Lesson 1: Cryptology

High School Cybersecurity Unit: CyberEthics, the Moral Quarrel

Lesson Overview	Career Highlight
Since the development of language and communication, humans have needed to communicate clearly and selectively. As civilizations developed and separated, power struggles and politics emerged. Codes were used to ensure security from other tribes and kingdoms. One of the ancient codes we are aware of is Egyptian hieroglyphics, where only trained scribes could transmit codes for kings. As communication and technologies advanced from physical hieroglyphics to electronic files, more intensive codes and code-breaking skills evolved to compete with opposing civilizations. These ideas are now called cryptography and cryptanalysis. Cryptography is the art and science of creating secret messages to ensure security, while cryptanalysis is deciphering and breaking the codes. The invention of coding machines and computer technology shifted cryptology and cryptanalysis to be more mathematically focused. In this lesson, students will explore the history of code making and breaking, or cryptography and cryptanalysis by creating their own codes and breaking others. Ancient codes are introduced, such as the Caesar Cipher before more current case studies of cryptology are explored, including the creation of the Enigma Machine during World War II, and the Cuban Missile Crisis involving the U.S. The lesson concludes with an introduction to the ethics associated with secrecy and transparency as it relates to security and freedom.	Cryptologist: An expert in the study of codes who helps decipher, analyze, and protect information. Mathematician: A person who uses mathematics (numbers, equations, and algorithms) to solve problems, ranging from school teachers to computer programmers. Some research and develop mathematical theories while others use these theories to solve everyday problems. Mathematicians also analyze and interpret data for a variety of purposes such as business, engineering, or science decisions. Security Expert: Creates and implements security assessments of hardware and software systems, making sure they perform the way they are supposed to and are safe from attack. Espionage Agent: Employed to spy on another country or business competitor; military secret agents are hired to retrieve information about enemies. Cryptanalyst: A code breaker who is responsible for analyzing secret messages using various methods to decode or decrypt the data, which can be done with or without an encryption key.

STEM Course Connections	Timing
Computer Science Biology Chemistry Physics Earth Science Integrated Science Other: English, History, Sociology, Psychology, Anthropology	Five class sessions at 45 minutes each

Science and Engineering Practices	Engineering Activity
2. Developing and using models 4. Analyzing and Interpreting Data	Students will work in teams to develop and use models as they create codes to communicate secret information. Students will use mathematics and computational thinking as they analyze and interpret each other's codes in an attempt to decipher the secret message. Students will discuss and argue ethical topics dealing with security versus freedom.

Essential Questions

1. How can delicate information be communicated secretly and securely?
2. Why is it important to transmit certain information securely?
3. What are the risks and benefits of secrecy versus transparency?

Lesson Objectives

Learning Goals:

- Students will develop a code to communicate a secret message.
- Students will analyze and decipher a code to determine the message.
- Students will apply historical case studies to evaluate the pros and cons of secrecy versus transparency in communication.

Materials

All materials in Student Handouts, unless otherwise noted.

- Lesson 1 Handout: Days 1-5
- Day 4 Teacher Resources
  - Code Cards
  - Code-Breaking Example
- Code Breaking Case Studies
  - Case Study 1: Enigma Code
  - Case Study 2: Revolutionary War
  - Case Study 3: Native American Codes
  - Case Study 4: Mary, Queen of Scots
  - Case Study 5: General Scovell
  - Case Study 6: NSA
  - Case Study 7: Civil War
  - Case Study 8: Juanita Moody
- Cybersecurity Wiki Outline

Lesson

Day One: Introduction to Ciphers

Teacher Note: Consider inviting a STEM professional to help introduce students to codes and the historical context of cryptology.

- **Whole Group (10 minutes)**
  - Show students the first two minutes of the following video: *Oprah and Gayle Guess Slang Words | OG Chronicles* (Oprah Mag, 2019)
    - Discuss the following with the class: "What kind of appropriate slang terms can you use around your parents/guardians that they would not understand?"

