SHERLOCK HOLMES

THE EXHIBITION

Teacher's Guide

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Why Sherlock Holmes in the Classroom?

Sherlock Holmes is one of the most recognizable figures in literature. Beloved by generations of readers, the character has been renewed and reinterpreted countless times in popular culture, a testament to the enduring quality of Sir Arthur Conan Doyle's stories and their unforgettable hero.

The tales of Sherlock Holmes go beyond mere storytelling. As a chemistry and forensics expert ahead of his time, Sherlock uses seemingly trivial observations to solve the most complex crimes. His practices and techniques, created by doctor-turned-author Conan Doyle, profoundly influenced the way police work was conducted at the turn of the 19^{th} century. Many of Sherlock's methods still remain in practice today.

Sherlock Holmes has inspired generations of thinkers to use deductive reasoning and apply it to modern sciences. Many forms of forensic sciences were influenced by Conan Doyle's work, including serology, fingerprinting, and firearm identification (all methods that appear in the Sherlock Holmes stories). In the exhibit, students will be transported into Sherlock Holmes' London to solve a crime in a world that was being introduced to these ground-breaking methods for the first time.

The Sherlock Holmes stories can provoke rich classroom discussions relating to literature, history, science, technology, and psychology, making them an ideal subject for multidisciplinary study.

How to Use This Teacher's Guide

These materials have been developed as a supplementary resource for educators bringing their students to *The International Exhibition of Sherlock Holmes*. Included are eight science and language arts lesson plans, take-home versions of the four science lesson plans, and two observation-based games.

The hour-long lesson plans have been designated as either *pre-exhibit field trip* or *post-exhibit field trip* activities. The pre-exhibit activities are designed to prepare your students to visit the Sherlock Holmes exhibit by fostering interest in the scientific investigations pioneered by Sherlock Holmes. The post-exhibit activities are designed to enhance the exhibit experience by building on the concepts of deductive reasoning, analysis, and investigation introduced in the exhibit. However, these designations are flexible and are only suggestions; both pre-exhibit and post-exhibit lessons can be taught at any point and will even stand alone without the experience of a field trip.

These resources can be used independently or combined to ensure a rich experience for students visiting *The International Exhibition of Sherlock Holmes,* or adapted to meet your classroom goals.

Exhibit Overview

Note: it is recommended that you allow 60-90 minutes for students to complete their tour of the exhibition.

Footprints, spatter patterns, and the powers of observation mark the journey through *The International Exhibition of Sherlock Holmes.* The interactive experience combines science with history and culture to bring to life the historic underpinnings of author Sir Arthur Conan Doyle's rich and vibrant stories.

Students will learn how Sherlock Holmes, a scientific expert ahead of his time, used seemingly trivial observations of clues missed by others to solve some of his era's most puzzling mysteries. His practices and techniques, created in the mind of doctor-turned-author Conan Doyle, encouraged a change in the way police work was conducted and many remain in practice today.

The International Exhibition of Sherlock Holmes features original manuscripts and period artifacts, investigative tools influenced and used by Sherlock Holmes, and interactive crime-solving opportunities. Students will be transported into Sherlock Holmes' London to solve a crime in a quickly advancing world filled with innovation and experimentation – primed for his ground-breaking methods.

Students will learn about the practices of Sherlock Holmes, explore the world from which Conan Doyle drew to develop his stories, and gain an understanding of the core principles of forensic science. As visitors venture forth on a journey through Sherlock Holmes' London, they will ultimately find themselves immersed in modern-day Sherlockian pop culture and the science of today's real detectives.

Students will be guided through five separate galleries in the exhibition:

Dr. Conan Doyle's Study
Conan Doyle, a scientifically educated physician, was a curious and tireless investigator his entire life. Students will explore his world and life starting as a medical student at Edinburgh University, an apprentice at Royal Surgeons' Hall, a practicing physician in Southsea, Portsmouth in the 1880s, and finally as a creator of literary genius who moved to London in the early 1890s and became a full time author.

The centerpiece is Conan Doyle's desk, surrounded by vignettes of experiences that eventually brought Sherlock Holmes to life. Students are encouraged to explore academic, professional, and cultural influences: the professors who awakened Conan Doyle’s interest in observation and deduction, period-specific medical innovations, the state of Victorian London and its sensationalized crime, and contemporary mystery writers who influenced his writing. On display will be an original manuscript, letters, and illustrations that shed light on the experiences that influenced Conan Doyle in creating Sherlock Holmes.

Science and History

Sherlock Holmes solved mysteries using observation, deduction, and solid scientific experimentation, something real-world detectives (police or private) had not yet embraced. Students enter the Baker Street Underground Station and find themselves in the middle of a bustling center of innovation in the form of an International Science Exhibition.

As students enter the Science Exhibition, their photographs are taken in front of one of three painted murals in the style of the cutting-edge photographic technology of 1895. Students can don hats and other props to pose as though they are at 221B Baker Street, on a foggy London road, or in the Dartmoor countryside of *The Hound of the Baskervilles*. Photograph packages are available for purchase at the end of the exhibition.

Students will participate in experiments of their own by exploring the developments in science and technology in the 1890s – from telecommunications and printing to botany and chemistry – that are still highly relevant today. Supported by forensics expert and crime historian E. J. Wagner, author of *The Science of Sherlock Holmes*, the exhibition delves into real forensic studies in order to demonstrate the link between the Sherlock Holmes stories, detective science, and the world of today.

Baker Street

Next up is Sherlock Holmes’ and Dr. Watson’s sitting room at 221B Baker Street, London, where their investigations began and concluded – a room looming large in popular imagination around the globe ever since the first Sherlock Holmes tale, *A Study in Scarlet,* in 1887.

As students enter the sitting room, the space feels inhabited, as though Sherlock has just stepped out. The room is dark, lit only by the fire, gaslights, and the flickers of a chemistry set’s Bunsen burners. The air is thick and the clutter oppressive and overwhelming, though on closer inspection, the clutter shows the hand of a brilliant eccentric with many objects from his most recent cases still preserved throughout the room. A jackknife stuck in the mantel with a note from Sherlock Holmes states that the students are late, poorly dressed, and observing the unimportant. Students are instructed to play a recording made by Sherlock, which provides details about a recent crime. Students learn that they are needed to help solve a time-sensitive and mysterious event!

Become a Detective!

The new Sherlock Holmes mystery, written exclusively for the exhibition by Sherlockian and acclaimed writer and award-winning Conan Doyle biographer Daniel Stashower, takes the students on an adventure through the streets of London as they perform scientific experiments, observe details, chase clues, and solve a crime.

As Holmes' Baker Street Irregulars with hopes of becoming detectives-in-training, students use what they learned in the Underground Station Science Exhibition and Conan Doyle's study to solve the mystery. Each mystery location also provides additional information and clues. Scotland Yard's Inspector Lestrade sees the case differently from Sherlock; if the truth is not revealed in a timely manner, an innocent person may be charged with a terrible crime. Students must work diligently to make sure than an innocent person is not sentenced to a life behind bars.

Detective notebook in hand, students document the mystery by way of embossing, stamping, rubbing, punching and drawing. The experience guides them through a crime scene and five themed vignettes. Each vignette includes scientific, hands-on experiences that let the students try their hands as professional detectives, using and reinforcing each of the five science principles presented earlier.

Culture of Sherlock

Returning to the 21st century, students enter a contemporary gallery. Pop culture enthusiasts will enjoy a robust collection of all things "Sherlockian," ranging from vintage Sherlock Holmes-themed card games, comics, and magazines to radio scripts and movie and television show props and costumes.

Featured props include items from Warner Bros.' *Sherlock Holmes* movies set in the Victorian era, alongside costumes, props and behind-the-scenes tools from the hit CBS television show *Elementary* and the BBC's *Sherlock*, both of which set Sherlock Holmes in the present day. The exhibition offers students the most comprehensive display of Sherlock Holmes as portrayed in the popular imagination since his creation over 100 years ago.

Videos in the final gallery will investigate Sherlock Holmes' and Conan Doyle's influence on pop culture, history, and forensic science. Six of the country's leading forensic specialists, many from the Minnesota Bureau of Criminal Apprehension, share details of how they solve mysteries today using many of the very same techniques that Sherlock Holmes used more than a century earlier. Actual tools from the Bureau and evidence are shown, presenting an accurate example of the importance and complexity of real forensic science.

Detective’s Notebook (for student use in exhibit)

Every visitor will receive a notebook at the entrance of the exhibit. Students will use this notebook to help guide them through the exhibit, collect clues and evidence from the crime scene, and reflect on the material that they have been exposed to. This notebook is critical in solving the crime and will have items added to it at various stations throughout the exhibit. It is designed so that students will not need pencils to record observations, but will instead stamp, emboss, or punch their clues into the notebook. It can be used as an exhibit worksheet for field trips as students will be able keep the notebook after exploring the exhibit. This notebook is an important tool for students as it touches on key scientific concepts and provides guidance for navigating through the exhibit.

Educational Standards

The International Exhibition of Sherlock Holmes is intended to provide strong connections to science and language arts for students and educators.

The exhibit and the accompanying educational materials are aligned with the Common Core State Standards and the Next Generation Science Standards.

Educators can integrate these materials into their classrooms to further student understanding of the concepts presented in the exhibit while complementing classroom curricula. The following information is a summary of each set of standards used in the development of the exhibit and the accompanying classroom materials.

Common Core State Standards

The Common Core State Standards (CCSS) were created by the National Governors Association, teachers, schools, and experts in order to create a consistent framework to prepare students for college and the workforce through English Language Arts and Mathematics skills.

The CCSS are considered the most effective models from states across the US and have been reviewed and tested by thousands of teachers around the world. The goal of these standards is to allow consistency in student skill expectations country wide, regardless of where students live.

The Standards:

- align with college and work expectations
- are clear, understandable, and consistent
- include rigorous content and application of knowledge through higher-order skills
- build upon strengths and lessons of current state standards
- are informed by other top performing countries so that all students are prepared to succeed in our global economy and society

The Standards comprise three main sections: a comprehensive K–5 section and two content area–specific sections for grades 6–12, one for English and language arts and one for history/social studies, science, and technical subjects.

Each section is divided into strands. The K–5 and 6–12 English and language arts sections have Reading, Writing, Speaking and Listening, and Language strands; the 6–12 history/ social studies, science, and technical subjects section focuses on reading and writing. Each strand is headed by a strand-specific set of College and Career Readiness Anchor Standards that are identical across all grades and content areas.

Individual College and Career Readiness (CCR) anchor standards can be identified by their strand, CCR status, and number (R.CCR.6, for example). Individual grade-specific standards can be identified by their strand, grade, and number (or number and letter, where applicable), so that RI.4.3, for example, stands for Reading, Informational Text, grade 4, standard 3 and W.5.1a stands for Writing, grade 5, standard 1a.

Information taken from the Common Core website at http://www.corestandards.org/

Next Generation Science Standards

Through a collaborative, state-led process managed by *Achieve*, new K–12 science standards have been developed that are rich in content and practice and arranged in a coherent manner across disciplines and grades to provide all students an internationally benchmarked science education. The Next Generation Science Standards (NGSS) are based on the Framework for K–12 Science Education developed by the National Research Council.

States have previously used the National Science Education Standards from the National Research Council (NRC) and Benchmarks for Science Literacy from the American Association for the Advancement of Science (AAAS) to guide the development of their current state science standards. While these two documents have proven to be both durable and of high quality, they are around 15 years old. In addition, major advances have since taken place in the world of science and in our understanding of how students learn science effectively. These advances created a need for developing new standards to accommodate not just the new learning styles of today's students, but also the new sciences that are being discovered and taught.

The standards are organized by grade levels in kindergarten through fifth grade. The middle and high school standards are grade-banded. As with the titles of the standards themselves, the first digit indicates a grade K-5 or specifies MS (middle school) or HS (high school). The next alpha-numeric code specifies the discipline, core idea, and sub-idea. PS indicates Physical Science, LS is Life Science, ESS is Earth and Space Science, and ETS indicates Engineering, Technology, and Applications of Science. The number at the end of each code designates the order in which that statement appears in the framework.

Information taken from NGSS website at http://www.nextgenscience.org/

NEXT GENERATION SCIENCE STANDARDS

		The Proof is in the Powder	Busted by Biology	Curious Contraptions	A Matter of Spatter
Disciplinary Core Ideas					
PS1	Matter & Its Interaction	✓	✓		
PS2	Motion & Stability: Forces & Interactions		✓	✓	✓
PS3	Energy			✓	✓
PS4	Waves & Their Applications in Technologies for Information Transfer				
LS1	From molecules to organisms: Structures & processes		✓		
LS2	Ecosystems: Interactions, Energy, & Dynamics				
LS3	Heredity: Inheritance & Variation of Traits		✓		
LS4	Biological Evolution: Unity & Diversity				
ESS1	Earth's Place in the Universe				
ESS2	Earth's Systems				
ESS3	Earth & Human Activity				
ETS1	Engineering Design			✓	✓
Practices					
1	Asking questions & defining problems	✓	✓	✓	✓
2	Developing & using models			✓	✓
3	Planning & carrying out investigations	✓	✓	✓	✓
4	Analyzing & interpreting data	✓	✓	✓	✓
5	Using mathematics & computational thinking				✓
6	Constructing explanations & designing solutions	✓	✓	✓	✓
7	Engaging in argument from evidence	✓			✓
8	Obtaining, evaluating, & communicating information	✓			
Crosscutting Concepts					
1	Patterns	✓		✓	✓
2	Cause & effect	✓	✓	✓	✓
3	Scale, proportion, & quantity		✓		✓
4	Systems & system models		✓	✓	✓
5	Energy & matter			✓	
6	Structure & function	✓	✓	✓	
7	Stability & change	✓			

Lesson Plan Overview

Contained in this packet are a total of eight hour-long lesson plans designed for elementary, middle, and high school students. Each lesson contains themes from or is directly related to Sherlock Holmes and the exhibit. These activities were designed with the expectation that the students are somewhat familiar with Sherlock Holmes and have been crafted so that a supplementary trip to the exhibit will provide a strong context for each lesson.

Although each lesson was designed for a certain grade range, many lessons can be modified to either increase their sophistication and difficultly or decrease their complexity to use with lower grade levels. Suggestions for this process are included in each lesson under the “Optional Extensions” category.

Of the eight lessons, four are science-themed and four are language arts-themed. Each lesson is intended to fill a full hour but can be modified depending on class length.

Within each lesson, you will find:

- **Learning Objectives**
- **Alignment with Standards**
  Next Generation Science Standards for the four science lessons and Common Core State Standards for the four language arts lessons.
- **Advanced Preparation**
  These steps are designed to be done in the days or weeks before teaching the lesson.
- **Optional Extensions**
  Included are ways to adapt the activity for different age levels, as well as suggestions on how to extend the activity into multi-hour or multi-day lessons.
- **Background Information**
  Important information providing the educator with a thorough understanding of the concepts presented in the lesson.
- **Glossary**
  Prepare your students for the new terms they may encounter in the lesson or at the exhibit.
- **Supply Worksheet**
  At the end of each science lesson is a “shopping list” that can be used to calculate how many of each item is needed.
- **Student Handouts**
  Some lesson plans will include student handouts for teachers to print and photocopy for their students.
- **At-Home Versions**
  Each of the four science lesson plans includes an at-home version of the experiment for students to do with their family in the event that time does not allow for the full lesson in class.

Science Lesson Plans:

The following science lessons were designed to expand on the sciences presented in *The International Exhibition of Sherlock Holmes* and allow students to gain hands-on experience with forensic science. In order address all aspects of STEM education (Science, Technology, Engineering, and Mathematics), activities have been included that focus on engineering and math.

3rd Grade – 5th Grade

- **The Proof is in the Powder**
  Suggested as a pre-exhibit field trip activity
  In this activity, students will design a way to identify a mystery powder found at a crime scene by comparing it with known powders, with the goal of solving a crime. Basic chemistry and reasoning skills are utilized.

- **Busted by Biology**
  Suggested as a post-exhibit field trip activity
  In this activity, students will extract their own DNA from their cheek cells and learn how DNA is analyzed and used to solve crimes. Lesson concepts introduce students to cell structure and basic genetics and can be related to information on DNA forensics as observed in the exhibit.

6th Grade – 8th Grade

- **Curious Contraptions**
  Suggested as a pre-exhibit field trip activity
  In this engineering design activity, students will design, test, and build a "haunting machine" to solve a Sherlockian mystery. Students will use their creativity and imagination to invent a Rube Goldberg-inspired contraption.

- **A Matter of Spatter**
  Suggested as a post-exhibit field trip activity
  In this math-based activity, students will experiment to find how height and angle affect drops of liquid ("spatter") and then use this knowledge to solve a crime. Fractions or decimals, averages, angles, and measurement skills are reinforced in this activity.

At-Home Versions

In addition to the four science lesson plans listed above, there are four at-home versions of these same lessons. They are designed to capture a simpler version of the full lesson plans with instructions and materials simple enough for families to do together at home. If you are unable to carry out the full hour-long lessons in class, these activities are an excellent alternative that you can send home with students.

Language Arts Lesson Plans:

The following language arts lessons were designed to introduce the writing of Conan Doyle to the next generation while reinforcing writing and reading concepts within Common Core State Standards.

6th Grade – 8th Grade

- **On the Trail of a Mystery**
  Suggested as a pre-exhibit field trip activity
  Students will learn mystery vocabulary and story structure, work in pairs to identify mystery elements in a Sherlock Holmes story, and craft a persuasive response that predicts their own solution to the mystery. This lesson will familiarize students with mystery structure, which will be echoed as they solve the mystery at the exhibit.

- **The Game is Afoot!**
  Suggested as a post-exhibit field trip activity
  Students learn to recognize descriptive language, analyze its function in a Sherlock Holmes story, and employ it in their own writing. Students will participate in a fun writing exercise and use the character it inspired to write an original mystery story.

9th Grade – 12th Grade

- **Cheap, Healthful Literature**
  Suggested as a pre-exhibit field trip activity
  Students will view archival copies of *The Strand*, the magazine that originally published many of Conan's Doyle short stories. Students will explore short story structure and participate in a collaborative writing project.

- **Cracking an Ancient Case**
  Suggested as a post-exhibit field trip activity
  In this lesson, students will begin the lesson by solving a riddle that echoes the Sherlock Holmes story they have read. Students then learn to apply interrogation methods to academic sources and explore a real-life historical mystery.

Games to Engage your Class in Observation:

In addition to the lesson plans provided, we have also included two observation games inspired by the language arts lessons for teens and adults to play at home. These may also be adapted as a fun activity for your students to play during class.

1. **Spot the Liar!**
   Can you spot a liar? This game pits Sherlocks against Suspects to determine who is the best liar and who is the next Sherlock Holmes.

2. **If the Shoe Fits…**
   This game is a great way to put your Sherlockian powers of observation to the test! Players try to match shoes (or other distinctive personal items) to their owners using nothing but carefully observed clues about the item.

3rd Grade – 5th Grade

Upper elementary students will gain a wealth of information from *The International Exhibition of Sherlock Holmes*. This age group will enjoy the many hands-on components throughout the exhibition but may need extra guidance when solving the mystery portion of the exhibit. You may wish to have students work in partners or small groups accompanied by a chaperone to solve the mystery.

Two science lessons are included for this age group. **The Proof is in the Powder** allows students to practice their deduction skills by performing an authentic scientific investigation using many common ingredients found in the kitchen. **Busted by Biology** gives students a more in-depth understanding of what DNA is and how it can be used to solve crimes. Students will be introduced to DNA in the exhibition's modern forensics section. A conversation about what the students learned about DNA in the exhibit is an effective way to introduce this activity.

For more mature students, the two observation games **Spot the Liar!** and **If the Shoe Fits…** may be appropriate. These games reinforce scientific concepts of making observations and drawing conclusions while helping cultivate students' interest in Sherlock Holmes. These games could be played in preparation for your visit to the exhibit or after the field trip.

Middle School

Before visiting the exhibit, it is recommended that students complete the lesson **Curious Contraptions**. This engineering activity is sure to get students excited about their trip to see *The International Exhibition of Sherlock Holmes*. Students will use ingenuity, imagination, and a bit of patience to build machines similar to Rube Goldberg machines, all in the context of a Sherlock Holmes story.

The science lesson **A Matter of Spatter** is excellent for students studying angles, averages, or measurement. Teachers can choose to have their students use fractions or decimals and can decide if students will be allowed to use a calculator depending on what concepts are being reinforced. For younger students not yet familiar with angles or protractors, there is a suggestion in the Optional Extensions section on how to expand the portion of the activity that does not use angles so that the lesson remains a full hour in length. For more advanced students, there are also suggestions of how to incorporate basic trigonometry in the activity.

The activity **The Proof is in the Powder** may also be appropriate for this age level if the activity is expanded using the Optional Extensions. For more advanced students, the educator can provide fewer directions and allow students to design the experiment on their own as much as possible.

Two language arts lessons and two science lessons are included for middle school students. In the **On the Trail of a Mystery** lesson, students are introduced to a Sherlock Holmes story and learn about the structure and vocabulary of the mystery form, preparing them to jump into the mystery in the “Become a Detective!” portion of the exhibit. This lesson also includes information about the history of the mystery genre and Conan Doyle’s significant contribution to the form.

The post-exhibit lesson, **The Game is Afoot!**, focuses on the crucial role of descriptive language in Conan Doyle’s stories and in the students’ own work. Inspired by their visit to the exhibit, the students will write their own mysteries, integrating their own experiences the way Conan Doyle did when he incorporated his medical knowledge into the Sherlock Holmes stories. The two high school lessons plans, which focus on short story structure and “interrogating” academic sources, respectively, can be adapted for middle school students using the Optional Extensions sections from those lesson plans.

For science and language arts instructors, the observation games **Spot the Liar!** and **If the Shoe Fits…** can be used as fun classroom activities that encourage students to practice their Sherlockian observation skills. It may be possible to adapt these games to play while on a school bus for your field trip to keep students engaged and excited about viewing the exhibition.

High School

Two lesson plans are included for high school students. The first, **Cheap, Healthful Literature**, introduces students to *The Strand* magazine, the British magazine that published a great deal of Conan Doyle's work. *The Strand* archives are available online and students can peruse these rich sources of information on turn-of-the-19^{th}-century celebrities, science, technology, and literature before they "enter" that world in the exhibit. The students read one of the Sherlock Holmes stories that was originally published in *The Strand*, learn what makes a short story "work," and apply that knowledge to a collaborative short story writing project.

In the post-exhibit lesson, **Cracking an Ancient Case**, students will parlay their newly honed interrogation skills into academic research, choosing a "mystery from history" to explore and learning how to distinguish reliable sources from suspect ones. The two middle school plans, which focus on mystery vocabulary and conventions and descriptive language, can be adapted for high school students using the Optional Extensions sections from those lesson plans.

While high school teachers address unique course content, many of the middle school lessons can easily be adapted for this age level. **Curious Contraptions** encourages students to use the engineering design process to invent a Sherlockian Rube Goldberg machine. Higher-level students may surprise you with their enthusiasm for this type of activity as well as with the inventions they create! **A Matter of Spatter** has a strong math focus and would be an excellent activity for students learning trigonometric functions. The Optional Extensions section provides suggestions of ways to alter the activity to include higher-level thinking.

For science and language arts instructors, the observation games **Spot the Liar!** and **If the Shoe Fits…** can be used as fun classroom activities that encourage students to practice their Sherlockian observation skills. It may be possible to adapt these games to play while on a school bus for your field trip to keep students engaged and excited about viewing the exhibition.

The International Exhibition of Sherlock Holmes was developed by Exhibits Development Group and Geoffrey M. Curley + Associates in collaboration with the Conan Doyle Estate Limited, the Oregon Museum of Science and Industry, and the Museum of London.

SHERLOCK HOLMES

THE EXHIBITION

The Proof is in the Powder

Pre-Exhibit Field Trip: Grades 3-5

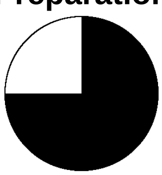
In this activity, students will design a way to identify a powder found at a crime scene by comparing it with known powders, with the goal of solving a crime.

LEARNING OBJECTIVES

- Students will learn to describe the various physical properties of chemicals
- Students will understand the types of changes that can occur in a chemical reaction
- Students will learn to use deductive reasoning to solve problems

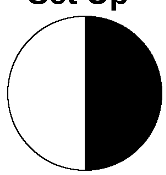
TIME REQUIRED

Advance Preparation



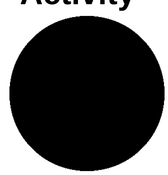
45 minutes

Set Up



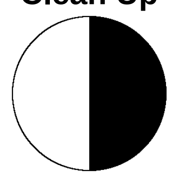
30 minutes

Activity



50-60 minutes

Clean Up



30 minutes

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	5 min
Crime Scene Story	Instructor-led Activity	5 min
Powder Testing	Partner Activity	20-35 min
Wrap up	Large group discussion	10 min

SITE REQUIREMENTS

- Ideal to have access to a sink

NEXT GENERATION SCIENCE STANDARDS

Practices
1. Asking questions and defining problems
3. Planning and carrying out investigations
4. Analyzing and interpreting data
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Crosscutting Concepts
1. Patterns
2. Cause and effect
6. Structure and function
7. Stability and change

Disciplinary Core Ideas

	Grade Level:	3	4	5
	Physical Science			
PS1	Matter and Its Interaction	n/a	n/a	✓
PS2	Motion and Stability: Forces and Interactions		n/a	
PS3	Energy	n/a		
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a
	Life Science			
LS1	From Molecules to Organisms: Structures and Processes			
LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a	
LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a
LS4	Biological Evolution: Unity and Diversity		n/a	n/a
	Earth & Space Science			
ESS1	Earth's Place in the Universe	n/a		
ESS2	Earth's Systems			
ESS3	Earth and Human Activity			
	Engineering, Technology, and Applications of Science			
ETS1	Engineering Design			

Topics: Physical Change, Chemical Change, Chemistry, Acids, Bases, Inquiry

SUPPLIES

Notes on activity setup:
The supplies section and activity instructions assume your students will use five different tests to identify six different powders. For a shorter activity, you may choose to use fewer tests to identify fewer powders, or substitute different powders, while still using the Crime Scene Story. See the Advance Preparation on page 5 for suggestions on how to alter the activity.

There are also a variety of ways to alter the activity if you choose not to use the Crime Scene Story. To create an abbreviated or extended version of the activity, see the following pages:

- Use five tests to identify 12 powders (page 31)
- Use three tests to identify eight powders (page 32)
- Use two tests to identify five powders (page 33)
- Use two tests to identify six powders (page 33)

In addition, there are different ways that you can set up this activity. You can give each student group all of the powders they will test or you can set up "stations" with particular powders that students will rotate through.

If each student group has all the powders, the activity provides more substantial and meaningful experiences for each student but requires more preparation and a greater number of powders, plastic cups, spoons, etc. Student stations are easier to set up and require fewer materials, but require more management as students rotate.

Permanent Supplies	Amount	Notes
½ gallon container	1	For cabbage juice indicator
Cafeteria trays (optional)	1 per group	To pass out supplies
Coffee or spice grinder (optional)	1	
Heat source (small candle or Bunsen burner)	1 per group	Or share between stations
Lighter (optional)	1	Optional, if using the heat test
Magnifying glasses (optional)	1 per group	Or share between stations
Permanent marker	1	For labeling
Strainer	1	For cabbage juice indicator
Tongs or oven mitts	1 per group	Or share between stations
White ice cube trays or Styrofoam egg cartons	1 per group	Or share between stations

Consumables	Amount	Notes
Baking powder	1 Tbsp per group	
Baking soda	1 Tbsp per group	
Detergent	1 Tbsp per group	Should contain sodium carbonate
Flour	1 Tbsp per group	
Powdered sugar	1 Tbsp per group	
Plaster of Paris	1 Tbsp per group	
Aluminum foil	7 pieces per group	See Advance Preparation
Cabbage juice indicator	1/8 cup per group	See Advance Preparation
Vinegar	1/8 cup per group	
Tincture of iodine	1-2 tsp	
Water	2 cups per group	
Pop-top squeeze bottle	3 per group	(e.g., water or sports drink)
Straws or eyedroppers	3 per group	Optional, use if pop-top bottles for liquids are unavailable
Small cups	1 per group	For water test
Plastic spoons	10 per group	Plastic or metal
Toothpicks	10-12 per group	
Powder testing area	1 per group	Laminated paper, non-porous plate, ice cube tray, Styrofoam egg carton, or Dixie cup-sized cups
Red cabbage	2 cups	For cabbage juice indicator
Salt	½ - 1 cup	For cabbage juice indicator
Proof is in the Powder Booklet	1 per student	On pages 26-27
Testing instruction Cards	5 per group	On page 28
Masking tape	1 roll	For labeling
Paper towels	1 roll per group	Or share between stations

ADVANCE PREPARATION

Determine Tests to Use
There are many possible ways to perform this experiment. Before beginning, determine which tests will be performed on which powders. The possible tests are listed below. The tests you choose will depend on available supplies, teacher preference, and the safety protocol at your school.

For the purposes of this outline, we will use all tests. However, not all tests are necessary to identify the six powders used in the crime scene story. Depending on supplies and teacher preference, you may choose not to perform all tests. The heat test or the cabbage juice test may be omitted if desired and the remaining tests will still positively identify the crime scene powder.

Type of Test	Chemicals it will Identify
Water Test	• Some chemicals will not dissolve; others will • Some chemicals will create a temperature change (i.e., Plaster of Paris) • Mixtures of both an acid and a base will fizz (i.e., Alka-Seltzer)
Vinegar Test	• Chemicals containing a form of carbonate will fizz and create carbon dioxide gas (i.e., baking soda)
Cabbage Juice Test	• Will turn different colors with an acid, base, or neutral chemical
Iodine Test	• Chemicals containing starch will turn a deep purple color (i.e., flour)
Heat Test	• Chemicals containing sugar will caramelize (i.e., powdered sugar)

Determine Powders to Use
There are many ways to alter the powders used in the story. Some possible suggestions include:
- To adhere to the crime story but make a shorter activity, omit any of the typical bakery powders (baking soda, baking powder, or flour).
- Plaster of Paris will permanently clog drains if poured down a sink. There are a few options for avoiding this issue:
    - Have students do the tests with Plaster of Paris but remind them they must throw all materials from their tests into the trash and NOT in the sink.
    - Before students begin, model the entire experiment procedure using Plaster of Paris. Have students record the data collected as you perform the tests on this powder. They can then test the remaining powders on their own.
    - Remove the Plaster of Paris entirely from the story and the experiment. If you prefer to omit Plaster of Paris but would still like to use the crime

scene story, substitute milk powder and associate it with the landlady (who may have needed it for her many children).

Ice Cube Trays of Powders:

- Use the masking tape and permanent marker to label ice cube trays with the names of the six known powders you will be using.
- Use the masking tape and permanent marker to label six plastic spoons with the names of the six known powders you will be using.
- Add about one tablespoon of each powder into its corresponding well.
- Put the correct spoon in each well.

Powder Testing Area:

- If supplies allow, students may test the powders in the wells of a white ice cube tray, a Styrofoam egg carton, or Dixie cup-sized disposable cups.
- Alternatively, a laminated piece of paper or a non-porous plate would work. Students will simply place their powder on the plate and add a few drops of liquid on top of it. If using this method, make sure students use as little liquid as possible to test the powders. 2-4 drops will be enough for the iodine, vinegar, and cabbage juice test. The water test should be done in a cup since more water is required to see if the powder dissolves.

Detergent:

- The detergent must contain sodium carbonate (also called washing soda). Check the label. Try out these detergents first: Arm & Hammer Fabricare, BioKleen, or Seventh Generation.
- If the detergent chosen has a chunky texture that is very different from the other powders, use a coffee grinder or similar to grind the detergent until it more closely resembles the texture of the remaining powders.

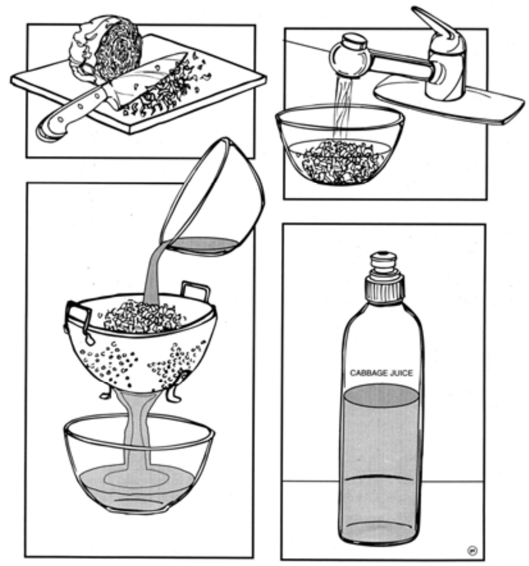
Pop-Top Bottles:

- Pop-top bottles (such as water bottles) are used to contain iodine, cabbage juice, water, and vinegar. You may give each group a bottle of each or share between groups.
- If bottles are unavailable, place these liquids in cups and have students use a straw or eyedropper to transfer just a few drops of each liquid to their powder testing area.

Cabbage Juice Indicator:

- Finely chop red cabbage with a knife.
- Place 2 cups or more in ½ gallon container.
- Add hot tap water until cabbage is just barely covered.
- Wait 2–5 minutes.
- Place strainer over large bowl. Pour cabbage and hot water through strainer, collecting water in bowl. The water should now be purple.

- Add ½–1 cup salt to the mixture and stir until dissolved (this prevents the cabbage juice from molding).
- Store the purple water ("cabbage juice indicator") in a labeled container in the refrigerator until ready for use. It does not need to be refrigerated on the day of use.
- Dispose of the solid cabbage as you would other vegetable scraps.
- Label one spoon per group "cabbage juice."



For more information on cabbage juice indicator, including a video of this procedure, see the "Of Cabbages and Kings" video listed in the Resources section (page 24).

Iodine Solution:

- Add 1 teaspoon of tincture of iodine to 2 cups of water (enough for one classroom of about 35 students).
- Divide this solution into pop-top squeeze bottles.
- Use masking tape and a permanent marker to label the bottles "iodine solution."
- Label one spoon per group "iodine."

CAUTION: Iodine is poisonous to ingest and may stain skin and clothing.

Water:

- Fill pop-top squeeze bottles with room temperature water.
- Label these bottles "water."
- Label one spoon per group "water."

Vinegar:

- Fill pop-top squeeze bottles with about 1-2 cups vinegar.
- Label these bottles "vinegar."
- Label one spoon per group "vinegar."

Heat Test:

- Cut or tear aluminum foil into about 5 cm by 5 cm (2 inch x 2 inch) squares. Create enough squares for each group to have seven squares. Alternatively, pass out a large sheet of foil to students and allow them to tear their own smaller squares.

Student Worksheets:

- Print the *Proof is in the Powder booklet* (one per student) and fold in half.

- □ Print and copy the Testing Instruction Cards (page 28). Depending on set up, you may wish to give each group instructions for all tests or place the directions for each test at the appropriate stations around the room.
- □ Students will also need their own notebooks or paper to record their observations.
- □ Depending on student level, you may wish to print or have students duplicate the Example Data Collection Chart (page 29) to record their data.

SET UP

Cafeteria trays are an excellent way of passing out complete lab setups to each group. Set out trays (one per group) with the following items on each tray:

For each group

- ❑ Vinegar in pop-top squeeze bottle with spoon (or in cups with straws or droppers)
- ❑ Cabbage juice in pop-top squeeze bottle with spoon (or in cups with straws or droppers)
- ❑ Iodine solution in pop-top squeeze bottle with spoon (or in cups with straws or droppers)
- ❑ Water in pop-top squeeze bottle
- ❑ Powder testing area (ice cube tray, plate, or laminated paper)
- ❑ Ice cube tray with 6 powders and 6 spoons, labeled
- ❑ 1 plastic cup
- ❑ 10-12 toothpicks
- ❑ Testing Instruction Cards
- ❑ *Proof is in the Powder booklet* (1 per student)
- ❑ 6 aluminum foil squares
- ❑ 1 candle or Bunsen burner
- ❑ Pair of tongs or oven mitts
- ❑ Magnifying glasses (optional)

With Teacher

- ❑ Paper towels
- ❑ Container of crime scene powder

INTRODUCTION

5 minutes

Notes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Suggested script is shaded.
Important points or questions are in bold.
Suggested answers are in italics.

What is a chemical? *Everything around us is a chemical - chemicals can be solid, liquid, or gas. Everything from the water we drink to the air that we breathe is made of chemicals. Some chemicals can be dangerous, but many are completely harmless or even necessary for life!*

How can we tell different chemicals apart? How do we know if a flask is full of water or something dangerous? *Chemicals that look alike can have very different properties. Chemists study these properties and can perform tests to determine what chemical they have. We should never taste a chemical if we do not know what it is!*

Today we are going to solve a mystery by examining a chemical found at a crime scene. We will have to carefully observe the chemical's properties to figure out what it is. Some of the properties we will be able to see - these are the physical properties of the chemicals. For the chemical properties, we will have to experiment to find out what they are. We will be looking for signs of chemical changes such as formation of bubbles or a change in color or temperature. As scientists, we will need to record all of our observations!

What do you think are some of the properties of chemicals we may observe? *Physical properties include color, state of matter (solid, liquid, or gas), viscosity (thickness), smell, freezing/boiling point, density, etc. Chemical properties include pH and how the mystery chemical reacts when combined with other chemicals.*
We will use both physical and chemical properties to discover the identity of a mysterious chemical today.

SAFETY PRECAUTION:

- Read the safety labels on all chemicals before beginning the activity. Make sure that you are familiar with the proper procedures in case of accidental ingestion or if a student gets a chemical in their eyes.
- If available, students should wear safety glasses or goggles throughout the experiment.
- Remind students not to rub their eyes and to wash their hands after the activity.
- Even if you are using edible chemicals such as powdered sugar, remind students that they should never taste a chemical during an experiment.
- If you are performing the heat test, make sure to review fire safety with students; remind them that they should never play with fire and know the location of the nearest fire extinguisher.

INSTRUCTOR-LED ACTIVITY

Crime Scene Story

5 minutes

Read the following story to the students. You may choose to have the mystery powder in a jar and explain that it is already been collected from the crime scene or you can recreate the crime scene and allow the students to take turns collecting a sample of the powder after they have completed testing the known powders.

Crime Scene Story

Alice owned a bakery, but no one would call her sweet. She was feuding with at least four of her neighbors. She thought the washerwoman was lazy. Her landlady had too many children, including a new baby that dared to cry sometimes. The postman was a complainer—it wasn't Alice's fault he had slipped on the bakery steps! She thought he was faking that broken foot anyway. Her greatest rival was the owner of the pastry shop down the road, a woman whose cakes and pies were legendary.

"What's so great about cakes and pies?" Alice was heard to say. "What's the matter with bread?"

Alice had plenty of enemies and she was very suspicious, so each night at closing time, she checked the street for strangers and made sure the door was locked. But late one night, when Alice was very tired, she forgot to check. She opened the door to leave and a masked stranger rushed into the bakery!

“Give me all the money you’ve got!” shouted the stranger, holding out a big black sack.

“Not a chance,” said Alice.

She rushed at the stranger, who was caught by surprise. She shoved the burglar out the door and locked it. Alice watched the burglar run down the street, and then she called the police.

By the time the police arrived, the burglar was long gone, leaving nothing but the empty sack behind. When the police examined the sack, they found grains of white powder on it. They thought the powder was probably just an ingredient from the bakery, but wanted to test it to be sure. They also asked Alice who might have a grudge against her:

The **washerwoman** had returned one of Alice’s skirts with a faint stain, so Alice refused to pay her.
The **woman who owned the pastry shop** was Alice’s biggest business competitor.
The **landlady** could not keep her children quiet, and Alice was not going to pay the rent until she did.
The clumsy **postman** had slipped on her steps and was blaming Alice for his broken foot.

Result:
Do not reveal until after students have completed the powder testing!
After students have finished the experiment, they will determine that the unknown substance is laundry detergent. Allow students to form a hypothesis as to why this powder indicates a suspect before revealing the answer: The washerwoman would be most likely to be indicated by the laundry detergent. The sack had picked up detergent from the washerwoman’s floor.

PARTNER ACTIVITY

Powder Testing

30-35 minutes

We have collected the mystery powder that was found at the crime scene, but before we can identify it, we need to collect information on the powders it might possibly be.

Walk around the classroom with the crime scene powder and allow students to get an up-close view of the sample.

Describe the crime scene powder. *White, smooth, fine powder, etc. Answers will vary.*

What kind of powder do you think this could be? *Answers will vary. Lead students to think of powders that might be found at a bakery (flour, baking soda, baking powder) and powders that may have been found on the suspect (Plaster of Paris, detergent, powdered sugar). Depending on student level, you may wish to talk with students at this point about why these powders may have been found on the suspects (Plaster of Paris would be from the cast on the broken leg; detergent would be from the job as a washwoman; powdered sugar would be from the woman who owns the pastry shop).*
Alternatively, you may wish to wait until the mystery powder has been identified and allow students to figure out why it would have been associated with a particular suspect.

As students brainstorm possible powders, pull out the powders that you have for the experiment as the students name them. Explain that the police have narrowed it down to these possibilities and now it is up to them to figure out which one matches. The possible powders include baking soda, baking powder, powdered sugar, Plaster of Paris, detergent, and flour.

How could we identify the powder found at the crime scene? *We can do tests to both the known powders and the unknown powder and see if they react in the same ways.*

What are some of the ways we can test it? *What the powder looks like, what happens when it is mixed with other chemicals, or what happens when it is heated.*

Depending on age and ability, guide students as they design what tests to run and how to run them. Alternatively, tell them what tests they will be running on the unknown powder as follows:

Give students the instructions below, then pass out the testing materials tray (See Set Up on page 8) to each group. Be sure to include the *Proof is in the Powder booklet* (on pages 26-27) for each student and the Testing Instruction Cards (on page 28) for each group. The booklet will give the students instructions, from Sherlock Holmes, how to record their results for each powder. Remind students to observe carefully and record all observations in their own notebook.

Student Instructions:

1. Five tests are listed on the Testing Instruction Cards. You can conduct any test, on any powder, in any order. Your goal is to record information in your notebook about each powder so that it can be used to identify the crime scene powder.

2. After all tests have been performed on all powders, collect one scoop of the powder from the crime scene. Perform the same tests on this powder and use the information you recorded to figure out what it is!

Points to remember:

- Be careful not to mix the powders and use a different spoon for each powder.
- Record all observations in your notebook.
- Be sure to clean out the plastic cup and powder testing area between tests.
- If using Plaster of Paris, pour any chemicals from your test into the **trash**. **Do NOT pour chemicals into the sink!** Then add a little water and wipe out the container with a paper towel.

Tests to Perform:

- **Physical Properties**
  What does the powder look like? Does it have a smell? Are there crystals or small, irregular chunks? Is it a fine or coarse powder?

- **Vinegar Test**
  Put a pea-sized amount of the powder on your powder testing area. Add ¼ spoonful (3-4 drops) of vinegar. Stir with a toothpick. What happens?

- **Cabbage Juice Test**
  Put a pea-sized amount of the powder on your powder testing area. Add ¼ spoonful (3-4 drops) of cabbage juice. Stir with a toothpick. What happens?

- **Iodine Test**
  Put a pea-sized amount of the powder on your powder testing area. Add ¼ spoonful (3-4 drops) of iodine solution. Stir with a toothpick. What happens?

- **Water Test**
  Add one spoonful of water to the plastic cup. Feel the outside of the cup. Add ½ spoonful of powder to the water. Mix with a toothpick. Feel the cup now. Did the temperature change? Does the powder dissolve?

- **Heat Test**
  Wrap a pea-sized amount of the powder in a piece of aluminum foil. Use tongs to hold the foil packet over a candle flame for 20 seconds. Unwrap the packet and look at the powder. Be careful as the foil will be hot. What happens?

General Suggestions

- ❑ Monitor students to see how much powder they are using. They only need a small amount (the size of a pea) for the vinegar test, iodine test, heat test, and cabbage juice test.
- ❑ Remind students to record all observations as soon as they perform a test. If they try to record their observations at the end they may not remember everything they saw.
- ❑ Before students begin the procedure, you may wish to show them the best way to smell a chemical: they should use their open hand to make a waving motion over the top of the chemical to gently move the smell towards their nose. This technique is called wafting.
- ❑ If students have experience with similar activities, you may wish to expand the activity. See the Optional Extensions section (on page 18) for more information.

Ongoing Assessment Questions

- When students do the vinegar test, ask them what gas they think is in the bubbles. *(The bubbles are carbon dioxide gas, which is created in the reaction.)*
- When students do the iodine test, ask them why it would turn black. *(The iodine reacts with starch, found in corn starch, powdered sugar, and baking powder.)*
- When students do the water test, ask them why the solution changes temperature. *(The powder is arranged differently when mixed with water and each different arrangement of molecules has a different energy; to change the arrangement of the molecules, energy is either used (cold) or given off (hot) and sometimes this change in energy is large enough to feel.)*
- When students do the cabbage juice test, ask them why the cabbage juice changes color. *(Cabbage juice is an acid-base indicator, a chemical that interacts with acids and bases and changes color.)*
- When students do the heat test, ask them why the powdered sugar changes color. (*Sugars will caramelize with heat*.)
- Listen to students' reasoning when they identify the crime scene powder. They should refer to their notebook when choosing the identity.

CAUTION: Plaster of Paris clogs drains PERMANENTLY. Caution students to throw all powders into the garbage unless they are absolutely certain the powder is NOT Plaster of Paris.

CAUTION: Iodine is poisonous to ingest and may stain skin or clothing.

WRAP-UP

10 minutes

Ask for student observations. There is no correct answer. Let students guide the discussion and present their hypotheses before discussing explanations.

What type of powder was collected at the crime scene? *Students should determine that detergent was the powder found at the scene of the crime.*

Who do you think the culprit is based on the results of your testing? Why? *Answers may vary. Remind students that a washerwoman was one of the suspects and would have reason to carry a bag coated in detergent.*

Have we collected enough information to be sure it was the washerwoman? *No, the police would need more information, but this lead will be a good place to start. More advanced students should understand that many pieces of evidence are needed to solve crimes, not just one.*

What reasoning did you use to identify the crime scene powder? *Answers will vary. The results of each test narrow down the choices for the identity of the crime scene powder. Depending on the order in which the students perform the tests, they may imediately rule out certain powders. Encourage students to talk through their reasoning.*

Which tests caused a chemical change in the powders? How do you know? *The vinegar test, iodine test, heat test, water test, and cabbage juice test all caused chemical changes in some of the powders. Evidence of a chemical change can include a change in color, change in smell, change in temperature, or the formation of bubbles.*

Which tests caused a physical change in the powders? How do you know? *The water test caused a physical change in some of the powders when they dissolved. We know because there were no signs of a chemical change. Observing the physical properties of the powder (grain size, crystal formation, smell) is also not a chemical change.*

Which powders were difficult to identify? *Baking soda, baking powder, and Plaster of Paris do not show much of a temperature change, so they can be more difficult to identify. If students accidently contaminated any of their powders, it may have been difficult to identify the crime scene powder.*

Did you get any unexpected results from any of your tests? Why would your results be different than your neighbors? *The primary reason students may have found different results than expected is because of contamination. If the powders or the spoons for each powder were mixed up, or if the testing area was not thoroughly cleaned between powders, students may have gotten incorrect results. This fact sometimes happens in real labs as well so scientists must be very careful and perform tests many times to make sure the results are correct.*

Would crime scene investigators always be able to collect a large jar of a mystery substance like we did? *Often only a very small amount of a mystery substance will be found. To challenge students to think critically about how to test only a very small amount of powder, see the Advanced Lesson ideas in the Optional Extensions on page 18.*

CLEAN UP

- Do not allow students to put Plaster of Paris down the sink. Plaster of Paris will permanently clog and destroy the drain.
- All other materials may be rinsed down the sink or thrown away.

CAUTION: Plaster of Paris clogs drains PERMANENTLY. Caution students to throw all powders into the garbage unless they are absolutely certain the powder is NOT Plaster of Paris.

CAUTION: Iodine is poisonous to ingest and may stain skin or clothing.

OPTIONAL EXTENSIONS

ADVANCED LESSON

To increase the difficulty of this lab, try the following:

- Tell students only a tiny amount (about one pea-sized scoop) of powder was recovered from the crime scene. Challenge students to figure out how the powder could be identified with such a small amount. Can any of the tests use a smaller amount of powder? Are there tests that should be performed first? Can the data from one test give clues about what tests should be done next?
- Mix two of the powders together and challenge students to determine what the combination is.
- Have students choose a mystery powder and give it to their partner to identify.
- Challenge students to identify more powders. Up to 12 are included in this overview. See pages 31-33 for alternative experimental set ups.

CHEMICAL VS PHYSICAL CHANGES

Review the difference between physical and chemical changes with students. In the powder lab, which tests resulted in a physical change and which tests resulted in a chemical change? Have students perform a range of simple experiments (freezing water, burning paper, making bubbles with vinegar and baking soda, dissolving salt in water, etc.) to demonstrate physical and chemical changes and identify each type of change.
For an example lesson for younger students, visit http://sadie423.hubpages.com/hub/hands-on-experiments-to-learn-about-chemistry

ACIDS AND BASES

Have students mix a variety of household substances with the cabbage juice indicator such as lemon juice, water, detergent, and baking soda. The juice changes color to indicate whether each substance is an acid or a base. This can also be done with indicator paper.
For an example lesson on acids and bases, visit http://www.omsi.edu/sites/all/FTP/files/chemistry/NH-PDF/NH-B17-OfCabbageKings.pdf

BACKGROUND INFORMATION

This background information is for teachers. Modify and communicate to students as necessary.

This activity requires students to gather information from multiple chemical tests of various white powders. Each test shows a different physical or chemical property of the powders. Students then analyze their results and find the identity of the powder collected at the crime scene.

Substances can undergo both **chemical changes** and **physical changes**. Chemical changes alter the atomic or molecular structure of a material and produce a new substance. Examples of chemical changes include burning, rusting, and oxidizing processes; cooking an egg results in a chemical change. On the other hand, physical changes do not produce new substances. Physical changes include processes such as freezing, melting, and vaporizing; making ice from liquid water is a physical change.

One way to help determine if something is a physical or a chemical change is to think about if you could reverse the change in order to return to the same materials you started with. For example, if you freeze water to change it to ice, a physical change, the ice could be melted back to liquid water. However, if you burn paper, a chemical change, you will never be able to turn the ashes back into paper.

Tests performed:

- **Physical Properties**
  Each powder is similar in color and composition, but students may still be able to find differences (especially if they have magnifying glasses). Depending on which powders are used, they may notice the milk powder usually has a bit of a cream color. Also, the baby powder can have a faint smell. Upon inspection, students should notice that salt, sugar, and Epsom salts are **crystals**. Alka-Seltzer, detergent, and milk powder are mixtures of various powders and they appear to be tiny, irregular chunks. The rest of the powders consist of very tiny particles and are classified as **powders**.

- **Iodine Test**
  Detergent is designed to remove stains, so the iodine fades when it is mixed with detergent. Milk powder removes the color of iodine because it contains a sugar called **lactose**. This sugar reacts with the iodine in solution, changing it from brown to colorless.

Iodine can be used to test for starch. Iodine is normally a yellowish-amber color. When iodine combines with starch, it turns dark blue, purple, or black. Iodine solution contains iodine in this form, I_2, where two atoms of iodine are connected. Starch chains are in a double helix form, similar to DNA, but the helix is much wider. The center of this helix selectively absorbs certain molecules, including I_2. When the iodine solution is mixed with starch, the iodine molecules (I_2) enter the center of the helix, where they bind to the starch to form a dark blue complex. Flour and baking powder (which contain starch) will both turn blue or black. Powdered sugar often contains cornstarch so it will typically turn blue or black as well.

- **Vinegar Test**
  Several of the powders contain some form of the arrangement of atoms called **carbonate,** which will react with vinegar. There are several forms of carbonate in the powders, as shown in the following table:

sodium bicarbonate is in:	sodium carbonate is in:	calcium carbonate is in:
baking soda Alka-Seltzer baking powder	detergent	Plaster of Paris

All these forms of carbonate react with vinegar to create carbon dioxide gas bubbles.

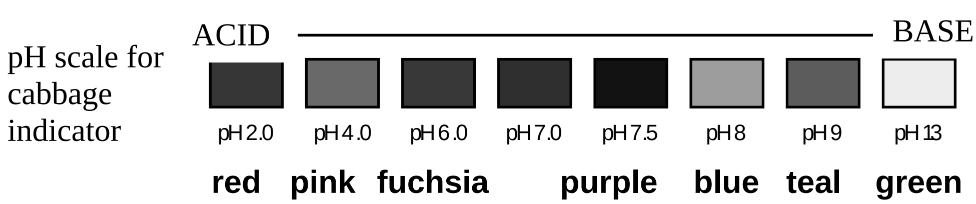
- **Cabbage Juice Indicator Test**
  Scientists put chemicals into two important families: **acids** and **bases**. Acids and bases are opposites in chemistry. Examples of acids are vinegar, battery acid, stomach acid, etc. Some acids are non-poisonous (such as citric acid, which is found in oranges, lemons, and limes) and when they are eaten the taste can be sour. Examples of bases are household cleaners like ammonia, detergent, and drain cleaner; blood and baking soda are also basic. When people taste non-poisonous bases (such as small amounts of baking soda), the taste is often bitter or soapy.

Many chemicals can be classified as either acids or bases. For instance, rocks such as limestone are bases and they will react with weak acids such as vinegar. Plants often produce bitter bases in their leaves that discourage animals from eating them. There are also many substances that do not act as acids or bases. For instance, gasoline, table salt, mineral oil, and most plastics are not acids or bases. In addition, distilled water is neither an acid nor a base. Such substances are said to be **neutral**.

Indicators are chemicals that tell us things we cannot see otherwise. One type of indicator is an acid-base indicator that will turn different colors depending on whether it is exposed to an acid or a base. Cabbage juice, for instance, can change to yellow, green, or blue in the presence of a base and it can change to red or pink in the presence of an acid. Baking powder, baking soda, and detergent are all basic and will turn the cabbage juice blue or green. Cream of tartar is an acid and turns the cabbage juice red or pink.

Plant Indicators
Cabbage juice produces so many colors because it contains several indicators that react with acids and bases. The indicators in cabbage juice are all **anthocyanins**, a class of color-changing chemicals often found in flower petals and fruit juices. In fact, many plants contain “natural” acid and base indicators that produce vivid color changes. We see these color changes as flowers bloom or as fruits ripen.

