Be a detectivE: the pAper Mystery

Target Grade: Elementary/Middle
Author(s): Erica Liu
Semester: Fall 2018

Brief Overview

“Data! Data! Data! I can’t make bricks without clay.” – Sherlock Holmes*, The Adventure of the Copper Beeches*

In this lesson, mentees will put on their detective hats and explore aspects of forensic science by solving a mystery of their own. Mentees will decode messages, use paper chromatography, and examine fingerprints to deduce the culprit.

Main Teaching Goals

- Introduce **forensic science** as an interdisciplinary field that combines skills from chemistry, biology, and engineering. “Forensic scientists preserve, collect, and analyze scientific evidence during the course of an investigation.” - *Wikipedia*
- **Cryptography** deals with the secure transfer of information by means such as encryption. For examples, computers are often used to encrypt information.
- **Chromatography** is a technique to separate components of a mixture based on chemical or physical properties such as size, charge, polarity, etc.
    - (*optional*) **Thin layer chromatography (TLC)** separates components based on polarity.
- Each person has unique fingerprints. Fingerprints are a useful form of identification.
- A piece of evidence can be analyzed in multiple ways to gather more information.

Careers and Applications

Sherlock Holmes is perhaps one of the best known fictional detectives and forensic scientists. Through a combination of observation, deduction, and forensic science, he solves crimes. Forensic scientists often work as or collaborate with crime scene investigators who gather evidence or analyze data in laboratories. With the advancement of technology, methods such as DNA analysis, chemical analysis, and chromatography are gaining prominence.

Agenda

- Introduction

- Module 1: Caesar Ciphers (20 min)
- Module 2: Paper Chromatography (15 min)
- Module 3: Fingerprint Analysis (15 min)
- Conclusion

Introduction

To begin the lesson, mentors should set up the mystery/crime scene. (Note: If mentors are more engaged in the set up, the mentees are more likely to be interested as well. The mentor introducing the mentees to the story should be especially enthusiastic.)

A reward that was supposed to be for today's BEAM lesson has mysteriously disappeared. (For sites that don't allow candy, stickers or an alternative will be the reward.) Lucky for us, however, the culprit left behind a coded note and an ink covered paper towel. After determining what the note says, which marker was used, and whose fingerprint was on the note, students will piece together the evidence to determine which mentor is responsible for the disappearance of the reward. DO NOT reveal that a mentor is responsible for the missing reward.

Once the mystery is set up, explain to the mentees what forensic scientists do and how today we'll use some cool techniques that scientists use to solve our mystery.

When first examining the note, ask the mentees what they notice about the note (i.e. the fingerprint). They should notice right away that the words on the note don't make sense.

Module 1: Caesar Ciphers

(adapted from "Deciphering Activity" by Ashley Chen and Tiffany Ma, Fall 2016)

Introduction

In this module, mentees will decode the message on the note left at the scene of the crime. Ciphers are a way of encoding information so that only someone who knows the algorithm can decode the information.

Teaching Goals

1. **Ciphers** are a way of encoding information. (Specifically, a cipher is an algorithm).
2. A Caesar cipher is a type of **substitution cipher**. Units such as letters are replaced by other units.

Background for Mentors

Ciphers are algorithms that are used to encode information. While there are multiple types of classical ciphers such as substitution ciphers or transposition ciphers, ciphers all have three main components: plaintext, ciphertext, and key. The **plaintext** is the original message. For example, "I like to eat". The **ciphertext** is the encoded message. For example, "I like to eat" becomes "n qnpj yt jfy" when a shift of 5 letters is applied. The **key** is information that helps decode the ciphertext. In the example above, the key is the shift of 5 letters.

We will be using a **Caesar cipher** in this module. The Caesar cipher is named after Julius Caesar and is a simple substitution/shift cipher. All of the letters are shifted a certain number of letters down. If a shift of 3 is applied, A→D and B→E and so on. The outer wheel serves as the plaintext and the inner wheel as the ciphertext.