  - Show students *50 Vintage Slang Words That Sound Hilarious Today* (Larkin, 2020), a list of antiquated slang words, and see if they can guess the meanings.
    - Tell students that young people have used slang as a way to communicate quickly, freely, and to keep current. Not everyone can understand the coding of slang, and a "key" is needed to decipher what is being said.

- **Small Group: Think/Pair/Share (five minutes)**
  - Tell students they are going to be discussing cryptology, which is communicating and storing data in secure, secret forms. Ask students the following discussion questions. Give them two minutes to discuss with a partner before discussing with the class:
    - "Think of a time you wanted a message to be sent to someone that was secretive. How did you get that secret message to them?"
    - "Many times, these secrets need to be shared in times of crisis, like during a war. When do you think other people need to send secret messages, like in times of war, and how might they send them?"
    - "What does a spy do in times of war?"

- **Whole Group (five to 10 minutes)**
  Teacher Note: If your students aren't familiar with the basics of World War II, you may wish to show a more extensive video describing the war.

  - Tell students that during World War II, the biggest and deadliest war in history, communicating secretly was very important. Show them *World War 2 - explained in 5 minutes - WW2 - WWII - mini history - 3 minute history for dummies* (YouTube, 2020) which describes the basics of World War II.

  - Tell students that during World War II, a machine called an Enigma Machine was used by the German military to encrypt, or encipher, top-secret messages (where troops were to move, where enemy troops were located, etc), making it incredibly difficult for other nations to decode German messages. However, English mathematician and cryptanalyst, Alan Turing, along with other researchers, found weaknesses in the Enigma code, eventually designing a machine that helped crack the most challenging codes, deciphering the secret messages. Some have credited the cracking of the Enigma code as the most important victory of the Allied powers during World War II, allowing them to prevent many attacks, although some attacks were allowed to be carried out to avoid Germans suspecting that their codes had been broken.

  - Show students *The Imitation Game Official Trailer #1 (2014) - Benedict Cumberbatch Movie HD* (YouTube, 2014). Have students read through the following discussion questions prior to viewing. After viewing the preview, invite students to discuss the following discussion questions as a class:
    - "What was the importance of breaking the Nazi code?"
    - "What do you think the world would be like if the Enigma Machine did not work?"
    - "We often see spies leading exciting lives, like James Bond. Do you think that's how it is in real life? What do you think a spy actually does?"
    - "How might mathematicians have behaved like spies in breaking the Nazi code?"

        - **(optional question based on student age)** "What have you learned about World War II from your history class?"

    - Tell students: "The Enigma Machine is based on mathematics, using algorithms, or calculated rules, to break a code. We'll now discuss how ciphers, or codes, have historically been used, and how they might be broken."

    - *Optional teacher background/student extension: Cracking the Enigma in 2021 - Computerphile (YouTube, 2021)*

- **Small Group (20 minutes)**
    - Give students Lesson 1: Day 1 of the Student Handouts.
        - Ask students to talk to their partner to define what they think these three words mean when sending coded messages:
            - Confidentiality
            - Integrity
            - Availability

        - After students have had a few minutes to discuss, tell them: "The CIA is important in making secure systems and policies. Confidentiality ensures messages are kept secret or private. Access to messages must be controlled for this reason, and information is only shared with the intended recipients. Integrity involves making sure the information is trustworthy and free from tampering. It must be authentic, accurate, and reliable. Availability means that communication systems are functioning properly and access is easy and available. Redundancy helps with this in case one way of communication is blocked. We will come back to this later to evaluate the CIA of an encryption system at the end of the day."

        - Introduce students to a Caesar cipher (*Wikipedia*, 2022) (show a picture) and have them explore the *Origin of Cryptography* (Tutorials Point, n.d.) answering guided reading questions.

        - Tell students to create a Caesar cipher shift of their choosing (make sure students write down their cipher so their message can be decoded!) and a school-friendly two-worded message of their own using a Caesar cipher.