Scientists use the **pH scale** to specify how much acid or base is in a solution. The pH scale goes from 1–14. A low number on the scale indicates an acid, the number 7 indicates a neutral compound (such as water), and higher numbers indicate bases. The cabbage juice pH scale is as follows:



- **<u>Temperature Test</u>**
  What does it mean to be “hot” or “cold”? If students could look at “cold” molecules in solution and “hot” molecules in solution, they would notice something right away. The “hot” molecules would all be moving, spinning, and shaking much faster than the “cold” molecules. In fact, when scientists say a substance is “hot,” what they mean is the molecules in that substance are shaking and moving a lot. In general, scientists define **temperature** as the average molecular motion of a substance. Cold substances have less molecular motion than hot substances.

  Because molecules are so tiny, students can never feel them moving. Yet by feeling the temperature, students are indirectly experiencing what happens when billions and billions of molecules move, shake, and twist.

  The energy changes in this experiment come from rearranging atoms and molecules. In general, when molecules move from high-energy arrangements to low-energy arrangements, they release energy.

This process is what happens when the detergent (containing sodium carbonate molecules in a high-energy arrangement) dissolves in water. The sodium carbonate molecules are rearranged in the water, releasing energy as heat. This transfer of heat out of a chemical system is called an **exothermic** process.

The opposite process occurs when Epsom salts, which are in a lower-energy arrangement, dissolve in water. These molecules make up the energy difference by absorbing energy from the surrounding solution. This cools the water down and makes the cup feel cool. The transfer of heat into a system (in this case, to the Epsom salt molecules from the water itself) is called an **endothermic** process.

Some powders require energy to dissolve (use an **endothermic** process) and feel cold when mixed with water. Some powders release energy (use an **exothermic** process) when dissolved and feel warm when mixed with water. Epsom salts are strongly endothermic; baking powder and baking soda are only slightly endothermic. Detergent is very exothermic; Plaster of Paris is slightly exothermic.

- **Heat Test**
  Depending on how long students left the powder sugar in the flame, they may have found that it turned brown and caramelized, or perhaps burned and turned black. The carbon, hydrogen, and oxygen in sugar react with fire and turn the powder into a thick liquid. Students will find that once this liquid has cooled, it will become a hard solid instead of a powder. This result is an excellent example of a chemical change.

- **Solubility Test**
  Alka-Seltzer, Epsom salts, salt, and sugar all **dissolve** in water easily; the powders can no longer be seen in the liquid. Baking powder, baking soda, cream of tartar, and detergent dissolve in water only a little and some of the powder can still be seen in the liquid. Milk powder, Plaster of Paris, and starch do not dissolve well in water.

Real-World Applications

The ability to quickly and accurately identify unknown substances is of great importance in many professions. Forensic departments need to identify everything from drugs to poisons to explosives. To identify unknown substances, many chemists will follow a process very similar to the one that the students just performed. Chemists determine the color, smell, and texture of materials and conduct a variety of tests, then compare the results with data of known materials. Recent technological breakthroughs have resulted in even more accurate and quick identifications through techniques such as spectroscopy and microscopy.

CROSS-CURRICULAR CONNECTIONS

ART

Make Your Own Paint
Present students with a number of various (safe) natural and household items that could be used to make a watercolor or paint. Suggested items include: Kool-Aid, berries, food coloring, water, bright flower petals, flour, and cornstarch. Then, on a canvas or thick piece of paper, have the students create a drawing and see how the colors look after their mixture has dried.

BIOLOGY/ BOTONY

Identifying Unknown or Poisonous Plant Life
Have the students learn to identify the signs of potential toxicity in plants and research what poisonous plants are native to their environment.

BIOLOGY

Taxonomy: Classify Your World
Give students multiple objects or pictures to group according to their characteristics. Younger students can identify a trait and group the blocks, tools, foods, plants, pictures of animals, rocks, etc. by the traits they share. Middle students can classify items according to common traits. Older students can use the traits of the items to build a dichotomous key—a series of yes or no questions that allows the identification of the item.

LANGUAGE ARTS

Write a Mystery Story
Have students write a short story to go along with the crime scene story from this activity. Ask them to write from the criminal's point of view. Why did they break into the bakery? What happened once they were there? Where did they go after they left?

For older students, have them read the Sherlock Holmes story *The Adventure of the Devil's Foot* and then devise a short crime story where either the driving plot element is an unknown powder they need to identify or that all the clues lead up to the consumption of an unknown powder.

RESOURCES

Books

The Crime Lab Case by C. Keene
Reading Level: 4^{th}-6^{th} grade
While Nancy and her friends are helping with a high school "chemystery" camp that teaches how science is used to solve crimes, a real mystery involving the professor in charge begins and Nancy takes over the made-up case and the real one.

One Minute Mysteries: 65 Short Mysteries You Solve With Science!
by E. Yoder and N. Yoder
Reading Level: 4^{th}-12^{th}
Each story, just one minute long, challenges your knowledge in earth, space, life, physical, chemical, and general science. Exercise critical thinking skills with dozens of science mysteries (solutions included) that will keep you entertained - and eager to learn more!

Web

NOVA: Three Advancements in Forensics
This article, by NOVA, discusses major advancements in forensic science. The section on "detecting chemical impurities" talks about identifying unknown powders in the case of terrorist attacks.
http://www.pbs.org/wgbh/nova/tech/three-advances-forensic.html

Using Chemical Change to Identify Unknown Powders
This PDF is packed with similar lessons on identifying mystery powders, as well as resources for teachers.
http://www.inquiryinaction.org/pdf/chapter5/Inv5.pdf

Video

Oregon Museum of Science and Industry "Of Cabbages and Kings"
This short video walks you through the process of making cabbage juice indicator and clearly demonstrates the various colors that can be achieved by mixing the cabbage juice with different acids and bases.
http://www.youtube.com/watch?v=biy6wiXujFU

GLOSSARY

Acid	A compound with an excess of available hydrogen ions; often sour in taste.
Anthocyanins	Color-changing chemicals often found in flower petals or fruit juices; may appear red, purple, or blue depending on pH.
Base	A chemical or compound that takes up hydrogen ions; often bitter in taste.
Carbonate	A chemical made of one carbon atom and three oxygen atoms; CO_3^{2-}.
Chemical change	Changes that affect the atomic or molecular properties of a material; a new substance can be created.
Chemist	An expert in chemistry, whose profession is working with chemicals.
Crystal	A chemical in solid form; usually refers to pure solids with shiny facets and faces such as diamonds.
Dissolve	When the molecules of a solid separate and become completely surrounded by the molecules of a liquid.
Endothermic	A chemical change that absorbs energy, causing the reaction container to feel cool.
Exothermic	A chemical change that releases energy, causing the reaction container to feel warm.
Indicator	A substance that changes color to indicate the presence or concentration of a certain chemical.
Ion	An electrically charged atom or group of atoms.
Physical change	A change that does *not* create a new substance.
Powder	Composed of particles that are too small to be seen easily.
Spectroscopy	The process of splitting light into different wavelengths and studying the brightness at each wavelength.
Temperature	The degree or intensity of heat present in a substance or object.
Unknown Substances	Some kind of unknown or unlabeled substance that has ambiguous or hard-to-identify characteristics.

SHERLOCK HOLMES

221B, BAKER STREET
LONDON

Dear trusted friends have you yet figured out this great mystery? What is the unknown substance and does it reveal to you the identity of the burglar who broke into Alice's bakery? Was it the washerwoman, the woman who owns the pastry shop, the landlady, or the postman? I hope you will describe to me how you solved this investigation I look forward to hearing about your great discoveries. Please kindly return this telegram to me at once.

Sherlock Holmes

THE CRIME SCENE POWDER IS:
THE BURGLAR WAS:

SHERLOCK HOLMES

221B, BAKER STREET
LONDON

My name is Sherlock Holmes. I am sending you this message with great haste as a crime has been committed. I am trusting you, my faithful partners in solving a mystery, to help me bring the criminal to justice.

As you have now heard, Alice was nearly robbed in her bakery. The thief ran away, but left behind a sack containing grains of white powder. We have narrowed down the suspects to four individuals the washerwoman, the woman who owns the pastry shop, the landlady, and the postman. You will use evidence to find out which person is the thief.

You will be gathering information about a series of white powders that may have been left by the burglar. You will need to record your observations carefully and exactly. Justice depends on your good work. I have provided an example of the tests I conducted on cornstarch, but I am leaving you in charge of testing the other powders. Farewell until we next meet, hopefully in happier times.

Sherlock Holmes

SHERLOCK HOLMES

221B, BAKER STREET
LONDON

Trusted investigators, please record your careful observations in your own notebooks as I have done here. When you have finished testing all the powders, you can then run your experiments on the crime scene powder.

Sherlock Holmes

	Investigator: S. Holmes

NAME OF POWDER:
cornstarch

DESCRIPTION OF THE POWDER (COLOR, TEXTURE, SIZE, ETC.):
fine texture, bright white, very small grains, feels soft

TESTS CONDUCTED AND RESULTS:

iodine test	*turns black*
water test	*forms a paste, does not change temperature*
cabbage juice test	*stays purple*
vinegar test	*nothing happens*
heat test	*nothing happens*

SHERLOCK HOLMES

221B, BAKER STREET
LONDON

My dear friends, I see that you have finished experimenting with all of the powders. Now comes your most important work of all. Please test the crime scene powder that was found in the sack left by the thief.

Sherlock Holmes

Investigator: ______________________________

NAME OF POWDER:
cornstarch

DESCRIPTION OF THE POWDER (COLOR, TEXTURE, SIZE, ETC.):

TESTS CONDUCTED AND RESULTS:

Testing Instruction Cards

Physical Properties
What does the powder look like?
Does it have a smell?
Are there crystals or small, irregular chunks?
Is it a fine or coarse powder?

Vinegar Test
Put a pea-sized amount of the powder on your powder testing area. Add ¼ spoonful (3-4 drops) of vinegar. Stir with a toothpick.
What happens?

Cabbage Juice Test
Put a pea-sized amount of the powder on your powder testing area. Add ¼ spoonful (3-4 drops) of cabbage juice. Stir with a toothpick.
What happens?

Iodine Test
Put a pea-sized amount of the powder on your powder testing area. Add ¼ spoonful (3-4 drops) of iodine solution. Stir with a toothpick.
What happens?

Water Test
Add one spoonful of water to the cup. Feel the cup.
Add ½ spoonful of powder to the water. Mix with a toothpick. Feel the cup now.
Did the temperature change?
Does the powder dissolve?

Heat Test
Wrap a pea-sized amount of the powder in a piece of aluminum foil. Use tongs to hold the foil packet over a candle flame for 20 seconds. Unwrap the packet and look at the powder. **Be careful** as the foil will be hot!
What happens?

The Proof is in the Powder

Example Data Collection Chart

Tests → / Powders ↓						
1						
2						
3						
4						
5						
6						
Crime Scene powder						

The Proof is in the Powder

Example Completed Data Collection Chart

Tests → Powders ↓	Physical Properties	Vinegar Test	Iodine Test	Cabbage Test	Water Test	Heat Test
1 **Baking Soda**	Fine powder	Bubbles	Orange-brown	Blue	Colder, dissolves a little	No change
2 **Baking Powder**	Fine powder	Bubbles	Black, bubbles	Blue, bubbles	Colder, dissolves a little	No change
3 **Flour**	Fine powder	No bubbles	Black	Stays purple	Stays same temperature, turns to a paste	Burns, turns yellowish
4 **Powdered Sugar**	Fine powder	No bubbles	Blue	Stays purple	Stays same temperature, dissolves	Turns brown and bubbles
5 **Plaster of Paris**	Fine powder	Bubbles	Orange-brown	Stays purple	Warmer, turns to a paste	No Change
6 **Detergent**	Coarse chunks (unless blended)	Bubbles	Orange-brown color fades	Green	Warmer, dissolves a little	No Change
Crime Scene Powder	Coarse chunks (unless blended)	Bubbles	Orange-brown color fades	Green	Warmer, dissolves a little	No Change

The Proof is in the Powder

These five tests identify 12 powders

Powder	Physical Properties	Vinegar Test	Iodine Test	Cabbage Test	Water Test
Alka-Seltzer	Coarse, irregular chunks	Bubbles	Orange-brown, bubbles	Stays purple, bubbles	Stays same temp, dissolves, bubbles
Baby powder	Powder, may have a smell	No bubbles	Orange-brown	Stays purple	Stays same temp, doesn't dissolve
Baking powder	Fine powder	Bubbles	Black, bubbles	Blue, bubbles	Colder, dissolves a little
Baking soda	Fine powder	Bubbles	Orange-brown	Blue	Colder, dissolves a little
Cream of tartar	Fine powder	No bubbles	Orange-brown	Red	Stays same temp, dissolves a little
Detergent	Coarse, irregular chunks	Bubbles	Orange-brown color fades	Green	Warmer, dissolves a little
Epsom salts	Small, sharp edged crystals	No bubbles	Orange-brown	Stays purple	Colder, dissolves
Milk powder	Fine powder	No bubbles	Orange-brown color fades	Stays purple	Stays same temp, turns milky
Plaster of Paris	Fine powder	Bubbles	Orange-brown	Stays purple	Warmer, turns to a paste
Flour	Fine powder	No bubbles	Black	Purple/pink	Stays same temp, turns to a paste
Starch	Fine powder	No bubbles	Black	Stays purple	Stays same temp, turns to a paste
Sugar	Small, sharp edged crystals	No bubbles	Orange-brown	Stays purple	Stays same temp, dissolves

The Proof is in the Powder

These three tests identify eight powders

Powder	Vinegar Test	Iodine Test	Cabbage Test
Alka-Seltzer	Bubbles	Brown, bubbles	Purple, bubbles
One of: epsom salts, baby powder, salt, sugar, milk powder	No bubbles	Orange-brown	Stays purple
Baking powder	Bubbles	Black, bubbles	Blue, bubbles
Baking soda	Bubbles	Orange-brown	Blue
Cream of tartar	No bubbles	Orange-brown	Red
Detergent	Bubbles	Orange-brown color fades	Green
Plaster of Paris	Bubbles	Orange-brown	Stays purple
Starch	No bubbles	Black	Stays purple

