5 - 20

5+ years

Reversibility Relay Race

How quickly can you reverse your path?

Learning Goals

- Understand what it means to be able to reverse an action or 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

- ❏ Mats, colored paper, etc. - at least 16
- ❏ Blocks or other objects to stack

Preparation

- Lay out the mats/paper in at least two grids that are 2 x 4 or longer. If using paper, tape it to the floor.
- Place blocks or other objects near the “start” of each grid.
- Decide on the correct path(s) for participants to take through the grid.

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 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

Facilitation Note: Consider conducting this activity after participants have engaged with the Reversibility Cards activity. If you have already read one of these books with the participants, you can skip the Engage.

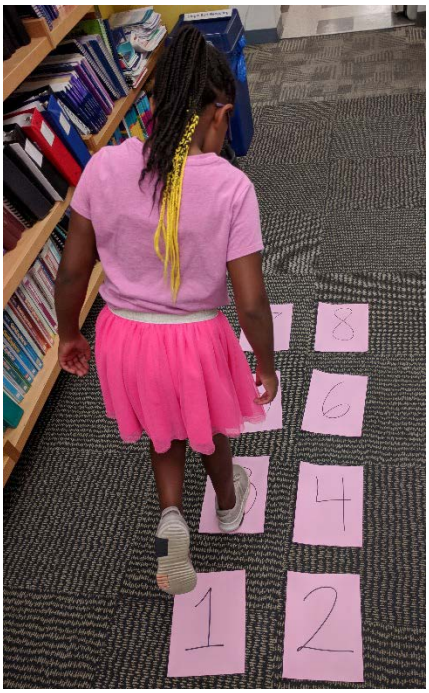
Literacy Connection

1. Read aloud one or more of the following books:
    - *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. Ask: How did the characters in the story reverse their actions?

ACTIVITY

1. Tell participants that you have a game for them to play where they can practice reversing their actions. Show them the grids of mats/paper and objects to stack that you have prepared. Explain the rules.
    a. You will show them the correct path to move from one end of the grid to the other.
    b. Each player has to follow the correct path to the other end of the grid and then *reverse* their path to get back to the start.
    c. If a player makes a mistake, then they have to go back to the start and begin again.
    d. Once a player has correctly moved from one end to the other and reversed their path, they can stack an object to create a tower.



Differentiation Note: Consider writing letters or numbers, or drawing shapes on the mats/paper to help participants find the correct path.

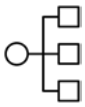
2. Explain if you will conduct the activity collaboratively or competitively.
    a. *Collaborative*: The teams in the activity work together to add blocks to a single tower, and each person that makes it down the path gets to add a block. How tall can the tower get?
    b. *Competitive*: Each team is trying to build its own tower. The first team to reach a certain height or the team with the tallest tower at the end of a given time is the winner.
3. Show participants the correct path through the grid by moving through it yourself and stating aloud each step. Ask: What do I need to do to reverse my path? [*Step on each of the mats in the reverse order.*] Invite participants to decide if it is important to remain facing in the same direction or if it's OK to turn around when you reverse the path. Demonstrate correctly reversing the path, then stacking an object to create a tower.

Facilitation Note: Choose any path you like! Consider variations including jumping with one or both feet, etc. Participants may also benefit from saying the steps out loud as they complete the path (e.g., 1 left, 3 right, 5 both, 8 left). Depending on time and interest, consider repeating the race multiple times with different correct paths.

4. Divide participants into teams and begin the race!

DISCUSSION

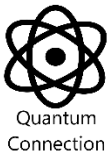
1. Explain to the participants that they just acted like pieces of code in a quantum computer. Quantum computers are different than classical computers because the operations they perform need to be reversible.
2. Ask participants to complete the *Is It Reversible?* worksheet.
3. Tell participants that 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+

4. 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.*]
5. 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.*]
6. 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.*]



7. 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 Concepts: Patterns
Science and Engineering Practices: Using Mathematics and Computational Thinking

Common Core State Standards

Standards for Mathematical Practice:

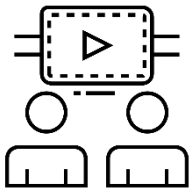
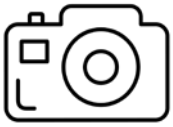
Acknowledgements

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.

