ❏ Sticky notes or index cards
- ❏ Chart paper (optional)
- ❏ *Reversible or Not?* worksheet (optional)
- ❏ *Is it Reversible?* worksheet

Preparation

- Make copies of the *Reversibility with Paper* sheet and cut along the dotted lines.
- Identify a location (e.g., wall space, chart paper) to post items generated by participants.
- Choose the version of *Is it Reversible?* that best fits your audience and make copies.



Background Knowledge

This activity conveys the idea of reversibility, or “uncomputing” in quantum computing. The basic idea of reversibility is something children can grasp – zipping a zipper is reversible, yet cracking an egg is not. Because of the laws of quantum physics, all quantum computation must be reversible. An operation is reversible if you can perform an opposite operation and get back to where you started. The jump to mathematical operations, only appropriate for older audiences, brings this concept closer to quantum computing. When a classical computer performs the operation: 12 + 7 = 19, some information is lost. With only the result and operation (addition), we cannot get back to the inputs of 12 and 7 since many pairs of numbers sum to 19. However, if we keep one of the inputs (for example, 12 + 7 = 19 (via 7)) then we can get back the 12 by subtracting 7 from 19. Quantum computing requires more memory bits because it has to maintain extra information in order to satisfy the reversibility constraint.

Facilitating the Activity

ENGAGE

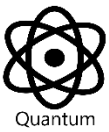

Literacy Connection

1. Choose one of the following options to begin.
    a. Consider reading or having available one or more of the following:
        - *Bears in the Night* by Stan and Jan Berenstain
        - *Go Away, Big Green Monster!* by Ed Emberly
        - *We're Going on a Bear Hunt* by Michael Rosen and Helen Osenbury

       In these stories, the characters end up in the same place they began. When discussing the story with participants, introduce the idea of reversing actions by comparing it to doing something backwards. For example, you can build a stack of blocks, then take them down one by one.

    b. Ask: *What do you think it means for something to be reversible? Is jumping in a puddle reversible?* You want to elicit more than just jumping out of the puddle because there are many potential elements to think about when we think about if something is reversible. Ask follow-up questions such as:
        - What do you need to do to reverse it?
        - Do you need to dry off your clothes?
        - If your clothes are stained, is that reversible?
        - Is the puddle the same?

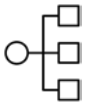
ACTIVITY


Quantum Connection

1. Introduce the purpose of this activity. Tell participants that one thing that computers do is perform a lot of mathematical operations. Quantum computing is a new type of computation. It has the potential to perform some types of calculations much faster than current computers. However, it has a limitation – all quantum operations must be reversible. If something is reversible, it means you can get back to what you started with. Let's explore what reversibility means in everyday actions.
2. Give each participant one of the prepared *Reversibility with Paper* sheets. Ask them to perform the action described on the sheet. Then ask them to reverse the action. Facilitate a discussion about reversibility by asking questions such as:
    a. Were you able to reverse your action? How?
    b. Can you get the paper back to the way it was when I gave it to you?
    c. Can you reverse your action so that no one can tell what happened to the paper?

In this discussion, you want to clarify the difference between fixing something (e.g., taping the paper back together, unfolding the paper airplane) and reversing back to the original state.

3. Show participants the Reversibility Cards. Ask participants to determine whether they think the action or change represented in the images on a given card is reversible, meaning they can be undone or reversed. Sort the cards into "reversible" and "irreversible" actions/changes. When a participant determines whether an action/change is reversible or not, probe for the explanation or reasoning behind their answer. As needed, return to the distinction between fixing something and reversing a change. Note that participants are likely to vary in the degree to which they think small differences that remain after reversing are important.



Differentiation Note: For younger participants, show the cards one at a time and consider the order in which you present them, starting with less ambiguous cards first.

DISCUSSION

1. Facilitate a discussion about determining if an action/change is reversible. Ask questions such as:
    - How did you decide if something was reversible or not?
    - Which card was easy to categorize? Why?
    - Which card was the most difficult to categorize? Why?
    - Of all the reversible actions, which is the most difficult to reverse? Which is the easiest? Why?
    - Did you find any actions that you thought could be both reversible and irreversible? How did you decide?
2. Lead participants in brainstorming other reversible and irreversible actions or changes. Ask them to write each idea on a sticky note or index card, including their reasoning of why it is reversible or irreversible. Alternatively, ask participants to complete the *Reversible or Not?* worksheet and provide time for them to ask another participant to share their thoughts on the action or change. Show participants where to post their ideas on the Reversibile Actions/Changes and Irreversible Actions/Changes charts.
3. Facilitate a discussion about what attributes you look for to determine if an action/change is reversible. Ask questions such as:
    - What rules or reasoning did you use to decide whether something was reversible or not?
    - Do all reversible actions have anything in common? What about irreversible actions?

Document their ideas on a Reversibility Rules chart.

4. Ask participants to complete the *Is It Reversible?* worksheet.
5. Tell participants that while quantum computers are fast at some things, they can only do so much because everything they do must be reversible. Ask: What would your life be like if you could only perform reversible actions? What would you need to give up? (For example, could you eat cooked food? Could you drive in gas-powered vehicles?) Have participants brainstorm their ideas and record them on sticky notes or index cards; show them where to post their ideas.