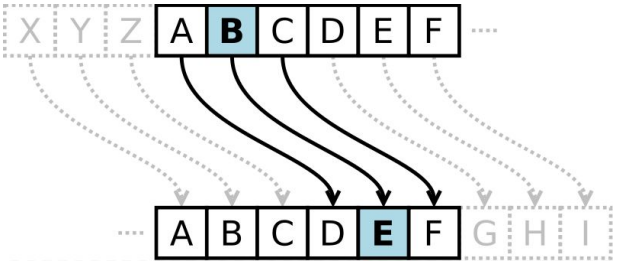


Figure 1. Caesar cipher with a shift of 3

With the development of computers, encryption and the algorithms used have become more complex. Files and information like credit card numbers are all encrypted for our privacy and require the proper key to be decrypted.

The **pigpen cipher** is another type of cipher that we will introduce to our more advanced students (see step 5 of the procedure). Pigpen ciphers are also a type of substitution cipher but use a geometric pattern where letters correspond to parts of the grid.

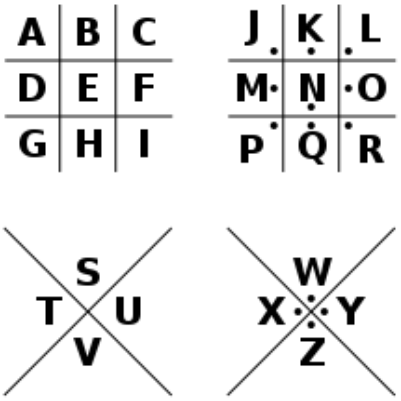


Figure 2. Pigpen cipher

For example, the word “science” becomes  .

Materials

- 1 paper printed with template per student
- 1 brass fastener per student
- 1 pair of scissors per group
- 1 copy of the message per group

Procedure

1. Have the students cut out the larger circle and the smaller circle from the template.
2. Secure the smaller circle on top of the larger circle using a brass fastener.

Figure 3. A Caesar cipher

3. Have students start with a shift of 1 and try to decode the first few words. They should quickly realize that the message still doesn't make sense and that they should try a different shift.
4. For this module, the shift will be 6, so A→G. During deCal, mentors will make the note that the students must decode. While there is flexibility in what the note says exactly, the plaintext should not reveal which mentor is the culprit and say something along the lines of "I have taken the object that you seek. Hurry up if you want its safe delivery. Sincerely, a BEAM mentor."
5. *(optional)* If time permits or for more advanced students, hand students another note to decode as an additional clue. This clue should eliminate at least one of the mentors as the culprit. For example, the plaintext could read, "The culprit does not have glasses." The students will have to use a pigpen cipher to decode the message.

Additional Notes for Mentors

While only one note is left at the scene of the crime, it might be helpful to write the encoded message either on the whiteboard or to make multiple copies so that all the students can try to decode the message.

Module 2: Paper Chromatography

(adapted from "Marker Mystery" by Rachel Jang and Patrick Oare, Fall 2017)

Introduction

Now that the mentees have identified all of the mentors as potential suspects, they have to determine which mentor has the candy. In this module, mentees will be cutting a strip of ink covered paper towel and performing a chromatography experiment to determine the composition of the marker used to write the note.

Teaching Goals

1. **Chromatography** is a technique to separate a mixture into its components.
2. (optional) Paper chromatography separates pigments based on **polarity**.
    a. Polarity refers to the separation of charge a molecule can have when its atoms have different abilities to attract electrons. This leads to a positive end and a negative end of the molecule.

Background for Mentors
Chromatography is a separation method that separates compounds based on properties such as size, polarity, charge, etc. It can be used for purification or analytical purposes. Within chromatography, there are two broad categories: column chromatography and planar chromatography. We will be focusing on **planar chromatography**.

In planar chromatography, the stationary phase is planar like a strip of paper or a plate. The **stationary phase** is immobile, while the **mobile phase** is a solvent that travels up the plate. In paper chromatography, paper is used as the stationary phase and water is commonly used as the mobile phase.

Paper chromatography is similar to another type of planar chromatography that is widely used in laboratories. **Thin Layer Chromatography (TLC)** is a plate with a thin silica coating (other coatings can be used). After a sample is dotted near the base of the plate, the plate is placed in a shallow beaker of solvent. As the solvent travels up the plate, it separates the sample into its components. Since the components have slightly different chemical structures and properties, they usually have different polarities. How well the sample separates and the rates at which the components separate depend on the polarity of the components as well as the solvent and their affinity for the mobile or stationary phases.

