45-60 minutes

Grades 4-8

Communication without Speaking

Magic trick for communicating without words

Learning Goals

Students will:

- Explore alternative modes of communication by analyzing the magic trick
- Understand that qubits offer novel methods for communication.

Materials

- ❏ Magic Trick Instructions, for teacher
  - ❏ Instructional Video
  - ❏ 1 assistant, trained in advance
- ❏ 1 standard deck of 52 cards
- ❏ *Communication without Speaking* Slide Deck

Importance in Quantum Computing

Quantum computers store and process information in the form of quantum bits (or qubits). The ability of qubits to exist as superpositions of 0s and 1s allows quantum computers to store and process information in ways that would be difficult or impossible for classical computers. The unique features of qubits offer new ways to secure information.

Preparation

- Read Magic Trick Instructions
  - Learn magic trick
  - Teach assistant their role in trick
- Check that you can project the slides

Background Knowledge

While humans are used to communicating by speaking or writing words, computers must use other mechanisms to encode words and other types of information. Classical computers store and transmit data in the form of bits, sequences of 0s and 1s. Every email, image, or video file on your computer is stored in the form of bits, and computing devices communicate to each other by transmitting sequences of 0s and 1s. Many creative methods for communicating bits have been invented for when we need to communicate information more efficiently or privately. For example, the magic trick in this activity describes a method for privately communicating the identity of a card by cleverly ordering a set of four playing cards.

However, there are limits to what we can do with classical computing devices, even with clever tricks. For example, widely used forms of cryptography we rely on to send private information over the Internet might one day be found unsafe to use. Quantum computing is a new field of study that goes beyond what we can achieve with ordinary bits. **Quantum computers** are a new type of computing device that stores information in the form of quantum bits (qubits). A qubit can exist in a superposition of 0 and 1 at the same time. The unique features of qubits allow quantum computers to solve certain computational problems more efficiently than classical computers. And, they also offer novel ways of securing private information that is sent over communication networks.

Facilitating the Activity

MAGIC TRICK (15 minutes)

Facilitation Note: *This lesson involves a two-person magic trick. In advance of the lesson, learn how to do the Magic Trick and train your assistant.*

Tell students that you and your assistant are going to perform a magic trick. Shuffle the deck of cards and take 5 cards from the deck. Tell students that you are going to hide one of the cards, and that your assistant will figure out which card you hid.

Perform the magic trick.

DISCUSSION

Facilitate a discussion about how the magic trick that you performed works.

Tell students that they observed a method of communicating information that privately reveals the identity of the fifth card to the assistant.

- Tell students that the 4 remaining cards were used to communicate information about the *hidden card* to your assistant, and that your assistant was trained in advance to decode the information.

ASK: How do you think the magic trick works? How did the Magician communicate the identity of the hidden card to the assistant?

Some suggestions for discussion about the magic trick.

1. When you perform the magic trick, you have the option of letting the students also see the 4 cards that the assistant receives or not letting the students see the 4 cards. We suggest letting the students observe the 4 cards along with the assistant. The easiest part of the trick to figure out is that the first card reveals the suit of the hidden card. Getting this part of the trick is a good way to promote discussion and lead to some ideas for how the assistant figures out the value of the hidden card and how to use the other 3 cards.

2. Another way to promote discussion about how the trick works is to ask the students to try to first reverse engineer the trick with more than 4 cards. For example: If I give the assistant 7 cards, how would you perform the trick?

After discussing with students both the magic trick and possible ways that it could work, briefly explain how the magic trick works if they haven't figured it out yet:

> Tell them that the first card reveals the suit of the *hidden card*, and the specific order of the remaining 3 cards convey the value of the *hidden card*.
>
> Depending on time available, share more details about how the 3 remaining cards are ordered. Consider demonstrating the magic trick again, while also explaining how the trick is done.

Use the slide deck to facilitate a discussion about how computers store and communicate information and connect this to quantum computing.