Discussion Extension for Ages 9+

6. Remind participants that quantum computers aren't performing actions like cooking food or cracking open eggs. They are doing mathematical operations. Ask: What are mathematical operations? [*Addition, subtraction, multiplication, division.*]
7. Ask: What do you think it means for a mathematical operation to be reversed? Facilitate a discussion and clarify that it means that you have enough information to get back the original numbers you started with, called inputs. For example, if you add 12 and 7 and get the result 19, what information do you need to get back the inputs?
    - If you only know the result (19) and the operation (addition), can you get back the inputs? [*No.*]
    - What other information do you need to know to get back the inputs? [*You need to know one of the inputs.*]
    - Let's think about another example: incrementing, or adding by 1. If you know that you incremented 5 times and the result was 17, can you get back the original input? [*Yes. It is 12.*]
8. Facilitate a discussion of this question: What do you need to know to make a mathematical operation reversible? [*You need to know the result, the operation, and at least one of the inputs.*]
9. Tell participants that quantum computers can perform operations on many numbers in very little time, the constraint of reversible operations means that it needs to save extra information so that it can reverse the operations, which takes up space. That extra information is stored in *ancilla bits*.

Connections to Standards

Next Generation Science Standards*

Crosscutting Concept: Patterns, Cause and Effect
NGSS Science and Engineering Practices: Using Mathematics and Computational Thinking, Constructing Explanations, Engaging in Argument from Evidence

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grants 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.

Reversibility with Paper

Cut or tear the paper in half.

Fold the paper in half.

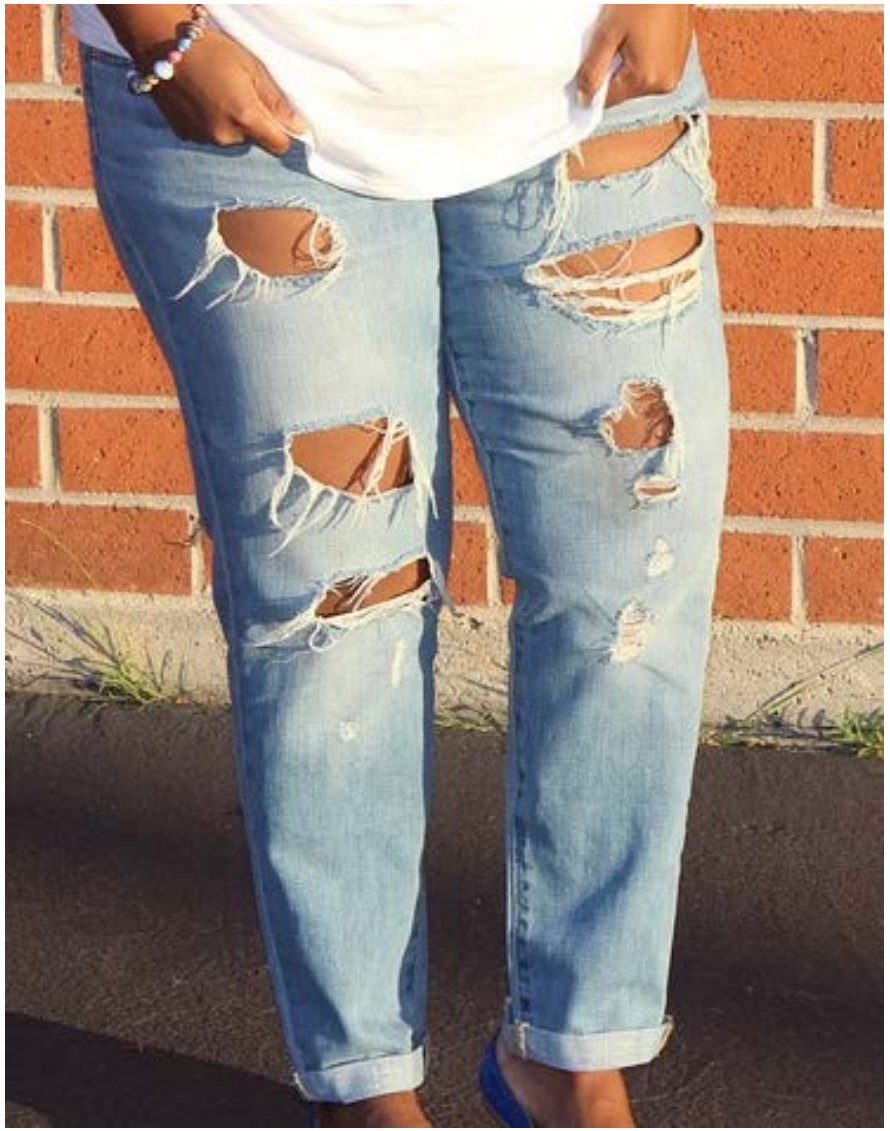
Cut or tear the paper.

Make a paper airplane.