Several different pigments are mixed together to make black ink. When water is travels up the paper, it separates the black ink into different pigments because the water carries the pigments at different rates based on polarity.

Materials

- 3 types of black markers per group (i.e. Sharpie, Crayola, store brand)
    - *(optional)* other colored markers
- 4 pencils per group
- 4 binder clips per group
- 4 clear plastic cups per group
- Water
- 1 paper towel
- 1 pair of scissors per group

Procedure

1. Divide the mentees into small groups with one mentor per group.
2. Cut the paper towels into *1" x 3"* strips.
3. Mark the center 2 cm from the bottom with dot of black marker. Make sure to remember which marker corresponds to which sample.
4. Fill the cup with about 1 cm of water (make sure the marker dot is above the water line).
5. Attach the binder clip to the pencil and paper towel strip as shown in Figure 4 below.

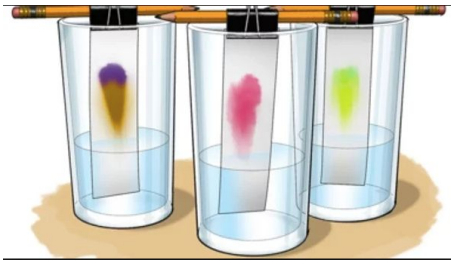


Figure 4. Paper Chromatography Setup

6. Repeat Steps 3 - 6 for the remaining markers.
7. As the solvent (water) travels up the paper, some of the markers will separate into multiple colors. At that point, you can remove the paper towels from the cups and let them dry.
8. Now to analyze the ink from the paper towel left at the crime scene. Mentors will make these with the same marker they use to write the note during decal. Cut the strip if necessary. Repeat steps 6-7.
9. Compare the ink from the chromatography to the ink from the three known markers to determine which marker was used to write the note.
10. *(optional)* Have the students try different colored markers. Have the students predict what colors the marker inks are composed of beforehand.

Additional Notes for Mentors

- Try to start with a non-permanent marker like Crayola instead of a permanent marker so kids can see multiple colors

Module 3: Fingerprint Analysis

Introduction

Finally, the mentees will solve the candy mystery by examining the fingerprint on the note. They will also examine their own fingerprints and classify them as whorl, arch, or loop.

Teaching Goals

1. Fingerprints arise from friction ridges that form at the tips of our fingers during development. They keep the same pattern over time.
2. The three main fingerprint pattern types are **whorl**, **arch**, and **loop**.
3. It's important to note that latent fingerprints, like the nearly invisible fingerprints left on a surface, can be smudged and difficult to analyze.

Background for Mentors

The word "fingerprint" refers to the impression left on a surface by raised ridges of the skin. They are unique to the individual and develop during the first and second trimesters of pregnancy. Fingerprint patterns are thought to be mostly random and can differ from finger to finger. Not even identical twins have the same fingerprints, so they are a valuable form of identification.

The three general pattern types are **whorl**, **loop**, and **arch** (see Figure 4 below). The whorl resembles a whirlpool and has concentric circles. The loop pattern resembles, as the name

suggests, curved loops. This is the most common type of pattern. Finally, the arch pattern looks like stacked waves, arches, or whatever analogy you prefer. This is the rarest pattern type.

Materials

- Ink pad
- White paper
- Printed paper describing three basic shapes of fingerprints and suspect prints