The Proof is in the Powder

These two tests identify five powders

Powder	Vinegar Test	Cabbage Test
Alka-Seltzer	Bubbles	Purple, bubbles
Cream of tartar	No bubbles	Red
Detergent	Bubbles	Green
Baking powder or baking soda	Bubbles	Blue
One of: Epsom salts, baby powder, Plaster of Paris, milk powder, salt, sugar, starch	No bubbles	Stays purple

These two tests identify six powders

Powder	Iodine Test	Cabbage Test
Alka-Seltzer	Brown, bubbles	No color change, bubbles
Baking powder	Black, bubbles	Blue, bubbles
Baking soda	Orange-brown	Blue
Cream of tartar	Orange-brown	Red
Detergent	Orange-brown color fades	Green
Starch	Black	Stays purple
Baby powder, Epsom salts, sugar, Plaster of Paris, salt, milk powder	Orange-brown	Stays purple

SUPPLY WORKSHEET

The Proof is in the Powder

Recommended group size: 2-3

Number of Students: ☐ Number of Groups: ☐

Supplies	Amount Needed	Supplies on Hand	Supplies Needed
Note: This list assumes you will be testing six powders with five tests; modify supplies as needed.			
½ gallon container	1		
Aluminum foil	7 squares (2”x2”) per group		
Baking powder	1 tablespoon per group		
Baking soda	1 tablespoon per group		
Cafeteria trays (optional)	1 per group		
Candles	1 per group (or share between groups)		
Detergent	1 tablespoon per group		
Flour	1 tablespoon per group		
Ice cube trays (to distribute powders)	1 per group (or share between groups)		
Lighter	1		
Magnifying glasses (optional)	1 per group		
Masking tape	1 roll		
Paper towels	1 roll per station or group		
Permanent marker	1		
Plaster of Paris	1 tablespoon per group		
Spoons (for powders and liquids)	10 per station or group		
Pop-top squeeze bottles (e.g., water or sports drink) 6 oz. or larger	3 per group (or share between groups)		
Powder testing area (ice cube tray, non-porous plate, or laminated paper)	1 per group		
Powdered sugar	1 tablespoon per group		
Red cabbage	2 cups		
Salt	½-1 cup		
Small cup (for water test)	1 per station or group		
Strainer	1		
Straws or eyedroppers (optional)	3 per group		
Tincture of iodine	2 tsp per class		
Tongs or oven mitts (to hold foil over flame)	1 per group (or share between groups)		
Toothpicks	10–12 per station or group		
Vinegar	1/8 cup per group		
Water	2 cups per group		
Coffee grinder (optional)	1		

SHERLOCK HOLMES

THE EXHIBITION

Busted by Biology

Post-Exhibit Field Trip: Grades 3-5

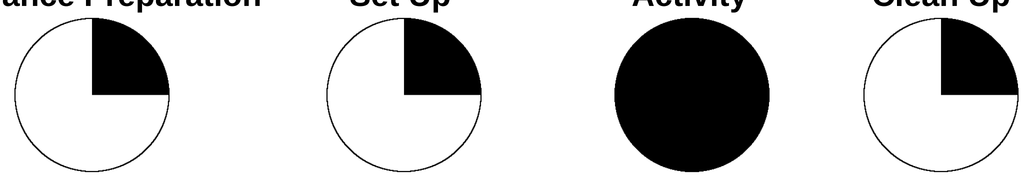
In this activity, students will extract their own DNA from their cheek cells and learn how DNA is analyzed and used to solve crimes.

LEARNING OBJECTIVES

- Students will understand that “identity” is a combination of inherited and environmentally influenced traits (both nature and nurture) and that inherited traits are determined by DNA, the “instruction book” for living creatures
- Students will understand that every individual has unique DNA
- Students will learn the how DNA can be extracted from cells
- Students will understand that forensic scientists use DNA to help solve crimes

TIME REQUIRED

Advance Preparation	Set Up	Activity	Clean Up
15 minutes the day before	**15 minutes**	**50-60 minutes**	**15 minutes**



PROGRAM FORMAT

Segment	**Format**	**Time**
Introduction	Large Group Discussion	5 min
DNA Clues	Individual Activity	20 min
Chromatography	Partner Activity	15 min
Wrap-up	Large Group Discussion	10 min

SITE REQUIREMENTS

- Ideal to have access to a sink

NEXT GENERATION SCIENCE STANDARDS

Practices
1. Asking questions and defining problems
3. Planning and carrying out investigations
4. Analyzing and interpreting data
6. Constructing explanations and designing solutions

Crosscutting Concepts
2. Cause and effect
3. Scale, proportion, and quantity
4. Systems and system models
6. Structure and function

Disciplinary Core Ideas

	Grade Level:	3	4	5
Physical Science				
PS1	Matter and Its Interaction	n/a	n/a	✓
PS2	Motion and Stability: Forces and Interactions	✓	n/a	
PS3	Energy	n/a		
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a
Life Science				
LS1	From Molecules to Organisms: Structures and Processes		✓	
LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a	
LS3	Heredity: Inheritance and Variation of Traits	✓	n/a	n/a
LS4	Biological Evolution: Unity and Diversity		n/a	n/a
Earth & Space Science				
ESS1	Earth's Place in the Universe	n/a		
ESS2	Earth's Systems			
ESS3	Earth and Human Activity			
Engineering, Technology, and Applications of Science				
ETS1	Engineering Design			

Topics: Biology, Genetics, Cells, Traits, Solutions and Mixtures

SUPPLIES

Permanent Supplies	Amount	Notes
Freezer or a bucket of ice	1	To keep rubbing alcohol cold
Apron or smock	1	For creating “DNA” mixtures
Cafeteria trays (optional)	2 per group	
Goggles (optional)	1 per student	
Markers	1 per student	For labeling
Pencils	1 per student	Could use pen or marker
Permanent marker	1	For labeling
Pop-top squeeze bottles	1 per group	Any water or sports drink bottles
Ruler (optional)	1 per group	
Scissors (optional)	1 per group	
Small containers with lids	5	Baby food jars or plastic container with a sealing lid, for “DNA” mixtures
Sponges and towels	2-3	For cleanup
Teaspoon	1 per student	A normal spoon will work

Consumables	Amount	Notes
Small drinking cups	1 per student	Paper cups work well, to hold drinking water for students
Clear cup (or test tubes)	1 per student	Tall and narrow works best, for DNA clues experiment
Plastic or glass cup or jar	1 per group	8-12 oz works well, to hold rubbing alcohol
Dish soap	approx. ½ cup	Will be diluted with water
Water	1 bottle per group	Tap water will work
Rubbing alcohol (isopropyl)	approx. ¼ cup per student	99% or 70% isopropyl alcohol will work
Salt	A few Tbs	
Popsicle stick	1 per student	Or other item to stir with
Toothpicks	3 per student	
Clear plastic or glass cup or jar	1 per pair	8-12 oz works well. For chromatography
Coffee filters, filter paper, or paper towels	2-3 pieces per student	If using paper towels, they should be fine-grained and white
Food coloring	1 set of four colors	Neon colors work best if available
Disposable gloves	1 pair	For creating “DNA” mixtures
Tape	1-2 inches per group	Masking or scotch tape
Paper towels	1 roll	For cleanup
DNA Clues booklet	1 per student	On page 27-28
Chromatography booklet	1 per student	On page 29-30

ADVANCE PREPARATION

<u>Note</u>: There are two separate experiments that your students may do: 1) “DNA Clues” and 2) “Chromatography”. These can be done on the same day or stretched out over two sessions. The instructions below are divided for each activity.

<u>Experiment #1: DNA Clues</u>

Soap solution:

- Prepare a dilute soap solution: add 1 cup of water to ½ cup of liquid dish soap. (This is enough for one classroom of about 35 students.) Label this “soap solution”.
- If possible, leave the soap mixture in a refrigerated place until immediately before use.

Student Worksheets:

- Print the *DNA clues booklet* (1 per student) and fold in half.

Notes and Hints:

- The isopropyl alcohol should be very cold for the experiment. Place it in a freezer or ice bucket until immediately before the start of the activity.
- Tall, narrow cups or test tubes work best to see the layers of alcohol and cheek cell mixture.
- This activity will be most successful if students have not recently eaten or chewed gum. Try to plan this activity before lunch or at the end of the day.

<u>Experiment #2: Chromatography</u>

“DNA” Solutions:

- You will be making five food coloring mixtures to represent the four “Suspect DNA” samples and the “Crime Scene DNA” sample that the students will test. Begin by using masking tape and a marker to label four containers “Suspect [#1-4] DNA”. Label a fifth container “Crime Scene DNA”. Small containers with lids such as a baby food jar or a plastic container with a sealing lid work well.
- It is best to use gloves and an apron or smock when creating the solutions. Use a cafeteria tray or wax paper to protect the surface you are working on. Food coloring will stain clothes and carpet!
- Make sure each mixture is made up of a different combination of food colors, yet is dark enough that you cannot see the difference by merely looking at the mixture. A suggested mixture for each suspect is included in the chart below. You will need about 8-10 drops of each color to create enough samples for one class.

- The “Crime Scene DNA” solution will be identical to the “Suspect 3 DNA” solution. To insure that they are identical, make twice as much of the “Suspect 3” solution (about 20 drops of each color) and transfer half of the solution into a separate jar labeled “Crime Scene DNA.”
- Neon food coloring works best if available.
- After creating all four suspect solutions and the crime scene solution, perform the experiment following the student procedure (on page 13). If you cannot clearly identify which “Suspect DNA” matches the “Crime Scene DNA” after performing the experiment, you will need to alter the make-up of your DNA solutions by trying different color combination until you can successfully match the suspect DNA with the crime scene DNA.

Sample Suspect and Crime Scene “DNA” mixtures:

	Drops of Neon Food Coloring			
	Pink	Purple	Green	Blue
Suspect 1 DNA	8-10	8-10	8-10	
Suspect 2 DNA		8-10	8-10	8-10
Suspect 3 DNA (half of this solution will be used as the “Crime Scene DNA”)	15-20		15-20	15-20
Suspect 4 DNA			8-10	8-10

Paper Strips:

- Cut strips of paper from watercolor paper, coffee filters, or fine-grained paper towels. Alternatively, use commercially available chromatography paper (Whatman is a good supplier.) You will need 2-3 strips per group.
    - 5 centimeters by 7 centimeters (2 inch by 3 inch) strips of paper work well for 8 oz. cups. The strips should be long enough to reach down into the cup of water after being taped to a pencil, pen, or stick that is laid across the top of the cup (see Figure 1). They should also be wide enough (about 5 centimeters (2 inches)) for students to place multiple marks on each strip.

Student Worksheets:

- Print the *Chromatography booklet* (1 per student, pages 29-30) and fold in half.

Notes and Hints:

- To gain practice measuring, students can cut the paper strips themselves. You can give them the measurements in inches or centimeters. This step will add about 10 minutes to the activity and will require rulers and scissors for each group.

- Do not cut the strips longer than the cups they will hang in. Strips should be approximately 1 – 2 cm. (½ - 1 inches) shorter than the height of the cup. This technique allows the strips to hang down from the top so that their bottom edge is just touching the liquid in the cup.
- Alternative method: cut the strips wider and curl them into a funnel shape that stands by itself in the cup (see Figure 2).

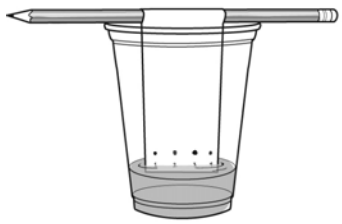


Figure 1. Older students can cut strips of filter paper to hang from the top.

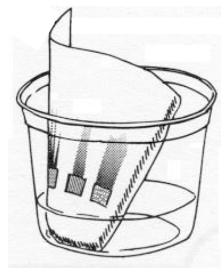


Figure 2. Younger students can use coffee filters that stand on their own in cups.

SET UP

Cafeteria trays are an excellent way of passing out complete lab setups to each group. Set out trays (1 per student pair) for each activity with the following items on each:

DNA Clues Tray

<u>For each student</u>

- 1 paper or plastic cup with about 1 cm (½ inch) of drinking water labeled “drinking water”
- ¼ cup **cold** isopropyl alcohol in a plastic cup labeled “alcohol”
- ¼ cup soap solution in pop-top squeeze bottle or small cup labeled “soap solution.” (May be shared between students)
- 1 teaspoon measure (or spoon)
- 1 clear plastic cup or test tube (6 oz. or larger; tall and narrow works best)
- 1 Popsicle stick
- 1 toothpick (optional)
- 1 *DNA Clues Booklet*
- 1 marker

<u>At a central location (or with the teacher)</u>

- sponges and towels for cleanup
- a bucket of ice or access to a freezer
- salt

Chromotagraphy Tray

<u>For each group or partners</u>

- 1 clear plastic cup or glass jar, 8–12 oz. size
- 2–3 cone-shaped #2 size coffee filters **OR** other filter paper strips (for example: 2" x 3" strips of watercolor paper or fine-grained paper towels) **OR** filter paper, scissors, and ruler for students to cut their own.
- Tap water in pop-top squeeze bottle
- Sample of Suspect 1-4 “DNA” and Crime Scene “DNA” (or allow students to come to the front of the room to collect all the samples)
- 5 toothpicks to transfer samples to paper
- 1 *Chromatography Booklet* per student

<u>At a central location (or with the teacher)</u>

- sponges and towels for cleanup
- DNA samples (set on tray or on top of newspaper or wax paper)

INTRODUCTION

5 minutes

Notes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Suggested script is shaded.
Important points or questions are in bold.
Suggested answers are in italics.