New jeans

Savaman from Sao Paulo City / Ipiranga, Brasil [CC BY 2.0 (https://creativecommons.org/licenses/by/2.0)]

Ripped jeans

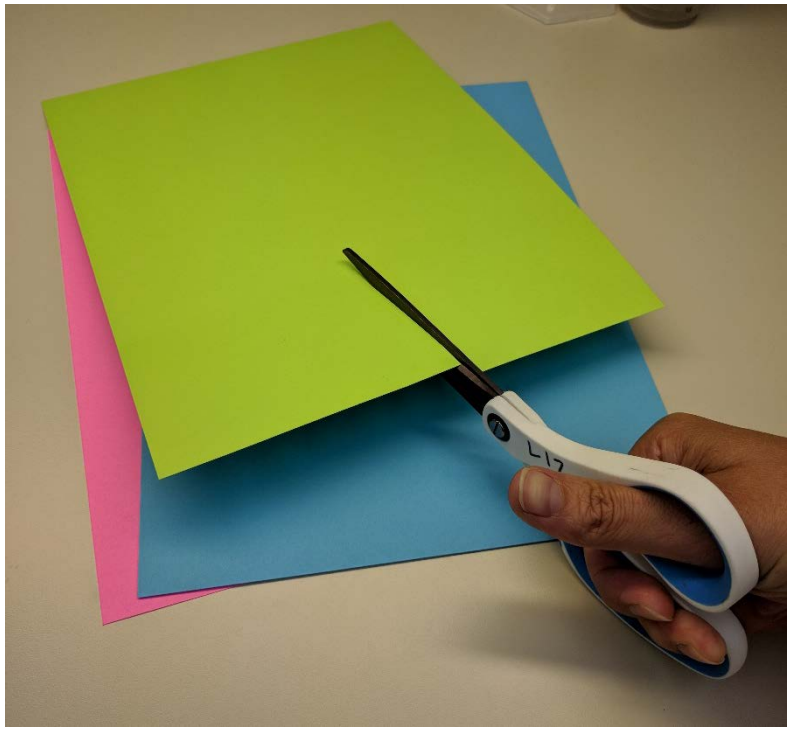


Samantha Sophia on Unsplash

Colored paper

Liz Lehman

Scissors cutting paper

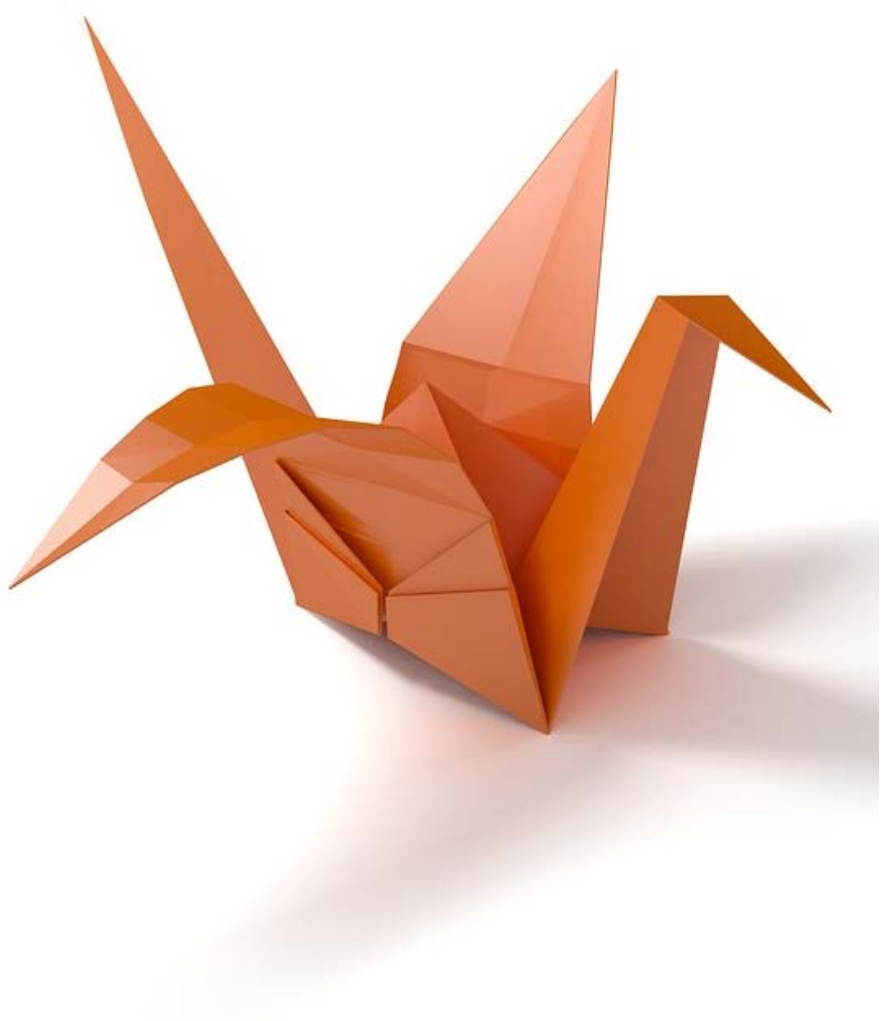


Liz Lehman

Unfolded paper

Ulrike Mai on https://pixabay.com

Paper folded into a crane



https://www.nicepik.com/

Eggs in a carton

congerdesign on https://pixabay.com

Cracked egg

CraftyPease on https://pixabay.com

Closed plastic eggs

https://www.nicepik.com/

Open plastic eggs

Circe Denyer, https://www.publicdomainpictures.net

Bread

Marco Verch, Flickr, [CC BY 2.0 (https://creativecommons.org/licenses/by/2.0)]

Toast

"Toast!" by John Mcclumpha is licensed under Creative Commons Attribution 2.0

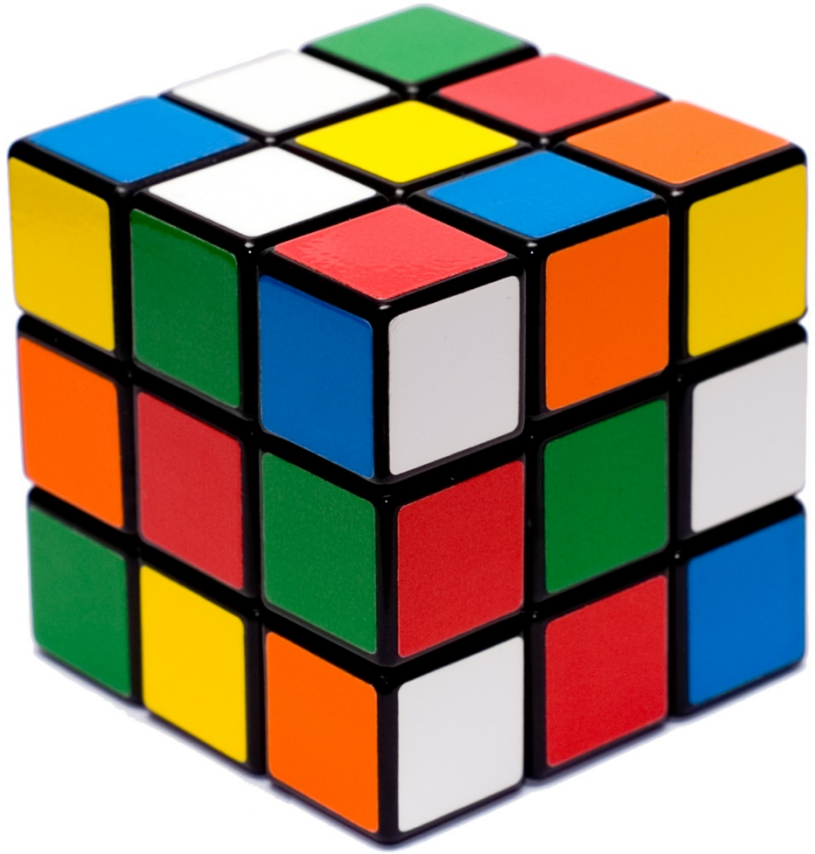
Glass of water

https://www.rawpixel.com

Glass of tea

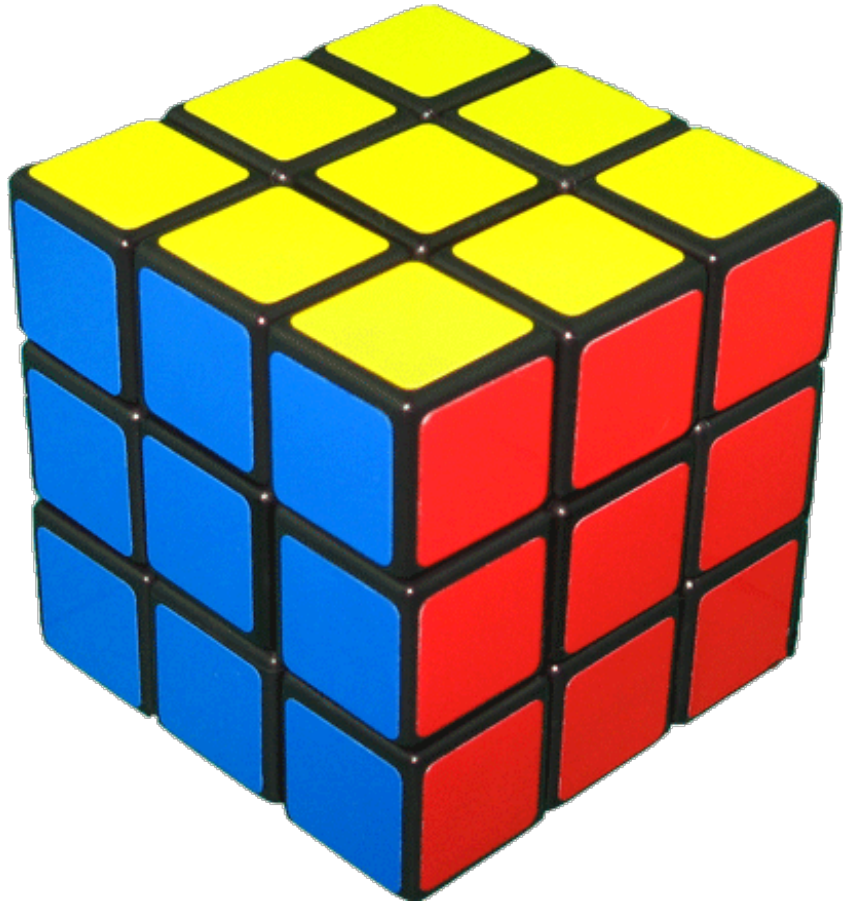
https://pxhere.com

Unsolved Rubik’s Cube



http://pngimg.com/ [CC BY-NC 4.0 (https://creativecommons.org/licenses/by-nc/4.0/]

Solved Rubik’s Cube



http://www.pngall.com [CC BY-NC 4.0 (https://creativecommons.org/licenses/by-nc/4.0/]