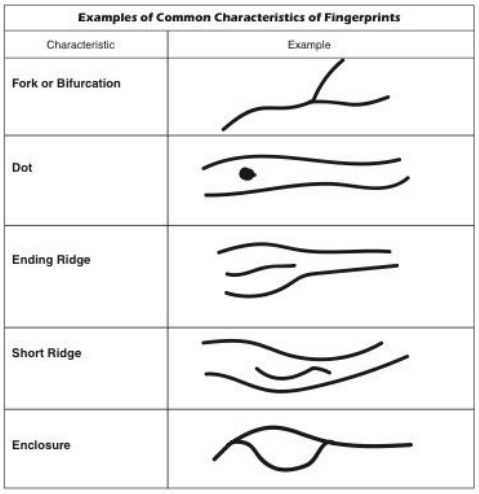
Procedure

1. Let mentees use their index fingers as stamps and press firmly into the ink pad.
2. The first fingerprint usually has too much ink, so have the students press the first fingerprint on a piece of scratch paper. Then, have them stamp their piece of paper.
3. We're using ink pads because latent prints can be hard to pull off glass surfaces without the right resources. What are some difficulties that investigators encounter when looking for fingerprints at a crime scene? (smudged, partial prints, etc.)
4. Now that you have a fingerprint, have them compare the handout that shows whorl, arch, and loop types to their own thumbprint to determine what fingerprint pattern they have. (Fun side activity: Tally up how many of each shape are present in the class. Which shape had the most?)

Loop, whorl & arch pattern examples.

Figure 5. Fingerprint Patterns

5. *(optional)* More advanced students can also try to identify other common fingerprint characteristics.



Examples of Common Characteristics of Fingerprints	
Characteristic	Example
Fork or Bifurcation	
Dot	
Ending Ridge	
Short Ridge	
Enclosure	

Figure 6. Common Fingerprint Characteristics

6. Once the mentees are familiar with the types of fingerprints, have them determine the type of fingerprint on the note by referencing the fingerprint supplemental (see materials).

Additional Notes for Mentors

Too much ink will likely result in a smudge instead of a readable fingerprint, so the second fingerprint with less ink turns out better. The ink should come off mostly with soap and water.

Conclusion

At this point, the mentees should have gathered enough evidence to solve the mystery. Recap briefly on the three techniques used (and teaching goals!) in the lesson and help them figure out who has taken the reward for the lesson. It might be easiest here to introduce the characteristics of the suspects. As a class, agree on what marker was used and what type of fingerprint was left on the note. Then, reveal which mentor used which marker and has which type of fingerprint. These will be predetermined during decal and unique combinations. (For example, mentor 3 will have used a crayola marker and have an arch print matching the suspect).

References

- Making Paper Cryptography Tools, Al Sweigart, *Invent with Python.* https://inventwithpython.com/hacking/chapter1.html
- Ink Chromatography, *Shodor.* http://www.shodor.org/workshops/forensic/labs/ink.html
- Black Magic:Discover the Colors in Black Ink, *Exploratorium.* https://www.exploratorium.edu/science_explorer/black_magic.html
- Trends in Fingerprint Analysis, Crystal Huynh, *TrAC Trends in Analytical Chemistry.* https://www.sciencedirect.com/science/article/pii/S0165993616300966#bib0030
- Principles of Fingerprint Analysis, *National Forensic Technology Center.* http://www.forensicsciencesimplified.org/prints/principles.html
- Finding Fingerprints. *Scientific American.* https://www.scientificamerican.com/article/finding-fingerprints/

Summary Materials Table

Material	**Amount per Group**	**Expected $$**	**Vendor (or online link)**
Black Markers	3 per group		Amazon (preferably 1 crayola, 1 sharpie, 1 daiso marker - twin tip water based)
Pencils	4 per group		Inventory
Clear Plastic Cups	4 per group		Inventory?

Binder Clips	4 per group		Amazon, mb inventory
Scissors	2 per group		Inventory
Brass Fasteners	1 per person	$3.50 per 100	Staples
Cipher template	1 per person	Printing fee?	Template (for elementary sites) Template (for middle school sites)
Paper towel	1 per group		Inventory
Ink Pad	1 per group	$0.98 each if buy in bulk	Multiple colors ok, https://www.bulkofficesupply.com/Products/CLI-Nontoxic-Foam-Ink-Pads__LEO92220.aspx
Fingerprint Supplementary	1 per group	Printing fee?	See below
White paper	1 per student		Inventory

Prints taken from suspects:

Name: (Writes in Crayola marker)	**Name:** (Writes in Crayola marker)	**Name:** (Writes in Crayola marker)
Name: (Writes in “Other” marker)	**Name:** (Writes in “Other” marker)	**Name:** (Writes in Sharpie)

Common Fingerprint Patterns: