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# Science, Technology, Engineering, and Mathematics (STEM) Activities on a Budget: Part I—Forensics

by RA Pesce-Rodriguez and A Rodriguez

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# Science, Technology, Engineering, and Mathematics (STEM) Activities on a Budget: Part I—Forensics

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## **1. Introduction**

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In fall 2016, the theme of National Chemistry Week (NCW) events, sponsored by the American Chemical Society (ACS), was “Solving Mysteries through Chemistry”. Publications designed for English- and Spanish-speaking students on this topic are available online (ACS 2016a, 2016b). A hands-on NCW public outreach program for elementary and middle school students and their parents was developed by the authors of this technical report. The program was presented as part of our “Chemistry in the Library” series, which was established in 2003 and now brings hands-on science, technology, engineering, and mathematics (STEM) programs to children and adults in public libraries in three Maryland counties. The “Solving Mysteries through Chemistry” program was subsequently adapted for a teachers’ training session to be presented at the 2019 Mid-Atlantic Regional Meeting (MARM) of the ACS held at the University of Maryland, Baltimore County. This technical report was written to better formalize the MARM session and make the content more broadly available to instructors looking for guidance for effective and inexpensive hands-on STEM activities.

It is currently envisioned that this is the first in a series of technical reports based on programs developed for our annual ACS NCW and Chemists Celebrate Earth Day events.

Note: Commercial products mentioned in this report are not endorsed by the US Army Combat Capabilities Development Command (CCDC) Army Research Laboratory.

## **2. Safety Considerations**

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As with all lab activities, students must be advised about never eating any item that is part of the activity, even if the items are common in their household (e.g., vinegar or sour gummy worms). Students must also understand that even household chemicals can be dangerous and must be treated with respect. Mastering this understanding at an early age will help students to keep safe throughout their home, academic, and professional lives.

While in these experiments students are only using “household” materials, eye safety must always be considered. If eye protection is available, it should be made available for students. Student-sized glasses are available from several sources: Amazon offers a 12-pack for less than \$15. While this would certainly be the largest expense associated with this program, the glasses could be used for years to come and would be an excellent investment for any school. If funds for personal

protective equipment (PPE) are unavailable from your school or group, an appeal to the parent council (or the equivalent for your school or organization) might be advisable.

### 3. Setting the Scene

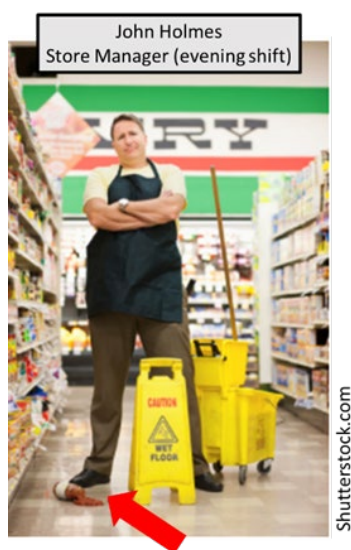
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While all of the modules described in this report can be done in isolation, the intent is to combine results of the four modules to identify a single perpetrator of a “crime”. Since this activity is directed toward young audiences, the “crime” should be something relatively innocent. The suspects for the forensic investigation can be fictional characters or volunteers from the children’s school or organization. A sample backstory is provided in what follows. Note that all “suspects” have an associated fingerprint, hair, paper sample, and white powder. The number of possible scenarios is limited only by the instructor’s creativity.

#### 3.1 The Investigator and Backstory

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For the sample backstory, the scene of the “crime” is the pasta aisle in a supermarket. One of six customers (the “suspects”) was seen entering the store between 5:00 and 5:15 PM on the store’s surveillance camera and broke a jar of tomato sauce (the “crime”). The store manager, Mr John Holmes (Fig. 1), likes to think he is related to the famous detective, Sherlock Holmes. Since childhood, he has been interested in solving mysteries and looking for science in the world around him. He has his own investigative tool kit that he will use to evaluate evidence collected at the scene of the crime to identify the perpetrator.



Thinks he’s related to a famous detective!

**Evidence:**

- Piece of hair
- White powder
- Corner of paper
- Partial fingerprint

**Tools:**

- Microscope
- Chemistry test kit
- UV flashlight
- Fingerprint kit

**Fig. 1** Details of the investigator

### 3.2 The “Suspects”

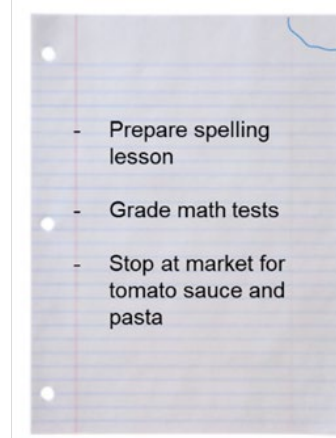
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The shoppers in this story all know Mr Holmes very well and are happy to play along with his investigation. They provide him with a fingerprint, a strand of hair, a sample of white powders that they used that day at home or at work, as well as their to-do list, which mentions the activity associated with the mystery powder and the reason for being at the crime scene. Summaries of the evidence are given for each suspect (Figs. 2–7).



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Suspect has dark hair  
White powder: Chalk  
To-do List: Loose leaf



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**Fig. 2** Details for suspect 1: the Teacher



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Suspect has short, Dark hair  
White powder: baking soda  
To-do List: Printer paper

Fig. 3 Details for suspect 2: the Pest Control Technician



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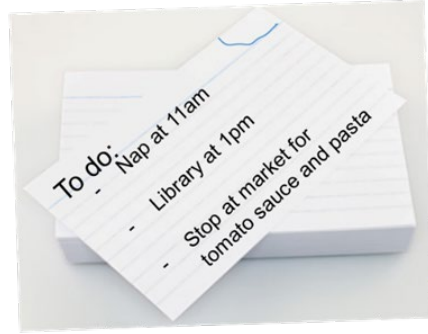
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Suspect has dark hair (synthetic extension)  
White powder: Sodium Polyacrylate  
To-do List: Notebook

Fig. 4 Details for suspect 3: the Polymer Chemist



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Suspect has gray hair  
White powder: Baby powder  
To-do List: Index Card

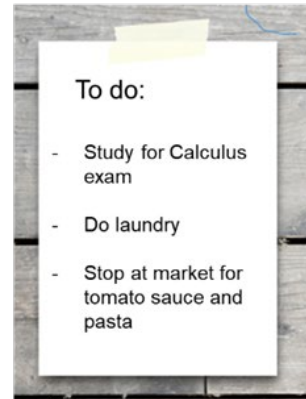


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**Fig. 5** Details for suspect 4: the Grandma



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Suspect has pink hair  
White powder: Laundry detergent  
To-do List: Card stock



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**Fig. 6** Details for suspect 5: the Student



Suspect has no hair – but has a dog  
 White powder: Flour  
 To-do List: Parchment Paper

Fig. 7 Details for suspect 6: the Baker

### 3.3 Module 1: Paper Analysis

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#### 3.3.1 Visual and Tactile Examination

For this module, students are given pieces of paper taken from the “to-do” list provided by each of the six suspects, plus the piece of paper found at the scene of the “crime”. Students will perform visual and tactile examination of the paper by looking at it and feeling the texture. They will notice that some papers are brighter than others. For example, printer paper is always a bright white because optical brighteners are added for this purpose. Inexpensive loose-leaf paper maybe be relatively dark in color because it is not used for archival purposes and generally used for a very short time. Brightness for this type of paper is often not critical. Cardstock and index cards will feel thicker than printer paper and loose-leaf. Parchment paper (for baking) will feel stiff and will be yellow in color. Students may be able to eliminate some specimens solely based on visual and tactile examination.

#### 3.3.2 Examination under UV Light

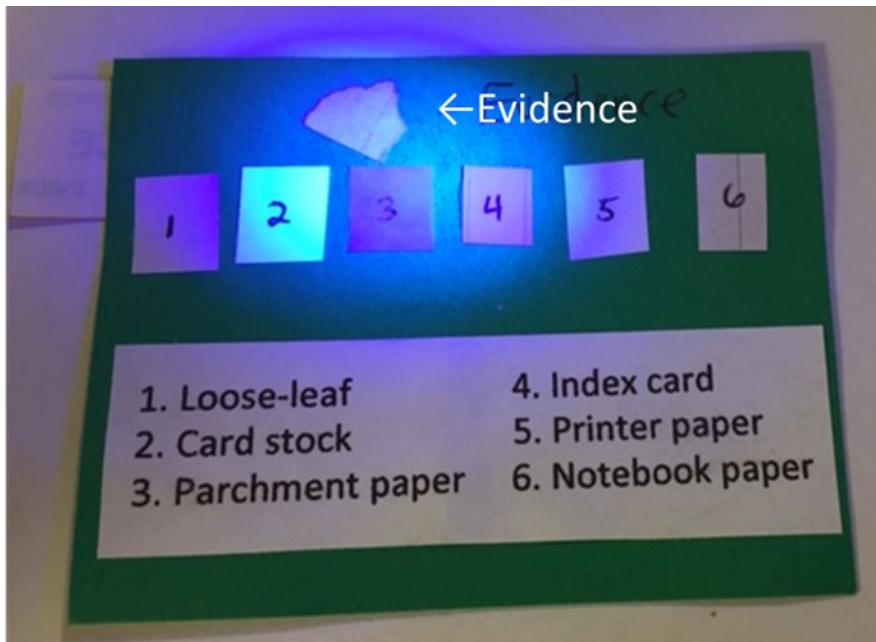
Examination of the paper under UV light will indicate those specimens containing optical brighteners (e.g., printer paper, index cards, and some loose-leaf paper). More information on optical brighteners can be found on Wikipedia (2019c). Low-cost full-sized LED UV flashlights can be purchased from Walmart for

approximately \$6. When using these, yellow safety goggles should be worn. Low-power mini-LED UV flashlights (“keychain” flashlights) can be purchased from Amazon for approximately \$0.70 each when purchased in a lot of 50 (Fig. 8). The output is sufficiently low from these flashlights that yellow safety glasses are not required. Still, students should be advised not to shine it in their eyes or anyone else’s eyes. Despite the low power, the mini-flashlights are sufficiently strong for the activities described. Some students may already have a similar mini-flashlight from “invisible ink spy pen” sets. Barnes and Nobel offers such a pen/light combination for less than \$3.



**Fig. 8 Mini-LED UV flashlight illuminating paper samples**

The effect of a mini-LED UV flashlight on several paper specimens is shown in Fig. 9.

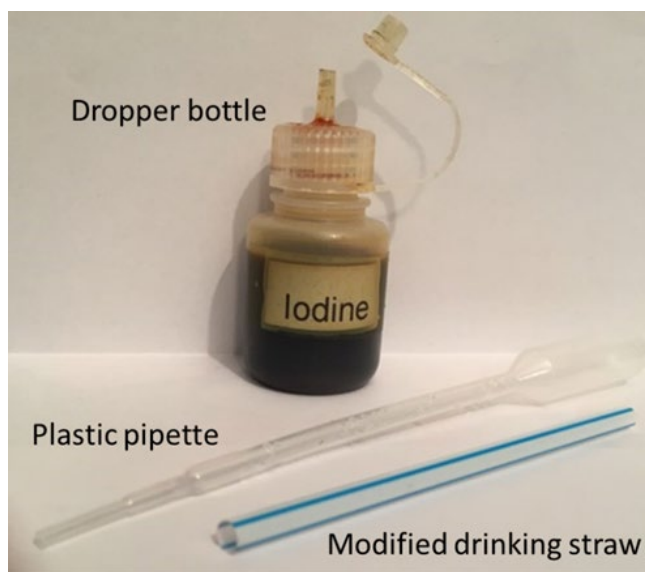


**Fig. 9 Photo of several specimens under UV light**

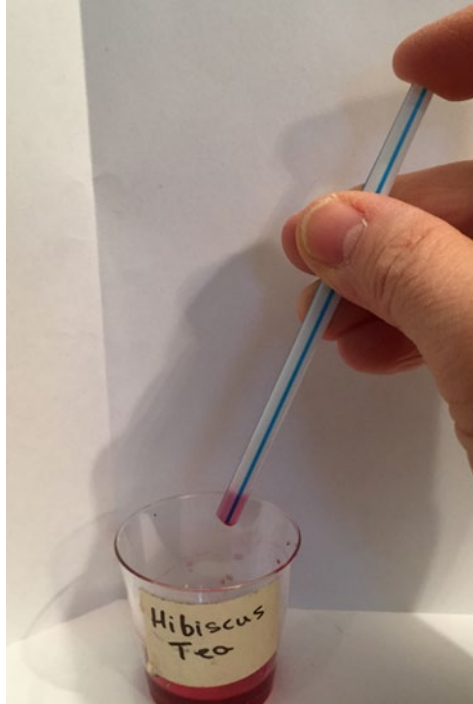
### 3.3.3 Iodine Starch Test

Chemical tests for paper include the iodine starch test, which may be conducted using povidone–iodine solution diluted with water (1:3). The stock solution can be purchased from any pharmacy for about \$6 per bottle. If kept in a cool, dry place, the contents can be used for years for laboratory tests. The solution can be applied to the paper specimen by several techniques, including a dropper bottle (relatively expensive for elementary and middle school teacher budgets) or a plastic pipette (“dropper”), which is a cheaper alternative to a dropper bottle (Fig. 10). Amazon offers 100 plastic pipettes for about \$10. We rinse ours after each session and use them over and over again. A very inexpensive, readily available alternative to dropper bottles and pipettes is drinking straws. A small volume of the solution will be drawn up into the straw when placed in the liquid and will remain in the straw if a finger is placed over the dry end (Fig. 11). When the tip of the straw is applied to a specimen of paper, the liquid is transferred and absorbed.

Reagent can be provided to students in 1-oz plastic cups. These can be purchased from several vendors. Amazon sells 100 for approximately \$7. These cups can be used, washed, and reused many times. They stack together well and take up little space in storage. Labelling can be done with a dark permanent marker on light-colored masking tape (Fig. 11).



**Fig. 10** Photo of a dropper, pipette, and drinking straw



**Fig. 11 Using a drinking straw to pipette a liquid**

A positive reaction for the iodine starch test is observed when the paper or other substrate changes color (brown to black; see Fig. 12). A simple explanation for the science behind the iodine starch test may be found on Wikipedia (2019b).



**Fig. 12 Photo of a negative iodine starch response for paper towel (left, brown color) and positive response for printer paper (right, black color)**

Paper specimens that respond positively to the iodine starch test are those to which starch sizing has been added to give a smooth surface finish. Printer paper and index cards will test positive for starch, but paper towels and toilet paper will not.

Note: While some individuals may report having an allergy to iodine, reports in the medical literature conclude that this is a myth (Dewachter and Mouton-Faivre 2015; Sampson et al. 2019). Iodine is an element that is essential to our health. It is true, however, that some individuals have experienced dermal sensitivity to iodine–povidone topical antiseptic. For this reason, instructors should be sure that students wash their hands in the rare event that contact with the dilute iodine solution occurs.

### **3.3.4 pH Test**

Depending on the types of paper chosen for this activity, it may be possible to tell something about their age with a simple pH test. For this, a liquid pH indicator is needed. Commercial universal pH indicators are available, but are relatively expensive and may expose students to potential toxins.

An alternate to commercial products is the juice of red cabbage, which works very well with a wide range of pHs. Demonstrations of the color changes associated with samples of various pH can serve as a lesson of its own. Common items that can be used for this demonstration are citric acid (acidic; lemon juice or sour candies work well), vinegar (acidic), baking soda (mildly basic/alkaline), dish detergent (basic/alkaline), and household ammonia (very basic/alkaline).

While red cabbage juice is a very good pH indicator, many students do not like working with it because of the odor. To avoid this problem, an instructor can use a commercial red cabbage extract (Fig. 13), which has no smell at all. The material can be purchased directly from Educational Innovations (<https://www.teachersource.com/product/red-cabbage-extract/chemistry>) or from Amazon for approximately \$11/bottle. The extract is very concentrated and will last for years of classroom use.



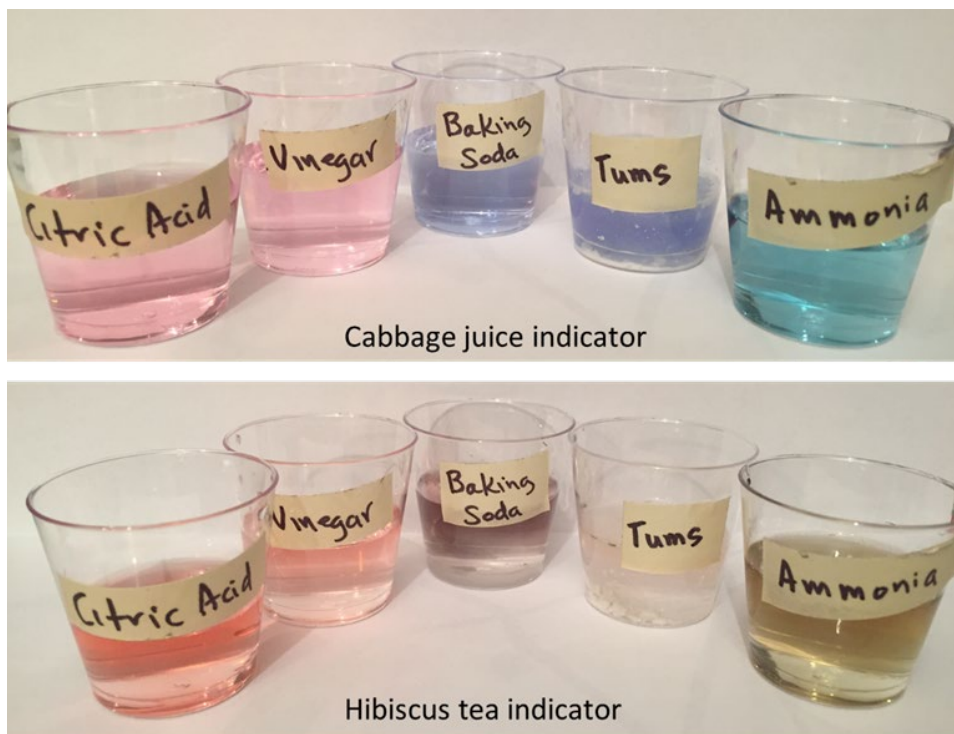
**Fig. 13** Commercially available dried cabbage juice extract, reconstituted with water (right). Color/pH chart shown at bottom.

An economical alternative to the commercial product and a less “fragrant” alternative to the juice collected from cooked cabbage is an alcohol extract of red cabbage, which can be easily prepared at home or in the classroom. To do this, a leaf or two of red cabbage is diced (this should be done by the instructor), then placed into a cup containing 50 mL of isopropanol (rubbing alcohol, 70% or 90% will work) and allowed to sit for several hours (or overnight). The process can be greatly accelerated by grinding the mixture with a mortar and pestle, which can be purchased for \$5–\$10 from various sources and can often be found at thrift shops for much less than that. The red cabbage alcohol extract gives excellent results when used for pH determinations, as described in this report.

Another alternative indicator for pH observation is hibiscus tea; one common commercially available product is “Red Zinger” tea by Celestial Seasonings. The tea can be extracted into water or isopropanol (rubbing alcohol, 70 or 90%) to make a concentrated solution. We have found that the extraction is faster in isopropanol than in water. (Fig. 14) While hibiscus tea can be used for pH determination, we find it to be inferior to cabbage juice in terms of the vibrancy and range of colors produced when added to solutions of various pH (Fig. 15).



**Fig. 14** Hibiscus tea extracted with isopropanol (rubbing alcohol, 70%)



**Fig. 15** Photos of various materials with added cabbage juice extract (top) and hibiscus tea (bottom)

Regardless of which pH indicator is used, it is advised that all activities involving the reagent are tested using the same type of water that will be used during the session. Results for pH indicators prepared with well water can be very different from those prepared with municipal water.

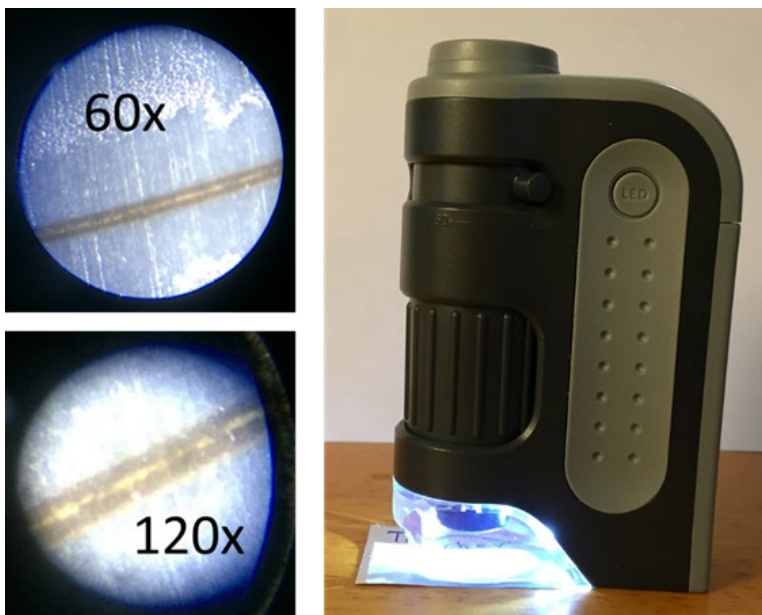
The science behind the use of hibiscus tea or red cabbage juice as pH indicators is based on the chemistry of anthocyanins, which are natural compounds that are responsible for the color in many flowers, fruits, vegetables, and autumn foliage. More information can be found on Wikipedia (2019a).

When testing the pH of paper, students will find that modern paper such as printer paper and index cards will be basic/alkaline, while older paper such as that from an old book from the thrift store will be acidic. The primary reason for this is the past practice (pre-1990) of using alum (aluminum sulfate) as a multi-use ingredient (deflocculating agent, sizing agent, bleaching accelerator, and clarifier) in paper production. While alum worked wonders for the production of paper, it makes paper acidic and contributes to the hydrolysis (breakdown) of cellulose fibers, resulting in yellowing and “old book smell” (Strlič et al. 2009).

### 3.4 Module 2: Hair/Fur Analysis

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For this module, it is essential that students have access to microscopes. While the need for microscopes for lab work may have been prohibitive in the past, several newer inexpensive microscopes have made the technology much more accessible. A model that we have been using for the past few years (i.e., Carson MicroBrite Plus; Fig. 16) is very popular with students and parents alike, and is available for about \$10 each. The microscopes are fairly robust, operate with a single AA battery and are illuminated with an LED bulb. Magnification goes to 120 $\times$  and is acceptable for hair analysis by students.



**Fig. 16** Photo of microscope, light brown hair samples (mounted with tape and clear nail polish), and magnified images at 60 $\times$  and 120 $\times$  (taken with a cell phone camera through microscope eyepiece)

Suspect hair samples can be obtained from friends and families who are willing to donate to the effort. We found that hair specimens can be fixed to small squares of aluminum foil substrate with a piece of scotch tape or by applying to wet clear nail polish on aluminum foil (Fig. 17). We prefer to use tape to fix the hair sample to the substrate because it does not require drying time and because the tape reinforces the foil substrate, helping it to be more “student proof”.



**Fig. 17 Photo of hair mounted on foil with tape and clear nail polish**

If colored hair (like the Student's pink hair) is not available, light hair (blond or gray) can be colored with a permanent marker. Synthetic hair, as used in a wig or weave, can also be used in this activity.

For the sample backstory given in this report, we intentionally included a bald suspect with a pet. We chose a German shepherd when we ran the program because of availability of the fur specimen. A classroom activity might include other available animal hair/fur (rabbit, hamster, cat, etc.). Discussions about hair analysis should include the basic structure of hair and the distinguishing characteristics between human and animals, and among different animals.

Students can look for the cortex, medulla, and follicle of hair (Fig. 18). A good discussion (including images) of what to look for in human and animal hair samples is given by Deedrick and Koch (2004).

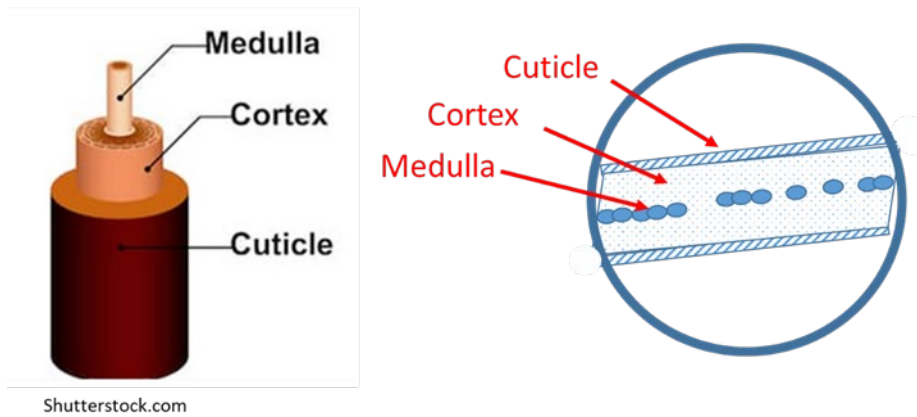


Fig. 18 Illustrations of hair and fur structure

### 3.5 Module 3: Fingerprint Analysis

This module gives students the opportunity to learn about the different types of fingerprint patterns (illustrated in Fig. 19), match partial prints with a known print, and obtain and analyze their own fingerprints.

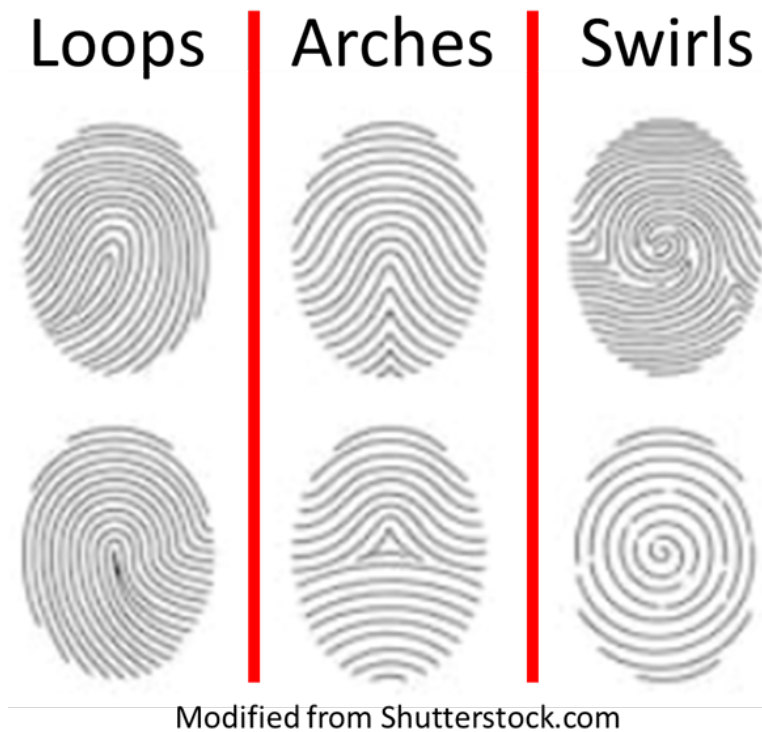
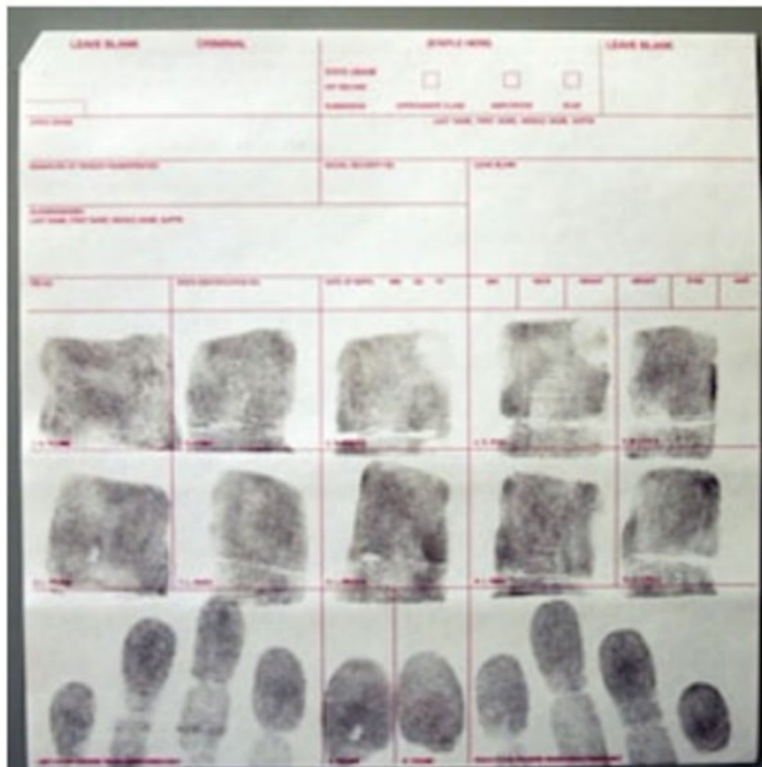


Fig. 19 Examples of the types of fingerprint patterns

Fingerprints for suspects may be obtained from the web or from colleagues, friends, and family who are willing to provide their own. Students will find that it is easier to compare suspect fingerprints with crime-scene evidence after first identifying the type of pattern (loops, arches, or swirls).

A useful reference for fingerprint analysis is given by NFSTC (2013).

Students may obtain their own prints in a somewhat “official” manner using fingerprint cards and a fingerprint ink pad. Fingerprint cards (Fig. 20) can be purchased from Amazon (25 cards for ~\$10) or students can make up their own cards using the template in the Appendix. “Easy-clean” or “inkless” fingerprint pads are available from many suppliers (including Staples) for \$6–\$8. Students can also obtain their fingerprints by depositing graphite from a pencil on paper and then rubbing their finger on it (Fig. 21), but this method is very messy. Regardless of the technique used, students will need to wash their hands after this activity.



**Fig. 20** Fingerprint card with fingerprints



**Fig. 21 “Old-school” finger printing using graphite from a pencil and a piece of clear adhesive tape**

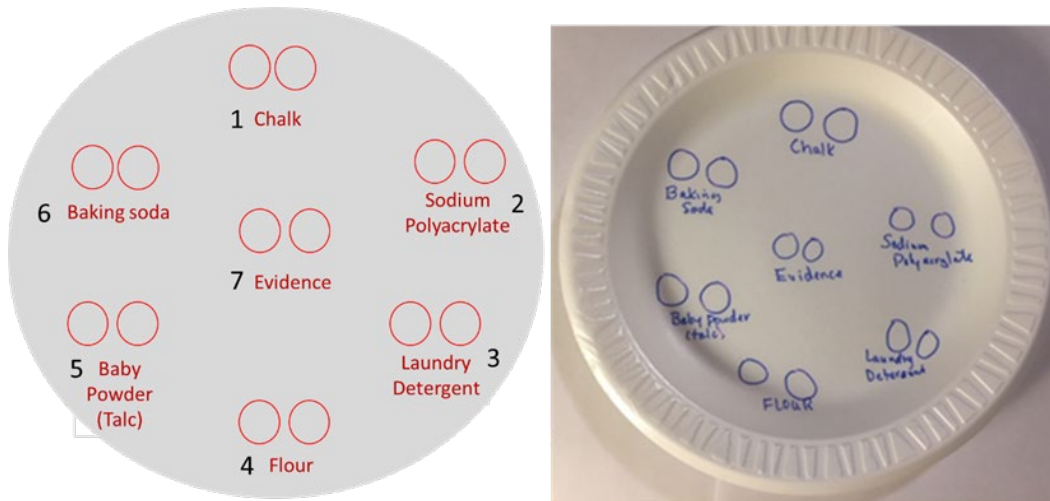
### **3.6 Module 4: Mystery Powder Analysis**

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There are a number of “mystery powders” that can be used for this activity. For this particular example, we have chosen the powders previously indicated for each suspect.

Powders can be provided to students in small plastic cups (1 oz) and dispensed using spatulas. Inexpensive alternatives include tasting spoons and plastic straws cut on a diagonal to create a sharp tip.

Powders should be placed on a prelabeled white plastic plate (as shown in Fig. 22). Labels can be made with a fine permanent marker or pen.



**Fig. 22** Recommended layout for mystery powder analysis. Two small piles of each powder are dispensed. One is used only for the iodine starch test; the other is used for the remaining tests.

**Important:** Wet chemistry tests should be performed in the following order. Results can be recorded in a table such as that in Table 1.