        - Have students switch ciphers and coded messages with their partner to read.

        - Optional: Students can switch one message with another team to try to break the team's code.

        - Students should end with a reflection on the CIA of their encrypted codes and weaknesses in the German code. This might be a good point of discussion as a whole group.

- Closure: Remind students of the importance of breaking the coding system Germany was using during World War II; it ended the war, and stopped Nazi Germany from advancing. Ask students what the weaknesses of the German CIA were when encoding messages. A tremendous amount of resources went into the effort to break the code. Ask students: "If this didn't take place, how might that have changed the outcome of the war?"

Day Two: Historical Use of Ciphers

- **Jigsaw: Reading/Small Group/Partner Discussion (15 minutes)**
    - Review what ciphers are and the purpose of using codes (from the previous day). Tell students today they will be investigating a historic case where codes were used to communicate information secretly and securely.

    - Have students split into their assigned case study, taking notes on Lesson 1: Day 2 of the Student Handouts as they read through the case individually. Students will work together to make their case study posters (e.g., four students per case may work best for your class). Students should begin by reading their assigned case in the Code Breaking Case Studies from Student Handouts. Students who have additional time or wish to further their understanding of the case may also wish to do further internet research.
        - Case Study 1: Enigma Code
        - Case Study 2: Revolutionary War
        - Case Study 3: Native American Codes
        - Case Study 4: Mary, Queen of Scots
        - Case Study 5: General Scovell
        - Case Study 6: NSA
        - Case Study 7: Civil War
        - Case Study 8: Juanita Moody

- **Small Group: Group Slide Deck/Poster Creation (15 minutes)**
  Teacher Note: Instead of a slide deck, students could create tangible posters and do a gallery walk to visit each poster.

    - Tell students they will be making one slide in a class slide deck that communicates what they learned about in their case. A visual representation should be included. Remind students of the time constraint and that they have 15 minutes to create their informational slide. The focus should be on communicating the information quickly and efficiently:
        - "Who is/was involved (Who made/broke the code)?"
        - "Why was coding important/needed (was it a war? time of struggle?)?"
        - "Where did this take place?"
        - "Why were secret messages needed to be sent at this time? What was the overall outcome?"

- **Whole Group (15 minutes)**
    - Tell students they will observe each other's work, and use the slides to fill in the missing information for four of the scenarios, such as who was involved and why coding was important.

    - Ask students what themes they may have noticed as they observed each other's slides. Write these ideas on the board as they come up. What connected the cases? What did they have in common? Have students vote as a class on the best connection. If students don't come up with something similar to "coding used to save lives", "right versus wrong", or "gray areas", you may wish to steer the discussion in one of these directions.

    - Encourage students to come up with some ethical questions based on the historical cases they viewed by asking them if they found anything that seemed uncomfortable about a case, or that they found a difficult decision being made. These points can then be turned into questions, like "Should the outcome justify the means to get there?". Tell students that ethical questions can begin with "should."

    - Tell students they will address the difficulties associated with ethical questions in the final

activity. They will create a running list of ethical questions that come up throughout the unit. They will be introduced to the space to place these questions tomorrow.

- Closure: Ask students: "What do you think the country's responsibilities are when dealing with these ethical dilemmas?"

- Optional: Make the ethical question list visible to students in the classroom to spark ideas as their final activity approaches.

Day Three: Cryptology/Cryptanalysis Practice and WikiPage

Teacher Note: Considering inviting a STEM professional into the classroom for the activity where students are creating and breaking each other's codes.

- Review the Code Breaking Case Studies from Student Handouts from the previous day with students. Remind them about the CIA triad. Ask them how each part is important and why it is problematic when one part is missing.

- **Small Group (25 minutes)**
    - Introduce students to the *CRYPTOLOGY GAME* and have them click on the "About" section.