Today we are going to study the science behind *identity*, what makes YOU, YOU. Everybody look down at your hands: every single person's hands are unique. Everybody wiggle your nose: no two people's noses are exactly the same. Everybody say, "Science is cool!" Notice that every single person has a slightly different voice from every other person. We have different brains, different bodies, different likes and dislikes, even different skills and different fears.

We know people are all different, but why? Why are YOU the way YOU are? (i.e., brunette, six feet tall, scared of snakes, good at music, etc.) *Parents are brunette, drank lots of milk as a kid, got bitten by a snake once, Grandma was a famous concert pianist, etc.*

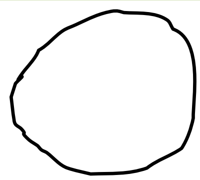
Some parts of your identity (such as the clothes you like to wear) are influenced by your experience, your choices, and the world around you. Other parts of your identity (such as your eye color) are determined by something called DNA. DNA is the body's basic instructions. It tells your lungs how to get oxygen from the air, it tells your hair whether to be curly or straight, and it tells skin how to repair itself after a cut.
All living things have DNA to help them survive and reproduce. The DNA that you and I have is mostly the same, but with tiny little differences. Those little differences make us all unique.

No two people have exactly the same DNA! However, there is one exception. Who might be the exception? *Identical twins, triplets, etc. For older students, you may wish to explain that new technologies are being created that can distinguish between the DNA of twins. See the Background Information (page 20) for more information.*

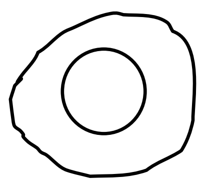
Where do we find DNA? *For younger students: DNA is in all parts of our body from our bones to our blood to our hair. For older students: our bodies are made of tiny parts called cells. Cells make up our muscles, blood, bones, skin, and more. Inside every cell is our own unique DNA. (Specifically, it is in the nucleus of the cell.)*

For older students, to give them a sense of where in the body DNA is located, you can draw on the whiteboard or chalkboard while explaining the following:

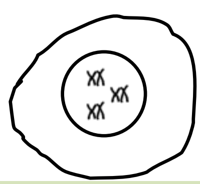
Every living part of our body, from the roots of our hair to our skin to our large intestines, is made of cells. Most cells are too small to see without a microscope. They are surrounded by a cell wall (in plants) or a cell membrane (in plants and animals).



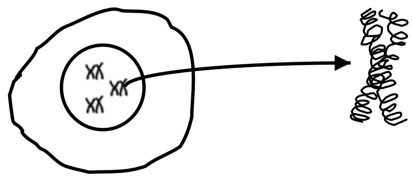
In the middle of the cell, like the yolk of an egg, is a part called a nucleus, which is surrounded by a nuclear membrane.



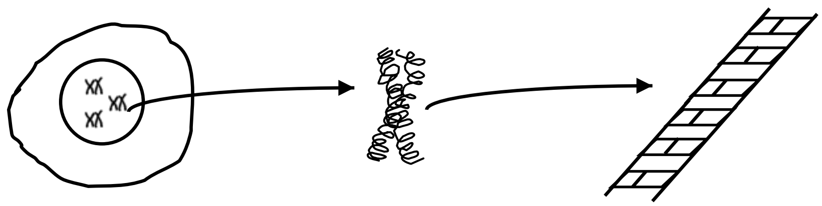
In the nucleus of that cell, we have something called *chromosomes.* Each human cell has 46 of them! You get 23 from your mom and 23 from your dad. Every cell in your body has the exact same 46 chromosomes. Now we are getting into some really small stuff.



Zooming in even farther, if we take a look at these chromosomes, we find they are made up of tightly coiled strands…



… And those strands in turn are made up of coils of DNA. Up close it looks like a twisted ladder. All the different molecules that make up the rungs go together in different combinations, like a code, making your DNA unique. We call sections of DNA *genes*. DNA is really, really tiny.



What do you think of when you hear the term "DNA"? *Most likely students have heard the term in daily life through newspapers, radio, or television. It may come up in stories related to crime solving, inheriting traits, treatments for disease, or identifying remains after an accident.*

What sorts of things have DNA? *All living things have DNA, including plants, animals, fungi, bacteria, etc. Some viruses have DNA. Rocks, water, clouds, and other non-living things do not have DNA.*

What role does DNA play in who we are? *DNA codes for the way you look - like height, hair color, eye color, etc. You can change the way you look by using hair dye, piercing your ears, or getting a tattoo. Dyed hair, colored contacts, tattoos, etc., are not determined by DNA. Your personality and behavior may be influenced by DNA. For example, things like interests and hobbies can be influenced by DNA but are also affected by how people grow up and the choices they make. Many scientists are studying to learn which characteristics of people are determined by DNA and which are influenced by their environment.*

Where do living things keep their DNA? *Many answers are possible, but students should know that copies of DNA are kept in every part of their body (in each cell, in fact). Cells are surrounded by protective barriers (cell walls and membranes; see the Background Information on page 20) that help organize and keep the DNA safe.*

How can we get pieces of DNA from a person or plant or an animal? *If we collect tiny samples of blood, skin, or saliva, there will be DNA in the cells of these samples. The DNA will be protected in cell walls or cell membranes. To get the DNA, we need to break down the cell walls and membranes and then separate the DNA out from everything else in the cell. Students will follow that procedure to isolate the DNA in this experiment.*

What do you think DNA looks like with the naked eye? *Students can draw pictures, or write a sentence or two. The double helix structure might come up, or the "x-like" structure of a chromosome. Individual molecules of DNA are too small to see even with microscopes (scientists use X-rays). On the other hand, thousands of strands of DNA all clumped together are visible even to the naked eye.*

INDIVIDUAL ACTIVITY

DNA Clues

20 minutes

Today we are going to take a close-up look at our *own* DNA! Using a simple process, we can get DNA from our own cheek cells. If we get a large enough clump of it isolated (by itself) we will be able to see what it looks like without a microscope.

Pass out the DNA Clues Tray (see Set Up on page 8) and the *DNA Clues Booklet* (on pages 27-28) to students. Ask students to follow along step-by-step with the class. For each step, help students understand why they are adding each ingredient and what is happening in the experiment.

Procedure:

1. Label the clear, empty cup "cheek cells" and write your name on it.

2. Take a sip of the water and swish it around your mouth for 30 seconds to remove cells from your cheek.
   - The skin on the inside of your cheek is constantly shedding dead cells (as you constantly make new cells). When you swish water in your mouth, cells from your cheek will be collected in the water.
   - Encourage students to gently rub their cheeks with their teeth as they swish to remove more cheek cells.
   - **Note: This step will be most successful if students have not recently eaten or chewed gum. Try to plan this activity before lunch!**

3. Carefully spit the water into the clear cup labeled "cheek cells."
   - You now have a solution of your cheek cells mixed with water. But we cannot get to the DNA yet because it is trapped deep inside the cheek cells (inside the nucleus of the cell, which is in turn inside the cell membrane.)

4. Add one spoonful of the soap mixture to the same cup.
   - We use soap to wash dishes because it is excellent at breaking up grease. In our cup, the soap is breaking down the membranes of the cells, which are formed from molecules similar to the grease we cook with - fatty molecules we call lipids. The soap breaks down the cell membrane and the nuclear membrane and lets us get to all those tiny strands of DNA inside.

5. Add a pinch of salt into cheek cell cup and stir slowly with a Popsicle stick.
   - Remind student to stir very slowly so that they do not create too many bubbles from the soap solution.
   - We add salt to the mixture in order to force the DNA out of the solution of water, cheek cells, and soap.

6. SLOWLY pour the alcohol so it runs down the side of the cup and gently floats on top of the cheek cell mixture.
   - The colder the alcohol is, the more DNA it will extract. It can be stored in the freezer without freezing solid.
   - **The hardest step is layering the alcohol.** Make sure students DO NOT pour alcohol directly on top of the cheek cell mixture at the bottom of the cup. They should tilt the cup and pour the alcohol SLOWLY so it flows down the side of the cup and floats on top. If the alcohol and water layers mix, the DNA will not separate (precipitate) out.
   - Alcohol is less dense than either saltwater or detergent, so it floats on top. DNA is also less dense, so it will float to the top as well.
   - Right now we cannot see the DNA because it is dissolved in the salt water and detergent solution (similar to the way salt is invisible in salt water). However, DNA will not dissolve in alcohol, so when it floats to the top where the alcohol is, we will be able to see it. When something that is dissolved in a liquid comes out as a solid, we say it precipitates.

CAUTION: Rubbing alcohol is poisonous if ingested.

7. Put the cup down and wait 30–60 seconds.
   - The long white strands you are looking at are a lot of DNA from many, many different cells. We cannot see individual strands with their helix shape because they are too small, but when enough of them clump together, we can see them!
   - Allow students to try to pull the DNA out of the cup using a toothpick or Popsicle stick to get a closer look. Try slowly twisting the long strands onto a toothpick for best results.

PARTNER ACTIVITY

Chromatography

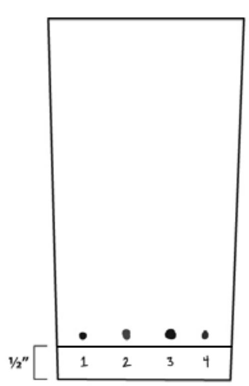
15 minutes

How do scientists analyze DNA? *Scientists use a process called electrophoresis (ih-lek-troh-fuh-**ree**-sis) to analyze DNA. First, a natural protein called an enzyme is* *used to cut up the DNA into small pieces based on each person's unique DNA pattern. These pieces are then put in a gel and electricity is used to move the DNA pieces across the gel. The longer pieces move slower and the shorter pieces move faster, separating the DNA pieces into a unique pattern, sometimes called a "DNA fingerprint." This DNA profile can be compared with the DNA "fingerprint" found at a crime scene.*

How do scientists identify DNA found at a crime scene? *Forensic scientists take DNA samples from suspects, victims, and sometimes even detectives to ensure a sample has not been contaminated. They analyze this DNA, along with DNA found at the crime scene, using electrophoresis. Detectives can also compare the DNA "fingerprint" found at a crime scene with a catalog of known DNA, called the Combined DNA Index System (CODIS), to see if there is a possible match.*

Does a DNA match always identify the criminal? *DNA may be used to prove someone is innocent or to greatly narrow down the possible suspects, but it usually cannot be used by itself to prove someone is guilty. DNA is just one of many types of evidence that detectives collect. It is important to examine other clues such as motives, weapons, or other information linking a suspect to the crime scene.*

We are going to analyze a sample in a similar method to how DNA samples are analyzed. You may want to model the procedure for students so they have the best success with the chromatography.

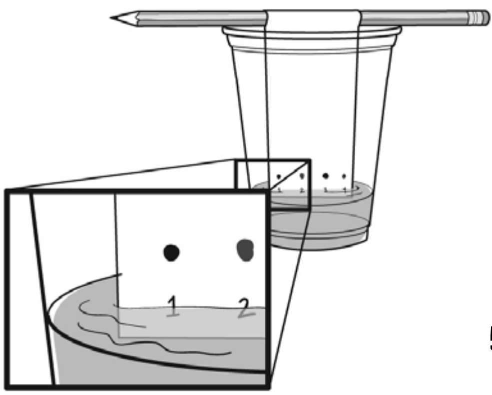


MAKE SURE the dots are at least **½"** from the bottom

Procedure:

1. Use a **pencil** to draw a line across the filter paper ½ inch from the bottom edge. Then, write the numbers 1 to 4 below the line. The numbers should be at least ½" apart.

2. Above each number and above the line, use a toothpick to place a small dot of each suspect's "DNA" sample. Sample #1's dot should be directly above the #1, and so on.



Only the very end of the paper should touch the water. **DO NOT** let water touch your ink spots.

3. Tape the top (the opposite end from the dots) of the filter paper to a pencil.

4. Add about ½ inch of water to the cup. Slowly lower the paper into the cup until the pencil rests on the edge of the cup, making sure that **only** the bottom edge of the strip (below the pencil line) is wet. **Do not** let the water cover any part of the samples! If the bottom edge of the strip does not touch the water, remove the pencil, add a little more water, and try again. Repeat this procedure until there is the right amount of water to touch the bottom of the filter paper without touching the dots on the paper. If there is too much water, pour some out before trying again.

5. Watch the water soak upward until it is about an inch from reaching the pencil. Take the pencil and paper off the cup and set the paper aside to dry.

6. On a new piece of filter paper, use a toothpick to place a dot of the "crime scene DNA". Tape this piece to the pencil and hang inside the cup. Be careful not to let the water cover the sample.

7. After the water reaches 1" from the top, remove the second strip of filter paper and allow it to dry as well. Compare the two strips.

General Suggestions:

- Use a **pencil** to label the filter paper. Ink will separate in this activity and labels will be ruined if they are written in ink.
- The most common mistake students make is accidentally submerging the sample spots in the water. This process happens when they have too much water in the cup, cut the strips too long, or place the sample spots too low on the paper.
  - Remind students to dot their papers at least ½" above the bottom edge (a "finger width"). If the dots are too low, it is hard to keep the water from touching them.
  - Students should have just enough water to touch the bottom ¼" of the paper.
  - Students should carefully lower their papers with "DNA" samples into the cups to see if they have so

much water that it will cover up their spots. If they do, they should pour some water out. Alternatively, they can hang their paper higher.

- Tiny sample dots work better than big dots or smears, which do not separate as well. Use toothpicks to apply a small dot.
- Each chromatogram only takes a few minutes to run, so encourage students to try them several times (if they have supplies).

CAUTION: Food coloring will stain clothes and carpet. Use caution when handling.

WRAP-UP

10 minutes

Ask for student observations. There is no correct answer. Let students guide the discussion and present their hypotheses before discussing explanations.