**Table 1** Data table for mystery powder analysis (completed for sample scenario)

Powder Sample	UV light (glows?)	Water (dissolves/swells/wets?)	Indicator* (color/pH)	Vinegar (reacts?)	Iodine (turns blue?)
Flour	No	Wets	Pink neutral	No	Yes
Chalk	No	Wets	Blue alkaline	Yes	No
Talc	No	Beads	Pink neutral	No	No
Laundry Detergent	Yes	Wets	Blue alkaline	No	No
Baking Soda	No	Wets	Blue alkaline	Yes	No
Sodium Polyacrylate	No	Swells	Pink neutral	No	No
Evidence (conclusion?)	(Is/is not XYZ)	(Is/is not XYZ)	(Is/is not XYZ)	(Is/is not XYZ)	(Is/is not XYZ)

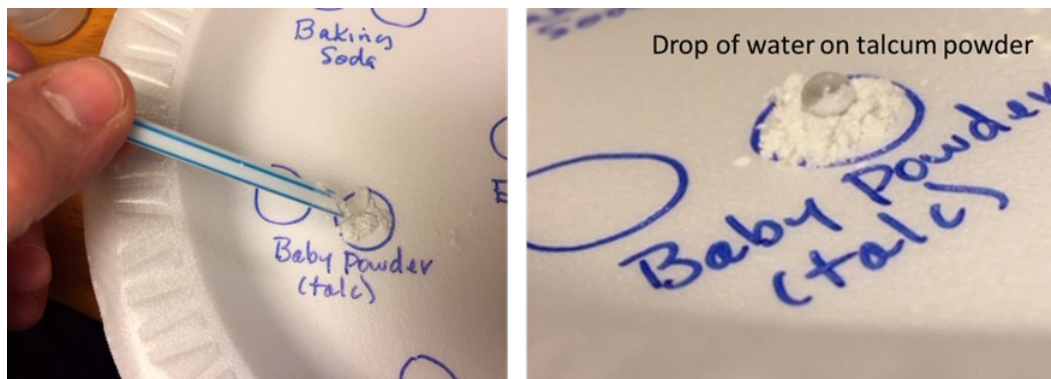
### 3.6.1 UV Test

Dry powders are illuminated with a mini-UV flashlight. Of the samples in the scenario given, only the laundry detergent will luminesce. It does so because of the optical brighteners that are added to laundry detergent. These materials are only stable in powders and are not part of liquid laundry detergent formulations.

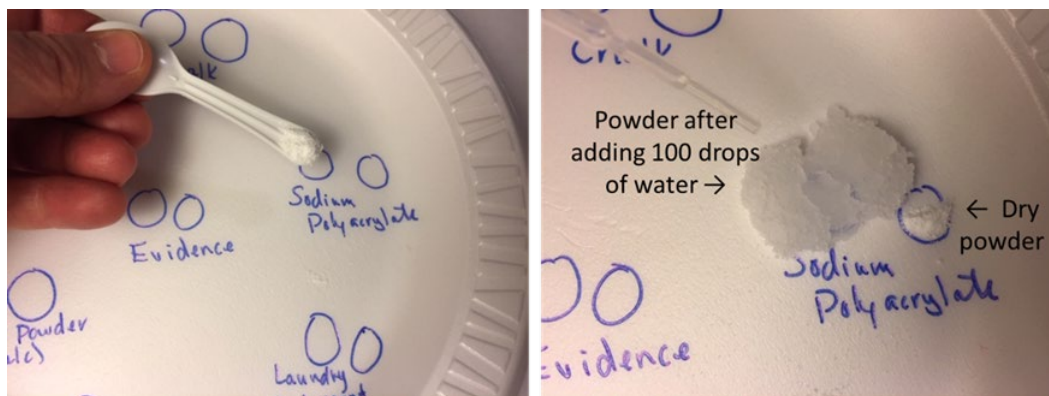
Students should compare the appearance of the mystery powder (evidence) with that for the standard/known materials and draw conclusions about the identity of the unknown powder.

### 3.6.2 Wettability

Using a dropper bottle, plastic pipette (dropper), or plastic straw as described in Section 3.3.3, students should add 2–3 drops of water to each sample and observe the response. Samples like salt (sodium chloride [NaCl]) or sugar (neither used in this scenario) will dissolve. Flour and laundry detergent will absorb the water, but not dissolve. Talcum powder (talc) will repel the water resulting in a nearly spherical drop (Fig. 23). Super-absorbing polymer can be obtained from a disposable baby diaper or Amazon (35 g for approximately \$10) and is typically one of students' favorite powders. For this sample, students should add at least 20 drops of water. They will observe that the polymer absorbs it all and grows into a mound (Fig. 24)!



**Fig. 23** Photos of wettability test. Left image shows the use of the diagonally cut drinking straw to dispense talcum powder. Right image shows same after addition of 1 drop of water. The talc is not wetted by water, which forms a bead.



**Fig. 24** Photos of wettability test. Left image shows the use of the back side of a tasting spoon to dispense sodium polyacrylate (super-absorbing powder). Right image shows same after addition of 100 drops of water.

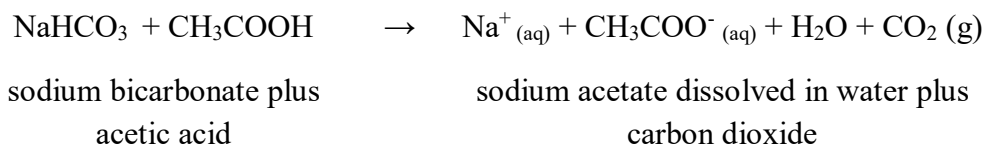
Students should compare the appearance of the mystery powder (evidence) with that for the standard/known materials and draw conclusions about the identity of the unknown powder.