Inflated balloon

K Whiteford (publicdomainpictures.net)

Popped balloon

Andrew Magill, Flickr, [CC BY 2.0 (https://creativecommons.org/licenses/by/2.0)]

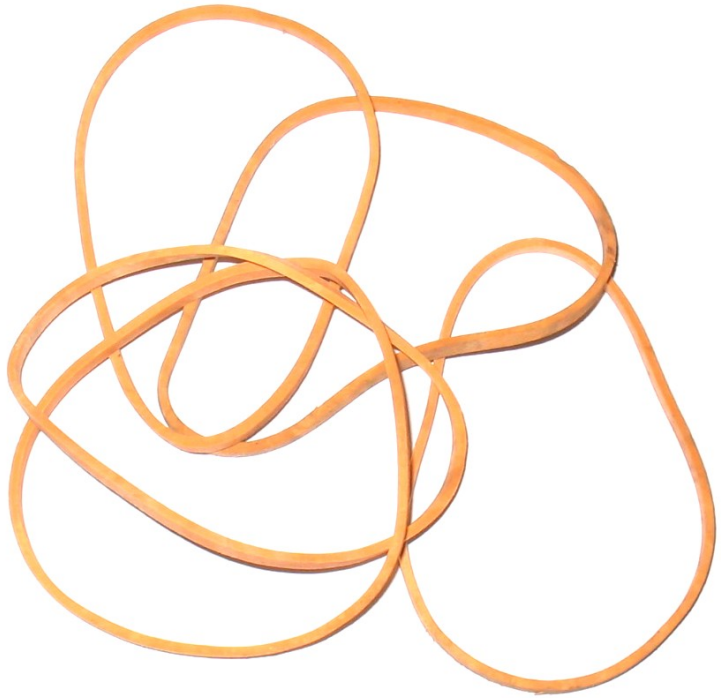
Puzzle pieces

Jared Tarbell [CC BY 2.0 (https://creativecommons.org/licenses/by/2.0)]

Solved puzzle

https://www.nicepik.com/

Rubber band



FML [CC BY-SA 2.5 (https://creativecommons.org/licenses/by-sa/2.5)]

Stretched rubber band

Enric Fontvila [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)]

Balls of yarn

Skeeze on https://pixabay.com

Knitted mittens

Ugglemamma on https://pixabay.com

Uninflated balloons

Charles Rondeau (publicdomainpictures.net)

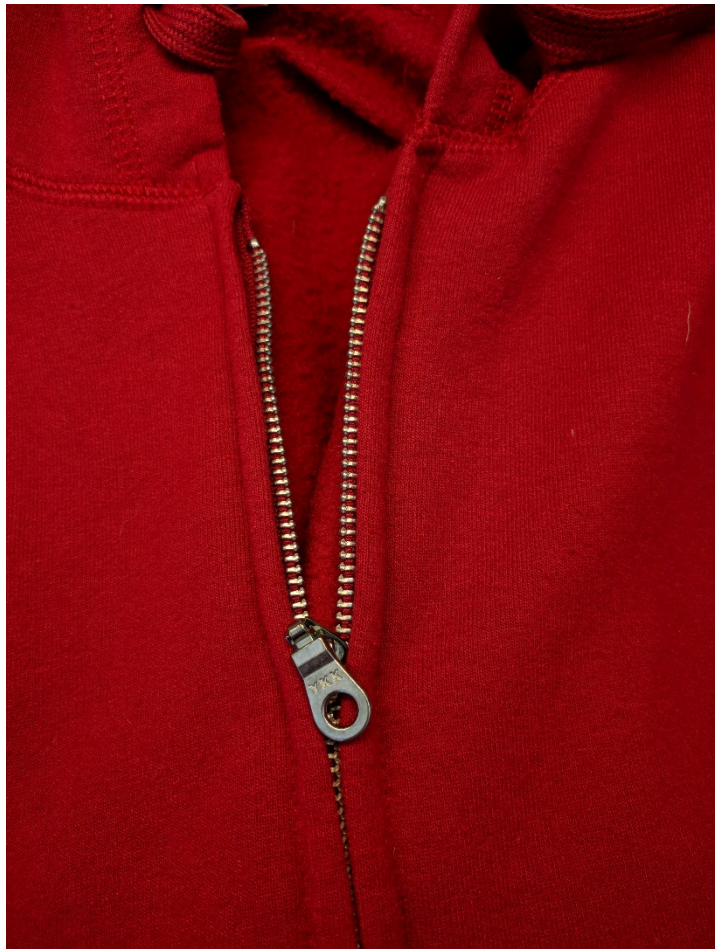
Inflated balloons

https://www.rawpixel.com

Zipped zipper

Liz Lehman

Unzipped zipper



Liz Lehman

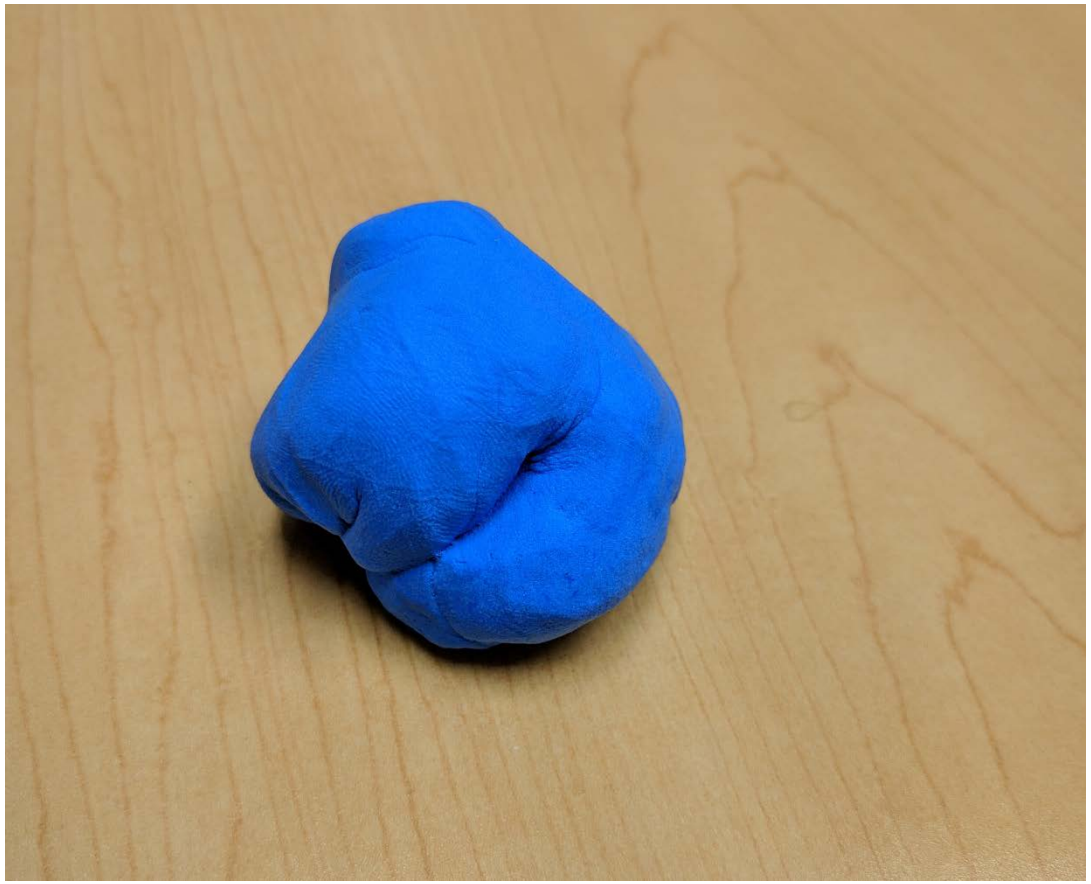
Ice cube tray filled with water

Liz Lehman

Ice cube tray with ice

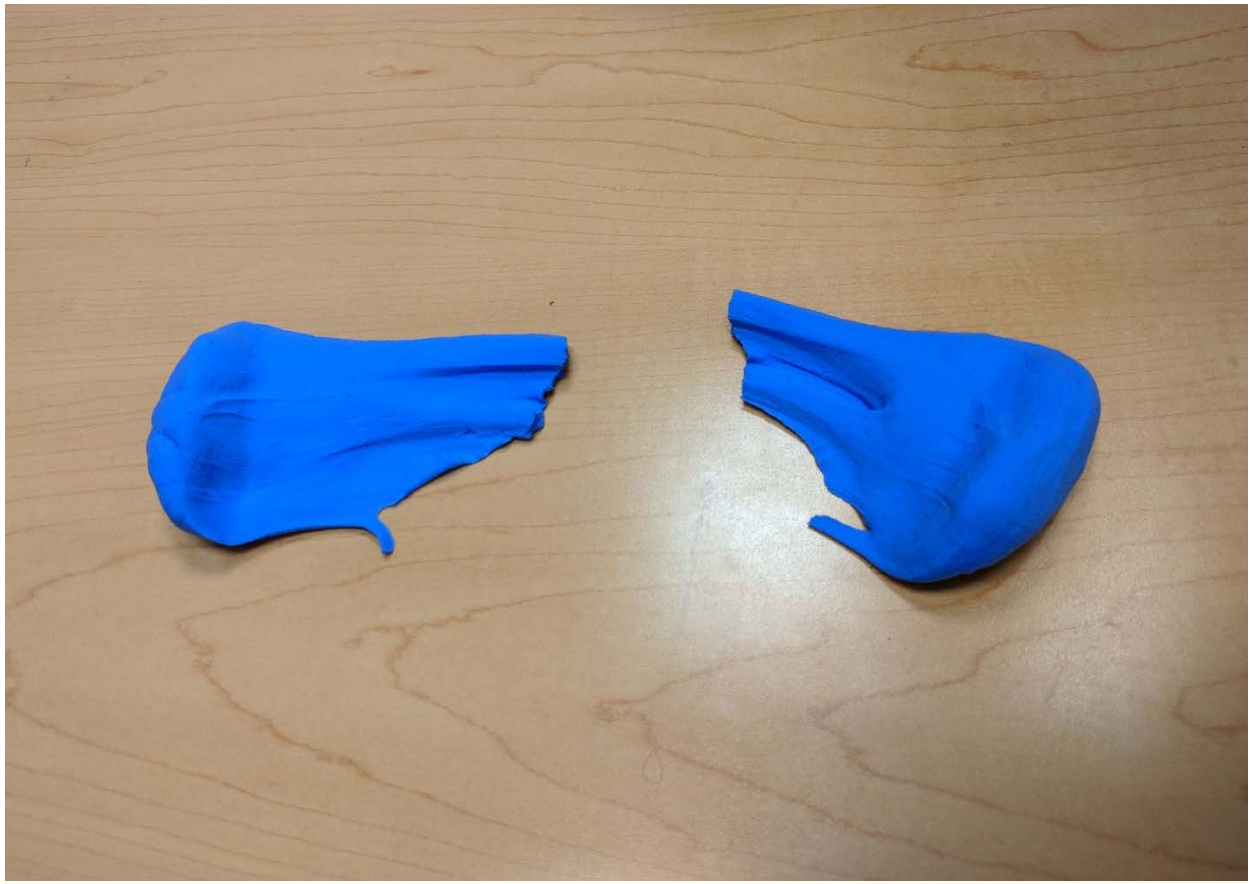
Liz Lehman

Clump of play dough



Liz Lehman

Clump of play dough in 2 pieces



Liz Lehman

Uncolored coloring page

Liz Lehman

Colored coloring page

Liz Lehman

I am in grade _____

Reversible or Not?

Draw or describe an action or change.

I think this action or change is ▢ reversible ▢ NOT reversible

I think this because _____

_____

_____

Ask a friend what they think!

▢ I think the action or change is reversible because_____

_____

_____

▢ I think the action or change is NOT reversible because_____

_____

_____

▢ I'm not sure because _____

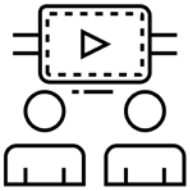
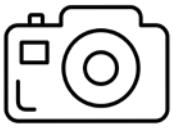
_____

_____

I am in grade _____

Is It Reversible?

Consider each of the actions described below.
Circle the actions that you think are reversible.
Cross out the actions that you think are not reversible.
It's OK if you're not sure!

Building a tower of blocks 	Watching a movie 	Jumping in a puddle 	Climbing a ladder 
Painting a picture 	Taking a photograph 	Baking a pie 	Turning on a lamp 
Braiding hair 	Pouring water into a cup 	Letting the cat out of the bag 	Making a popsicle 

Pick one action and explain your thinking about it. How did you decide if the action was reversible or not?

_____

_____

_____

I am in grade _____

Is It Reversible?

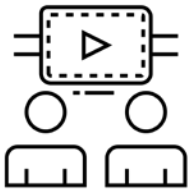
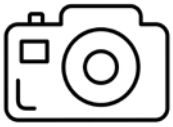
Consider each of the actions described below. Mark if you think it is reversible or not, then explain your thinking. It's OK if you're not sure!

Action	**Is it reversible?**	**Explain your thinking.**
Building a tower of blocks	❑ Reversible ❑ Not reversible	
Watching a movie	❑ Reversible ❑ Not reversible	
Jumping in a puddle	❑ Reversible ❑ Not reversible	
Climbing a ladder	❑ Reversible ❑ Not reversible	
Painting a picture	❑ Reversible ❑ Not reversible	
Taking a photograph	❑ Reversible ❑ Not reversible	
Baking a pie	❑ Reversible ❑ Not reversible	
Turning on a lamp	❑ Reversible ❑ Not reversible	
Braiding hair	❑ Reversible ❑ Not reversible	
Pouring water into a cup	❑ Reversible ❑ Not reversible	
Letting the cat out of the bag	❑ Reversible ❑ Not reversible	
Making a popsicle	❑ Reversible ❑ Not reversible	