SLIDE 2: People communicate with words, but computers cannot directly understand words

SLIDE 3: Everyday computers use classical bits which have value 0 or 1

SLIDE 4: **Communicating with Classical Bits**

- Many creative methods have been invented to communicate information more reliably or privately.
- Our magic trick is an example of how to use clever tricks to communicate information privately.
- Classical computers have their limits, even with clever tricks

SLIDE 5: **Introducing Quantum Computers**

- Quantum computers are a new kind of computer
- Quantum computers will help solve previously unsolvable problems

SLIDE 6: **Quantum Cryptography**

- Widely used forms of cryptography may be discovered to be unsafe in the future
- Quantum computers use qubits to store and communicate information
- Unique features of qubits offer new ways to send private information over the Internet

Magic Trick Instructions

Overview

This magic trick requires two people: a ***magician*** and an ***assistant***. The magician, given 5 cards from a shuffled deck, removes 1 card and gives the remaining 4 cards to the assistant. The assistant examines the 4 cards and identifies the ***hidden card!*** The magician strategically chooses the *hidden card* and uses the four remaining cards to communicate information about the hidden card's suit and value.

Set-Up

1. Pick 5 cards

Someone in the audience shuffles a standard deck of cards, picks 5 cards, and gives them to the magician. At this time, the assistant does NOT look at the cards.

2. Choosing the *Hidden Card*

Given the 5 cards, the magician identifies 2 cards that have the same suit (called the ***suit pair).*** If there are more than 2 cards that share a suit, it doesn't matter which you choose - any 2 cards of the same suit will work.

MATH CONNECTION: THE PIGEONHOLE PRINCIPLE

Why is it always possible to find 2 cards that have the same suit?

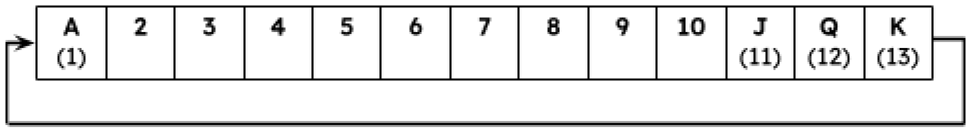
This trick leverages a mathematical idea called the pigeonhole principle:

> If (N+1) pigeons roost in N holes, then 1 hole must have at least 2 pigeons

A standard deck of cards contains 52 cards with each card having both a face value (between 1 and 13) and a suit (clubs ♣; diamonds ♢; hearts ♡; spades ♠). When applying the Pigeonhole Principle to this card trick, the magician sorts 5 cards according to their suits. So, given 5 cards ("pigeons") and only 4 possible suits ("holes"), the Pigeonhole Principle tells us that there will be at least 2 cards that share the same suit.

Now, the magician decides which of the two cards in the *suit pair* will be the ***hidden card.***

Determine each *suit card's* face value (between 1 and 13), compare the values, and determine the *hidden card*. The *hidden card* is the card with a face value that is at most six "larger" than the other card. When you reach the K (13), you continue counting back at A (1), not unlike hours on a clock.



Card face values (viewed as a cycle)

Example: If the suit pair is 4H and 6H, then the *hidden card* is 6H, because 6 is not more than 6 larger than 4.

Communicate the Hidden Card's Suit

The first card the magician gives to the assistant is the "smaller" suit pair card, so the first card that the assistant will see reveals the ***hidden card's*** suit.

Communicate the Hidden Card's Value

Information about the face value of the *hidden card* is communicated through a strategic ordering of the 3 remaining cards.

Hidden Card FACE VALUE = Remaining Suite Pair FACE VALUE + ORDER VALUE

The assistant knows the face value of the "smaller" *suit pair* card, because it is the first card that is presented. The assistant must then look at the order in which the remaining three cards are presented by the magician.

The magician calculates the difference between the *hidden card's* face value and the remaining *suit pair* card's face value. Then, using the table to the right, determines which card order has that same value.

The 3 remaining cards can be ordered based on their value. If we need to break any ties, the suits are ranked alphabetically: **C**lubs < **D**iamonds < **H**earts < **S**pades

Consider the ranked order of the three remaining cards to be: A < B < C. There are 6 possible orderings of these three cards: ABC < ACB < BAC < BCA < CAB < CBA

Example: For an *order value* of 4, the magician would order the three cards as BCA.

ORDER	VALUE
ABC	1
ACB	2
BAC	3
BCA	4
CAB	5
CBA	6

Example 1

<table>
<tr><th>Magician</th><th>Assistant</th></tr>
<tr><td>Audience chooses 5 cards:
6H, 5S, 10C, 4H, 1D
Choose the Hidden Card:
● There are two hearts, 4H and 6H.
● One of the two cards is at most 6 larger than the other card.
● Because 4 + 2 = 6, 6H is the larger card, and the order value is 2.

The hidden card is 6H.</td><td>The assistant receives 4 cards: 4H-1D-10C-5S</td></tr>
<tr><td>Communicate the Suit:
● Give 4H to the assistant.</td><td>Determine the Suit:
● The first card we see is 4H, so the hidden card's suit is heart.</td></tr>
<tr><td>Communicate the Value:
● The 3 remaining cards are: 5S, 10C, 1D
● These three cards are ordered as:
A = 1D, B = 5S, C = 10C.
● ACB = 2, so we choose the order 1D-10C-5S</td><td>Determine the Value:
● The smaller suit pair value is 4.
● The 3 remaining cards 1D, 10C, 5S, have an ordering of:
A = 1D, B = 5S, C = 10C
● The 3 cards were presented in the order ACB, which has an order value of 2.
● The hidden card's value is 4 + 2 = 6</td></tr>
<tr><td>Hidden card: 6H
Assistant receives: 4H-1D-10C-5S</td><td>Hidden card: 6H</td></tr>
</table>

Example 2: Counting card values in a cycle

Magician	Assistant
Audience chooses 5 cards: 9C, 1D, 1H, 1C, 4S **Choose the Hidden Card**: • There are two clubs, 1C and 9C. • One of the two cards is at most 6 larger than the other card. • When we view the card face values as a cycle, 9 + 5 = 1, so 1C is the “larger” card, and the *order value* is 5. The hidden card is: 1C	The assistant receives 4 cards: 9C-4S-1C-1D
Communicate the Suit: • Give 9C to the assistant.	**Determine the Suit**: • The first card we see is 9C, so we know the *hidden card’s* suit is club.
Communicate the Value: • The 3 remaining cards are: 1D, 1H, 4S • These 3 cards are ordered as: A = 1D, B = 1H, C = 4S • CAB = 5, so we choose the order as: 4S-1D-1H	**Determine the Value**: • The *smaller suit pair value* is 9. • Remember that suits are ranked as C < D < H < S. • The 3 remaining cards 4S, 1C, 1D are ordered as: A = 1D, B = 1H, C = 4S • The 3 cards were presented in the order 4S-1C-1D, CAB, which has an *order value* of 5. • When we view the card face values as a cycle, 9 + 5 = 1. • The hidden card’s value is 1.
Hidden card: 1C Assistant receives: 9C-4S-1D-1H	*Hidden card:* 1C

Connections to Standards

Next Generation Science Standards*

Performance Expectations

4-PS4-3. Generate and compare multiple solutions that use patterns to transfer information.*

Common Core State Standards
Standards for Mathematical Practice:

QIS K-12 Key Concept
4. Qubits

The quantum bit, or qubit, is the fundamental unit of quantum information, and is encoded in a physical system, such as polarization states of light, energy states of an atom, or spin states of an electron.

7. Quantum Computing

Quantum computers, which use qubits and quantum operations, will solve certain complex computational problems more efficiently than classical computers.

8. Quantum Communication

Quantum communication uses entanglement or a transmission channel, such as optical fiber, to transfer quantum information between different locations.

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