    - Tell students to investigate/play through the "normal" level ciphers. Remind students that these codes are ways to send secret information. If time permits, you may have students investigate the "hard" level ciphers. Have students take notes in their Lesson 1: Day 3 of the Student Handouts on each cipher, identifying what makes them good ciphers, why they would be hard to break, and potential weaknesses.
        - Extension: You may wish to show students *How did the Enigma Machine work?* (YouTube, 2021) to give them a better understanding of the inner workings of the Enigma Machine.

        - Tell them: "If an Enigma Machine were taken apart, it may be 'reverse engineered' or easily decoded. Would this be the same if a computer were used for the enciphering message?"

- **Whole Group (five minutes)**
    - Show students an example of a Wiki page (either of your choosing or tell them to look up the Wiki page of something important to them). Discuss with students the layout and features of an effective *5 Essential Tips For Creating A Killer Corporate Wiki* (Singh, 2017).

- **Small group (15 minutes)**
  Teacher Note: A Wiki page is a tool to help students with their discussions in Lesson Six. This does not need to be a graded assignment.

    - Tell students they will be creating an ongoing Wiki page (Google Doc, Google Slide, or website such as Weebly) to document their learning throughout each lesson. Remind them that this will be a necessary tool for their final project, where they will have discussions around the ethically challenging world of cybersecurity.

- Tell students that throughout the unit, they will add to their Wiki page using the format in this Cybersecurity Wiki Outline. In today's entry of their Wiki page, students should capture what they learned in this lesson by including the following content:
    - 10 vocabulary words written at a 10th Grade reading level (e.g., cipher, decipher, cryptology, Cuban Missile Crisis, enigma, code breaking, espionage, cryptography, cryptanalysis).
    - Careers (at least two mentioned in previous day's lessons; these will also come up in the following day's lesson).
    - At least one ethical question that came up from previous activities. Ethical questions begin with the word "should".
    - Cite sources/footnotes (if applicable today).

- Tell students to finish their Wiki page for homework if not completed in class (or if an extra day is desired, this can be extended).

- Optional Extension: For historical context, this would be an excellent time to insert a brief lesson on the events leading up to and included in the Cuban Missile Crisis if you wish for students to have a deeper understanding prior to the next lesson.

Day Four: Case Study of Cuban Missile Crisis and Careers

- **Small Group (20 minutes)**
    - As a callback to Enigma and the Cuban Missile Crisis, ask students: "Who do you think were the most important players/careers and what might they have done to make/break codes?" (i.e., security expert, mathematician, politician, spy)
        - Encourage students who studied the Cuban Missile Crisis case to share more here (or other students can share and the students who studied the Cuban Missile Crisis can prompt others if they need help).

    - Ask students to discuss the following question with their partner and to record their initial thoughts on their Lesson 1: Day 4 of the Student Handouts.: "Does secrecy protect peace?"

    - Tell students: "We will soon engage in an activity where secrecy and peace are in conflict."

    - Tell students: "You will take on a stakeholder role in the Cuban Missile Crisis. A stakeholder is someone who is interested in or affected by a decision."

    - Split students into groups of eight. Have each student choose one person from the list and research a brief description of their person in relation to the Cuban Missile Crisis, recording their research on Lesson 1: Day 4 of the Student Handouts.. Encourage students to choose roles from both the US and the Cuban/Russian side to have a well-balanced understanding of the Crisis.
        - U.S. Roles in the Cuban Missile Crisis:
            - President Kennedy
            - Robert Kennedy
            - Ted Sorensen
            - Dean Rusk: U.S. Secretary of State
            - Gordon Wlechman
            - Oleg Penkovsky

- Attorney General
- Cybersecurity Expert
- War Photographer

■ Cuban/Russian Roles in the Cuban Missile Crisis:
- President Castro
- Nikita Khrushchev
- Soviet Ambassador: Anatoly Dobrynin
- Anastas Mikoyan
- Cybersecurity Expert
- Mathematician

○ Remind students that a well-functioning team is composed of a variety of individuals, each with their own strengths to contribute. Have students discuss and summarize their person with their group, noting a strength their member might bring to the group.