### 3.6.3 pH

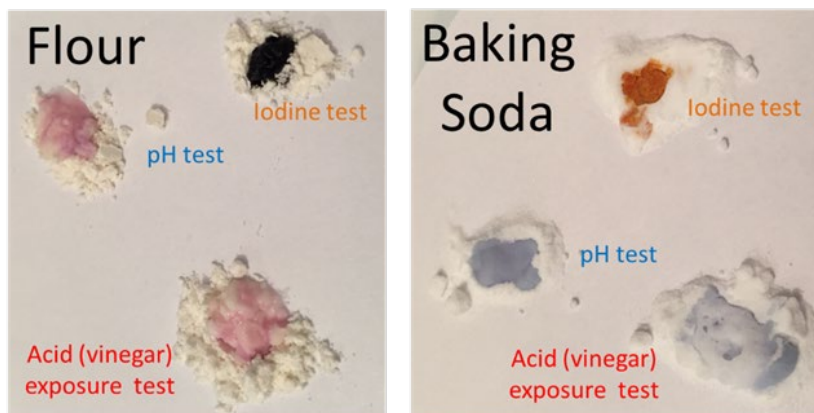
For this test, pH indicator (red cabbage juice or hibiscus tea) is added directly to the wettability sample. The color is observed and compared with that of the standard/known material. The flour, talc, and super-absorbing polymer will have a neutral pH, while chalk, baking soda, and detergent will be slightly basic/alkaline.

### 3.6.4 Vinegar

For this test, vinegar is added directly to the pH/wettability sample. Chalk and baking soda will be observed to fizz as the result of carbon dioxide (CO<sub>2</sub>) gas generation (Fig. 25). Students should compare the response of the mystery powder (evidence) and compare with that of the standard/known material. While students will not understand the chemistry involved, the reaction that takes place is provide for instructors who are interested in this information:



(baking soda) + (vinegar) = (fizz)



**Fig. 25** Results of addition of iodine starch reagent, pH indicator, and vinegar to flour and baking soda. Flour contains starch and turns black on addition of iodine. Baking soda is basic/alkaline.

### 3.6.5 Iodine Starch Test

Students should apply 1–2 drops of iodine solution to a *clean* powder sample and look for a positive response as discussed in Section 3.3.3 (i.e., color change from brown to black; see Fig. 25). Students should compare the response of the mystery powder (evidence) with that of the standard/known material.

When done with the wet chemistry tests on the mystery powders, it is recommended that a paper towel be used to wipe all of the solids into a trash can. Do not put the super-absorbing polymer down the drain!

## 4. Conclusions and Recommendations

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Depending on time available and the level of the students involved, the recording of data and reporting of results could range from very detailed to very limited. The key objective for each activity is to compare the results for the evidence with the standard materials. Even without recording results, students will instinctively draw conclusions based on their observations. While some tests may be inconclusive (e.g., baking soda and chalk have similar response to wet chemistry tests), other evidence (hair, paper, and fingerprints) should allow students to identify the perpetrator of the “crime”.

Just as the depth of student involvement in the activity may vary, the same is true for the level of accompanying instruction that is required. Each module has a significant amount of science behind it, much beyond what many students can absorb. It will be left at the discretion of the instructor to determine if empirical observations are sufficient for participating students or if additional background information is desirable. While several references for easily available background

information have been provided, a quick search of the Internet will provide additional information that will supplement the activity to meet the needs of a particular class or group of students.

The answer to the “Whodunit?” question may not always be clear, despite the evidence. In our session, all the evidence pointed to the Teacher. But what if she just happened to have left evidence at the scene, but was not the one to actually break the bottle? While it is important to discuss this with student so that they do not jump to conclusions without all the necessary evidence, most students seem to understand that the backstory is just for fun and that the important thing is what they learn from each of the modules. More important is follow-up discussion on how the techniques they have learned can be used for other applications. We have found that most students are very eager to use UV flashlight to examine other things in their world. To stimulate interest, we generally demonstrate the luminescence of tonic water (contains quinine), ketchup (looks yellow under UV light), diamonds (approximately one-fourth of all natural diamonds are fluorescent), and American currency, which has several security features that are enhanced by UV radiation. Most students are very impressed by the color changes exhibited by red cabbage juice when in the presence of various acids and bases. Given that red cabbage juice is so easy to work with, students can be encouraged to ask for some to be cooked up at home so they can perform their own tests. Lemon juice on red cabbage looks beautiful on any plate. While many students are familiar with the vinegar–baking soda reaction, they might not know that chalk and Tums antacid tablets can undergo the same transformation when exposed to vinegar. They will also not likely have considered that such a simple test can be used to distinguish among powders that look so similar. The same is true for the iodine starch test.

Overall, we have found this session to be very well received by both students and their parents. We hope that the content of this report will encourage teachers and parents to explore the simple activities described here with their students and encourage them to think about the fascinating chemistry that is all around them.

## 5. References

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## **Appendix. Fingerprint Card Template**

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This Appendix appears in its original form without editorial change.

Approved for public release; distribution is unlimited.

Name		School/Grade		
R. Thumb	R. Index	R. Middle	R. Ring	R. Pinkie
L. Thumb	L. Index	R. Middle	R. Ring	R. Pinkie
L. Four Fingers		L. Thumb	R. Thumb	R. Four Fingers

## List of Symbols, Abbreviations, and Acronyms

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ACS	American Chemical Society
CH <sub>3</sub> COO-	acetate
CH <sub>3</sub> COOH	acetic acid
CO <sub>2</sub>	carbon dioxide
H <sub>2</sub> O	water
LED	light-emitting diode
MARM	Mid-Atlantic Regional Meeting
Na	sodium
NaCl	sodium chloride or salt
NaHCO <sub>3</sub>	sodium bicarbonate
NCW	National Chemistry Week
STEM	science, technology, engineering, and mathematics
UV	ultraviolet

1 DEFENSE TECHNICAL  
(PDF) INFORMATION CTR  
DTIC OCA

2 DIR ARL  
(PDF) IMAL HRA  
RECORDS MGMT  
FCDD RLD CL  
TECH LIB

1 GOVT PRINTG OFC  
(PDF) A MALHOTRA

1 CCDC ARL  
(PDF) FCDD RLW LB  
RA PESCE-RODRIGUEZ