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?

_____

_____

_____

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 _____

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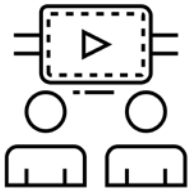
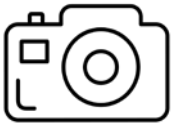
Building a tower of blocks 	Watching a movie 	Jumping in a puddle 	Climbing a ladder 
Painting a picture 	Taking a photograph 	Baking a pie 	Turning on a lamp 
Braiding hair 	Pouring water into a cup 	Letting the cat out of the bag 	Making a popsicle 

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.

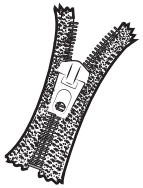
A PEEK INTO...

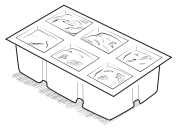
Quantum and Reversibility

Reversibility is all around us!

Shoes can be tied & untied.

Zippers open & close with a simple pull.

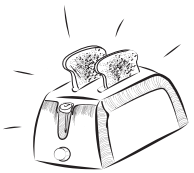




A tray of ice left out to melt refreezes when put back in the freezer.

Some things are NOT reversible

You can't UNBAKE a cookie...

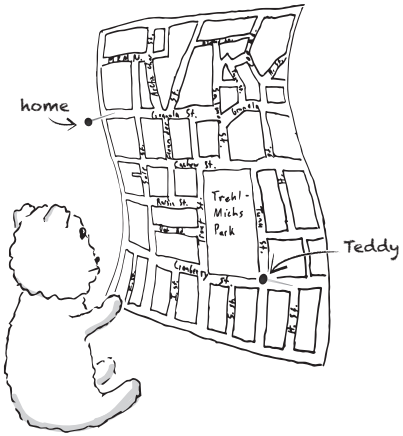


Or UNTOAST bread...

Or UNRING a bell!

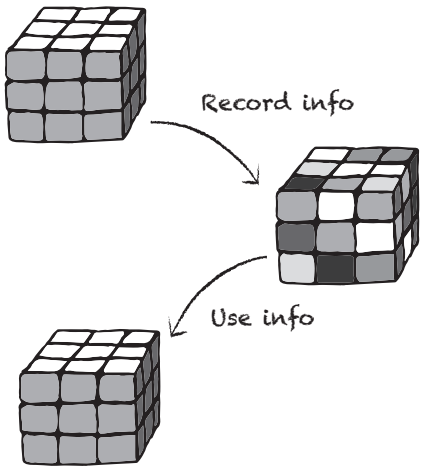
I didn't want toast! Let's untoast it!

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?

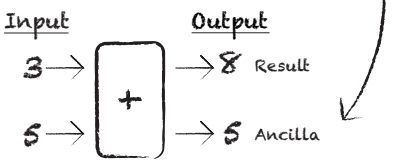
$1 + 7 = 8$
$2 + 6 = 8$
$3 + 5 = 8$
$4 + 4 = 8$

Addition is NOT reversible!

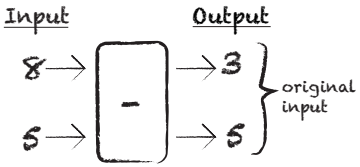
In programs, you know the **order of operations** and **result** but not the **starting value**

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!

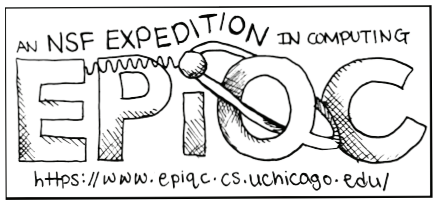


For more Quantum Computing Zines visit:

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.