Small Group: Creating Ciphers (25 minutes)

○ Split the groups of 8 into groups of 4, each small group becoming a team: Team 1 and Team 2.

○ Tell students that their team of four will be using codes/ciphers to create messages about the events of the Cuban Missile Crisis that need to be transmitted secretly/securely while ensuring the message is able to be successfully decoded by their allies. Whichever team is able to decipher all the opposing team's messages before time is up wins and nuclear war is avoided. If neither team completes all codes, then both teams lose.

○ Give each team four key event messages from the Code Cards. Instruct teams to create codes for the following messages:

■ Team 1 Codes (team 1 codes the message, team 2 decodes)
- Dec. 19, 1960: Cuba aligns itself with the Soviet Union, cutting diplomatic ties to the U.S.
- April 17, 1961: The U.S. tries and fails to overthrow Castro's government in Cuba in the 'Bay of Pigs.' Castro seeks help from the Soviet Union.
- July 27, 1962: Pres. Castro announces that any direct U.S. attack on Cuba would result in the equivalent of a world war.
- Aug. 10, 1962: CIA director informs Pres. Kennedy that Soviet medium-range ballistic missiles will soon be deployed in Cuba.
- Oct. 14, 1962: Photos obtained from the U.S. as evidence of nuclear missiles stationed in Western Cuba.

■ Team 2 Codes (team 2 codes the message, team 1 decodes)
- Oct. 23, 1962: 'Naval blockade' ordered by Pres. Kennedy to prevent the transportation of missiles.
- Oct. 26, 1962: Discussions begin in the U.S. to invade Cuba.
- Oct. 26, 1962: Pres. Khrushchev sends word to Pres. Kennedy offering to remove his missiles in Cuba on the condition that the U.S. never invade Cuba, and remove missiles in Turkey that are threatening the Soviet Union.
- Oct. 27, 1962: U.S. spy plane gets lost and enters Soviet air space.
- Oct. 28, 1962: Pres. Khrushchev announces that he will remove missiles in Cuba.

- Tell students they will have the remainder of the class to choose a cipher (for instance, the Caesar cipher) and encode their message, which will be used in the code-breaking activity on Day 5. An example can be found in Code-Breaking Example. Remind students that they may or may not want to use the same cipher as their group members, because if the opposing team figures out the cipher for that message, it will be easier for them to decode all messages. Each team will hand their opponents the coded messages and ciphers in a mixed pile tomorrow. Teams will use the given ciphers to try to decode the messages in a given time frame.

- Ask students what the strengths and weaknesses are for using or not using the same cipher. They may choose from the following easy or medium ciphers they used the previous day: pig pen, Caesar cipher, transposition, rail fence, atbash, or polybius. Remind students that the cipher they choose needs to be easy enough for their teammates to decipher in a short amount of time, but not so easy that the opposing team could intercept it.

- Allow students time to choose their ciphers and encode their messages. If students finish early, they may wish to test each other's ciphers to make sure they work appropriately.

Day Five: Breaking Codes to Avoid Nuclear War

- **Small Group (25 minutes)**
  - Show students the Spies Among Us video, introducing them to the issue of the nuclear arms race. Tell students they will be working with their group of four and will experience what it might be like to break a code and that it is up to them to avoid nuclear war.
    - *Teacher Note: For a more in depth history of the Cuban Missile Crisis, you may also want to show The history of the Cuban Missile Crisis - Matthew A. Jordan* (YouTube, 2016)

  - Remind students that the goal of this activity is to use the ciphers given to them from their opposing team to decipher the coded messages also given to them from that team. Before beginning, remind students to make sure that each coded message card is cut out and each cipher is cut out and mixed up so the opposing team has to work to match the correct cipher with the correct code.

  - Have groups exchange (intercept) codes and ciphers with other groups keeping the cards face down. When all groups have their cards, you may shout "GO!". Students should flip the cards over and try to break their opposing team's five codes as quickly as possible.

- **Whole Group (20 minutes)**
  - Tell students to discuss the following questions with their group and call on groups to share with the class:
    - "What parts of the CIA were emphasized in the activity?"
    - "When is it helpful to use codes?"
    - "Why is it important to have secure codes? What is at risk if your code is broken?"
    - "Do you think codes still exist today? How do you think they're used?"
    - "What do you think could be some problems with secrecy and intelligence gathering?"

- Follow-Up Questions:

- "If the advisory counsel was from a more diverse group, how do you think they may have advised the leadership in similar or different ways? Why?"
- "When making difficult decisions, why is it important to have a diverse group of people working on a solution?"
- "What ethical questions arise about secrecy and intelligence gathering?"

Teacher Note: Students may need more time and can continue answering these questions as homework, or as an opening activity for the next class period.

CTE Alignment

7.8 Explore issues of global significance and document the impact on the Information and Communication Technologies sector.

10.8 Understand security concepts including authorization, rights, and encryption.

Resources

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Code Cards

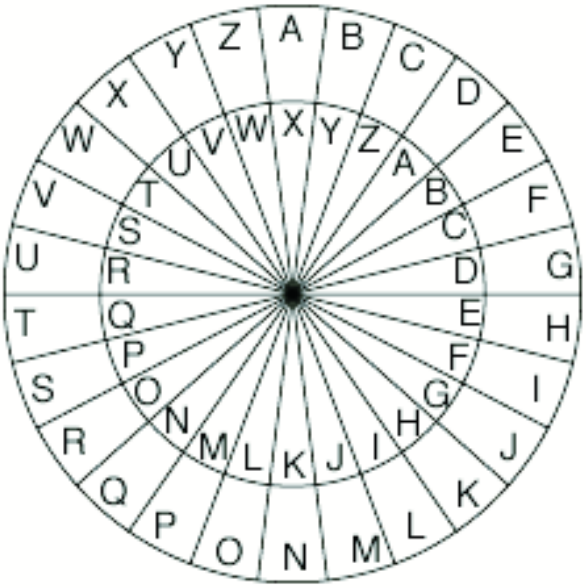
Teacher Directions: Choose four of the following for each team to encode. Cut out and hand to groups.

Russian Codes	**U.S. Codes**
Dec. 19, 1960: Cuba aligns itself with the Soviet Union, cutting diplomatic ties to the U.S.	Oct. 23, 1962: 'Naval blockade' ordered by Pres. Kennedy to prevent the transportation of missiles.
April 17, 1961: The U.S. tries and fails to overthrow Castro's government in Cuba in the 'Bay of Pigs.' Castro seeks help from the Soviet Union.	Oct. 26, 1962: Discussions begin in the U.S. to invade Cuba.
July 27,1962: Pres. Castro announces that any direct U.S. attack on Cuba would result in the equivalent of a world war.	Oct. 26, 1962: Pres. Khrushchev sends word to Pres. Kennedy offering to remove his missiles in Cuba on the condition that the U.S. never invade Cuba, and removing missiles in Turkey that threaten the Soviet Union.
Aug. 10, 1962: CIA director informs Pres. Kennedy that Soviet medium-range ballistic missiles would soon be deployed in Cuba.	Oct 27, 1962: U.S. spy plane gets lost and enters Soviet air space. Pr.es. Kennedy agrees with Pres. Khrushchev's proposal, and removes missiles in Turkey.
Oct. 14, 1962: Photos obtained from the U.S. as evidence of nuclear missiles stationed in Western Cuba.	Oct. 28, 1962: Pres. Khrushchev announces that he will remove missiles in Cuba.

Code-Breaking Example

Teacher Directions: Make copies for students to cut out, each box will be cut out and separated, each group will need two 1/2 of the following.

Coded Message
Example: Uif dbu buf uif sbu QEB ZXQ XQB QEB OXQ *(THE CAT ATE THE RAT)*

Cipher


Coded Message

Cipher