I am in grade _____

Is It Reversible?

Consider each of the actions described below.
Circle the actions that you think are reversible.
Cross out the actions that you think are not reversible.
It's OK if you're not sure!

Building a tower of blocks 	Watching a movie 	Jumping in a puddle 	Climbing a ladder 
Painting a picture 	Taking a photograph 	Baking a pie 	Turning on a lamp 
Braiding hair 	Pouring water into a cup 	Letting the cat out of the bag 	Making a popsicle 

Explain your thinking. How did you decide if an action was reversible or not?
Answers will vary, but look for explanations that include the idea that reversible actions can be undone, such that the elements return to their initial states or the way they were before the action was performed.

Expect variation in the level of reversal that is considered acceptable. For example, some may consider "Making a popsicle" reversible because you can melt it but others may consider it not reversible because it's difficult to get back the original, separate ingredients.

I am in grade _____

Is It Reversible?

Consider each of the actions described below. Mark if you think it is reversible or not, then explain your thinking. It's OK if you're not sure!

Action	**Is it reversible?**	**Explain your thinking.**
Building a tower of blocks	X Reversible ❑ Not reversible	You can dismantle the tower.
Watching a movie	❑ Reversible X Not reversible	You will remember it, even if you rewind the movie.
Jumping in a puddle	X Reversible X Not reversible	You can jump back out. You can't get all the water back into the puddle.
Climbing a ladder	X Reversible ❑ Not reversible	You can climb back down.
Painting a picture	❑ Reversible X Not reversible	You can't get all the paint off the canvas.
Taking a photograph	X Reversible X Not reversible	You can delete a digital photo. You can't un-do taking a film photo.
Baking a pie	❑ Reversible X Not reversible	You can't un-bake the pie.
Turning on a lamp	X Reversible ❑ Not reversible	You can turn it back off.
Braiding hair	X Reversible X Not reversible	You can unbraid it. You can't make hair exactly the same as it was before.
Pouring water into a cup	X Reversible X Not reversible	You can pour the water back. You can't get it all back in.
Letting the cat out of the bag	❑ Reversible X Not reversible	It might not want to go back. The other person can't un-learn your secret.
Making a popsicle	X Reversible X Not reversible	You can unfreeze it. You can't get back to the original ingredients.

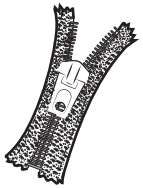
A PEEK INTO...

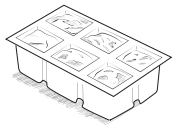
Quantum and Reversibility

Reversibility is all around us!

Shoes can be tied & untied.

Zippers open & close with a simple pull.

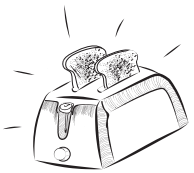




A tray of ice left out to melt refreezes when put back in the freezer.

Some things are NOT reversible

You can't UNBAKE a cookie...

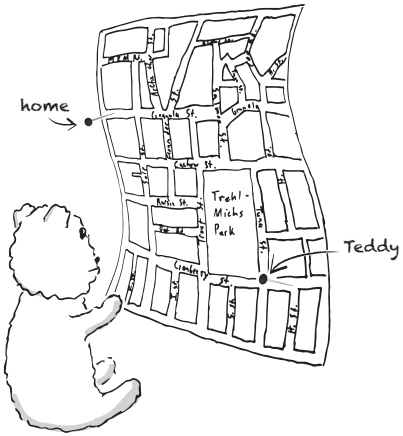


Or UNTOAST bread...

Or UNRING a bell!

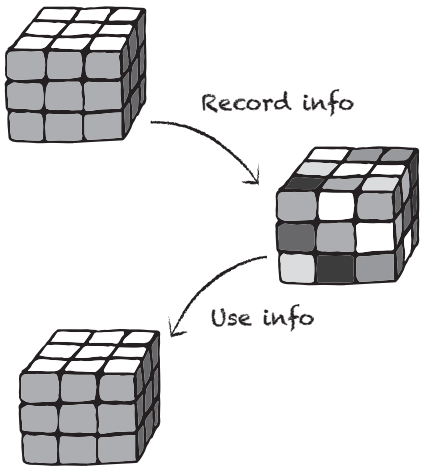
I didn't want toast! Let's untoast it!

Reversing may require recording information



Without a map, what information does Teddy need to get back home by the same route?

Let's solve a Rubik's Cube!



What information would you record to help unscramble your Rubik's Cube?

Is addition reversible??

If I added two numbers and got 8...

$$? + ? = 8$$

...can you tell me what those numbers were?

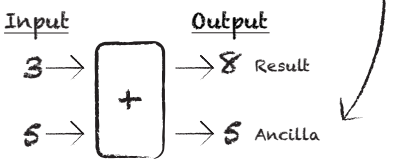
$1 + 7 = 8$
$2 + 6 = 8$
$3 + 5 = 8$
$4 + 4 = 8$

Addition is NOT reversible!

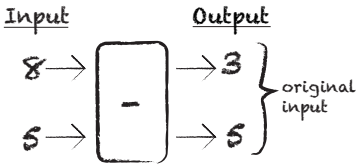
In programs, you know the **order of operations** and **result** but not the **starting value**

Reversibility in Quantum Computing

Quantum computers store extra information in ancilla bits so they can reverse operations.



With this extra information, we can use subtraction to get the original input!

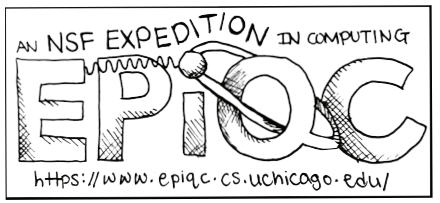


For more Quantum Computing Zines visit:

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

August 2019

This work is funded in part by EPiQC, an NSF Expedition in Computing, under grant 1730449



Share what you've learned about reversibility!

- Teach someone else about what it means for an action to be reversible.
- Identify reversible and irreversible actions during your daily activities.
- Create a Reversibility Obstacle Course: The leader directs actions for the other players to complete. After they have completed them, they have to reverse them to return to where they started. For example, the leader might say, "Hop forward 3 times, then run to the swings, then sit in a swing." After completing those actions, the players would then have to get up from the swing, run backwards, and hop backwards.

  Start with three actions, then increase the number. Try to figure out how many actions can the players remember to do in reverse.

  Be prepared to discuss the rules. For example, do the players need to perform the actions in reverse order?

- Play a game of Reversible Simon Says: The person playing Simon says actions for the other players to perform. The other players should only perform the actions stated by Simon if they are reversible. For example, Simon might say, "Take one step to the right." The other players should perform this action because it can be reversed by taking one step to the left.

  Be prepared to discuss if the actions are reversible or not.

- Play Reversibile Hopscotch: Start with 2 players on opposite ends of a hopscotch court. The first player hops across the course in any manner they choose. The second player has to correctly reverse the path. The players then alternate roles.