Why did the water move up the paper? *For younger grades, explain that the paper soaks up the water. For older grades, explain that the water moves up the tiny fibers in the paper through capillary action, just as it moves up the trunks of trees or a paper towel hanging into a wet sink.*

How and why did the colors move up the paper? *The water carried them up the paper because the colors were able to dissolve in the water.*

Why do some colors move farther than others? *Two factors affect the movement of the food color molecules: their size and their ability to dissolve in water. Some color molecules are larger and heavier, so they did not travel up the paper as easily. Also, those colors that did not dissolve well clung to the paper more, so they did not travel as far.*

How does this procedure model the way DNA is analyzed? *In gel electrophoresis, DNA pieces are separated out according to the size of the molecules, just like the food color "DNA" was separated according to the size of the color molecules.*

Which suspect's DNA matched the DNA at the crime scene? *Poll the class to see how their results match. If students have conflicting answers, bring up possible sources of error, such as cross-contaminating the samples by dipping the same toothpick into two samples.*

Do you think professionals ever make mistakes when matching a suspect's DNA to DNA at a crime scene? *There are times when even the professionals get something wrong. For interested or older students, this would be a great time to talk about the ethics and limitation of DNA testing, research, and application. (More information can be found in the Background Information on page 20.)*

CLEAN UP

Safety and Disposal Information

- If available, goggles are recommended for this activity.
- Unused isopropyl alcohol should be kept away from all sparks and flames. The small amounts used in this experiment may be poured down the sink drain, along with the cheek cell and soap solution. Flush with plenty of water. All other materials can be thrown away as solid waste.

CAUTION: Rubbing alcohol is flammable and poisonous if ingested.

CAUTION: Food coloring will stain clothes and carpet.

OPTIONAL EXTENSIONS

ALTERNATIVE DNA CLUES

As an alternative to extracting DNA from students' cheek cells, use fruit or vegetables for the extraction. Strawberries, wheat germ, or peas all work well. First, mash up the fruit or vegetable in a plastic bag, in a blender, or with a spoon. Then, follow the same procedure as used in this activity starting at step 3.

FINGER PRINTING

Police have been using fingerprinting as a form of identifying criminals for the past 100 years!

Have students use a pencil to make a dark scribble on a piece of paper until it is fully black. Then, have students rub their thumb or index finger it in the black mark until the pad of their finger is lightly coated in graphite. Next, have them stick a piece of clear tape onto their coated finger. Carefully peel the tape off to reveal the student's fingerprint! To keep the fingerprint, students can place the piece of tape on a piece of white paper.

For pictures of the different kinds of fingerprints and more information on this kind of lesson, go to pbskids.org/zoom/activities/sci/fingerprints.html

SUPER TASTERS

The test to see if one can taste phenylthiocarbamide (PTC) is one of the most common genetic tests on humans. A lesson on PTC and super tasters can be a great way to introduce a discussion on genetics and inherited traits.

To see if any of your students are supertasters, have each student place a PTC strip on their tongue to see what they taste. Non-tasters will taste paper or nothing, medium tasters may taste bitterness, and supertasters will taste a very strong bitter flavor. Record the results and see if it lines up with the world-wide average. (PTC strips can be found online in packs of 100 for under $6.)

Check out this lesson at http://www.howtosmile.org/record/1400 for more information.

BACKGROUND INFORMATION

This background information is for teachers. Modify and communicate to students as necessary.

BACKGROUND FOR ALL GRADES:

All living things are made of cells and each cell contains a molecule called **DNA**. DNA carries the genetic information that determines gender, physical appearance, vulnerability toward disease, and many other parts of who we are. Every cell in our body contains DNA. Even though cells can only be seen under a microscope, an uncoiled piece of DNA can be 2.8 inches (7.2 centimeters) long!

Getting at the DNA

Plant and animal cells store their DNA in the **nucleus**, a small compartment inside each cell that is surrounded and protected by the **nuclear membrane** (see Figure 1 below). A **membrane** is a flexible, thin film that only water and a few special chemicals can pass through. The **cell membrane** surrounds and protects the entire cell. Adding detergent or soap breaks the nuclear and cell membranes, releasing the DNA.

Plant cells, but not animal cells, also have a rigid **cell wall** around the outside of the cell. The students must expose the membranes inside to the soap or detergent.

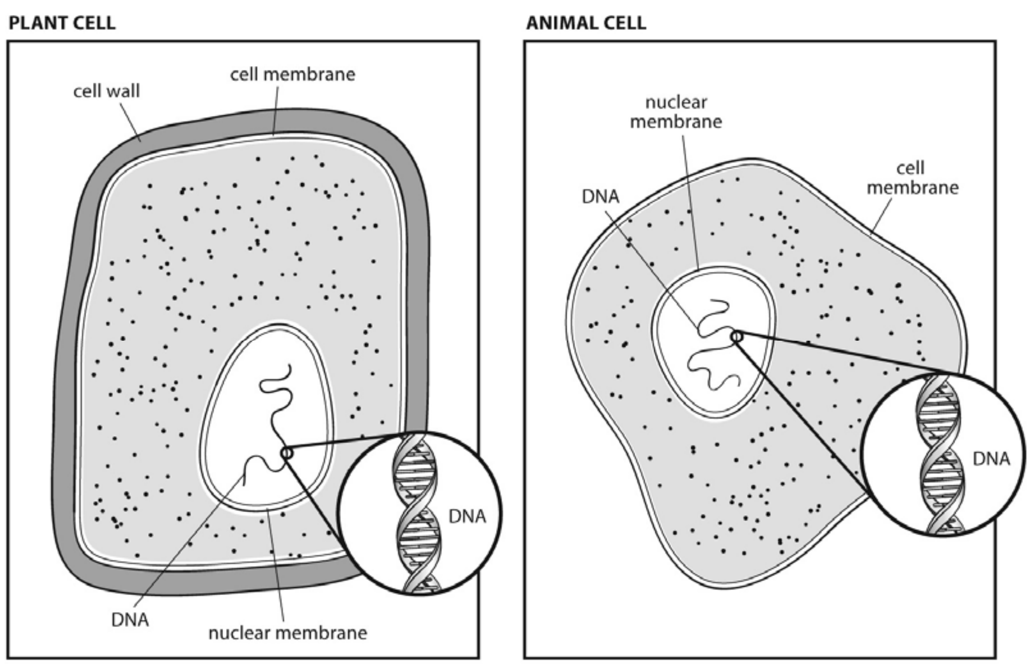


Figure 1: Plant cells have a cell wall and a cell membrane, while animal cells only have a cell membrane. Both plant and animal cells hold their DNA inside the nucleus.

Protecting the DNA

To prevent **viruses** and **bacteria** from invading the cell with their DNA, cells have **enzymes** (called **DNase enzymes**) that chop up any DNA floating around outside the nucleus. Once the cheek cell DNA is out of the nucleus, it becomes vulnerable to these enzymes. The students use cold ingredients to protect the DNA from DNase enzymes. Since reactions are slower at lower temperatures, using cold alcohol and other cold ingredients slows down the DNase reactions that break down DNA.

Separating the DNA
DNA is **soluble** in water, but not in salty water. All the other cell contents are soluble in water and salt water. This difference in solubility allows students to separate DNA from the rest of the cell. Students add salt to the mixture to force the DNA out of the solution of water, cheek cells, and soap.

DNA is not soluble in alcohol. Students add alcohol, which floats on top of the water, to lift the DNA out of the water and to separate it from the rest of the cell debris. When the DNA leaves the salty water mixture, it comes into contact with the alcohol and cannot dissolve. When DNA comes in contact with alcohol, it uncoils and **precipitates** (turns into a solid that forms from a liquid solution). It is visible as a kind of white goo. All the other cell contents stay in the salty water solution.

Studying Mixtures
Most substances are made of a mixture of different chemicals. For example, food coloring is a mixture of different colors and human cells contain mixtures of many different biological molecules (like DNA, proteins, sugars, etc.).

To study mixtures, scientists perform chromatography, a technique that separates chemicals using differences in their chemical or physical properties. In this experiment, students use paper chromatography to separate food color mixtures into a recognizable pattern on a piece of paper. Each of these patterns, called chromatograms, corresponds to a specific mixture of food colors.

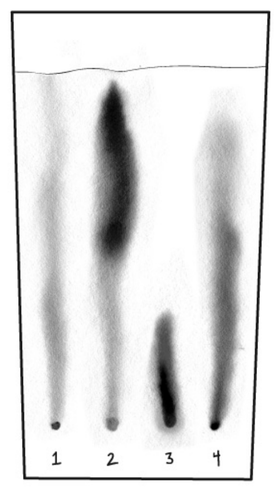


Figure 2. Sample chromatogram

Paper Chromatography
In paper chromatography, scientists first place tiny spots of chemical mixtures onto pieces of paper. They then suspend the papers vertically over a liquid solution, allowing only the bottom tip of the paper to touch the liquid. The liquid rises through the paper through a process called **capillary action**. (In capillary action, tiny wood fibers in the paper, like all tiny tubes, draw liquids up against the force of gravity.) Water rises up from the roots in trees in the same way.

As the climbing liquid passes the spot of ink in the paper, the ink **dissolves** and carries the colored inks up the paper. However, two factors affect the speed the colors travel up the paper. First, each chemical will “stick” to the paper to a different extent, depending on its chemical properties. In a similar way, each chemical will “stick” to the liquid a certain amount, depending on how chemically similar it is to the liquid. Since the colors move at different speeds in the experiment, they will travel different distances and create a unique pattern. This unique pattern, or **chromatogram**, allows scientists to identify mixtures.

In our experiment, chemicals that stick to paper tend to remain near the bottom of the paper as the water passes over them. On the other hand, chemicals that dissolve very well in water and do not really stick to the paper will travel farther up. Chemicals that fall between these extremes will travel midway up the paper.

Other Chromatography Processes
A powerful technique, called **gas chromatography**, uses gas to carry and separate the chemicals in a mixture. With gas chromatography, scientists can separate and identify many different mixtures, including paint chips, pharmaceuticals, brands of lipstick, food residues, and tobacco. **Forensic scientists** often use this technique to analyze evidence left at crime scenes.

Biochemists use another chromatography technique called **gel electrophoresis** to separate and analyze **DNA**. Biochemists insert a mixture of DNA fragments in a Jell-O-like gel. The gel is then connected to a source of electric current. The negatively charged DNA travels with the current and the fragments of DNA are separated by size. Again, larger molecules move through the gel more slowly, while smaller molecules travel faster and farther. This process creates a DNA chromatogram called a **DNA profile**. Forensic scientists who use this process can match the DNA found at a crime scene to a suspect, just as the students did in this experiment.

There are many other types of chromatography, each developed to help scientists understand the world. Chromatography is an extremely useful technique that is routinely used in the top research labs in the world.

Advances in DNA Analysis
The science of DNA analysis is an ever-growing field with breakthroughs still being made today. For example, although each person's DNA is unique, identical twins (who come from one single fertilized egg) have long been thought to have identical DNA. Scientists have recently discovered ways to differentiate between the DNA of identical twins. Life experiences, such as exposure to UV light or carcinogens, can actually change our DNA by causing it to mutate slightly. One twin may also carry a different number of copies of the same gene. These slight variations may be detected using recent technologies that are expanding as our understanding of DNA grows.

Questions in DNA Testing
The discovery of DNA was a scientific breakthrough and its application in solving crimes forever changed the field of forensics. However, DNA testing is not as simple and clear-cut as is often portrayed on television. Crime shows often depict an investigation team arriving at the scene of a crime, swabbing for DNA, and, minutes later, knowing exactly who committed the crime. In reality, DNA analysis is a much more complex process that can easily be tainted by human error and can raise many new ethical questions.

DNA analysis is often seen as nearly infallible evidence. While DNA evidence can be extremely reliable when collected and analyzed properly, there are many factors that can cause complications. Samples from crime scenes are often very small and may be degraded or contaminated in ways that make it impossible to obtain a full DNA profile. The likelihood of acquiring a coincidental match when using partial DNA profiles is much higher than when using a full profile. Other issues in DNA testing can include unintentional contamination, mistakes in labeling samples, misinterpretation of test results, or even intentional planting of DNA evidence.

DNA evidence can be contaminated when DNA from another source gets mixed with DNA relevant to the case. Contamination can happen as easily as when someone sneezes over the evidence or can even be something as uncontrollable as a single stray eyelash or bead of sweat falling in the area. Contamination can also occur before a forensics team reaches the crime scene. In Germany, there was a case where cotton swabs used by the forensics team (which are supposed to be sterilized before shipment) contained traces of a factory employee's DNA. The lab mistakenly came to the conclusion that there was a single person who was committing a rash of crimes across Germany. For the full story visit:
http://www.spiegel.de/international/germany/q-tip-off-police-fear-serial-killer-was-just-dna-contamination-a-615608.html

When mistakes like these occur in DNA testing, the probability of indicting the wrong person increases. Unfortunately, there are multiple cases in which DNA evidence has been used to implicate the wrong person. In one such case, a lab technician accidently mislabeled DNA samples, leading to the wrongful conviction of an innocent person:
http://www.reviewjournal.com/news/crime-courts/las-vegas-police-reveal-dna-error-put-wrong-man-prison

Since DNA analysis has become commonplace in criminal investigations, the question of when DNA should be sampled from a person has been debated. Many states and the federal government are trying to decide whether or not it should be legal to collect DNA samples from people who have not been convicted of a crime. Currently, law enforcement uses a national DNA databank, CODIS (Combined DNA Index System), which matches DNA profiles of convicted felons with DNA found at crime scenes. However, there is concern over the increasingly popular tactic of collecting DNA samples from arrested suspects instead of only those persons actually convicted of a crime and prosecuting people based solely on matches to partial profiles in CODIS.

Despite the many problems associated with analyzing DNA, there are also a number of benefits to the advancements in DNA testing. Groups such as The Innocence Project have dedicated their resources to reviewing cases where DNA testing was not used. These groups analyze DNA evidence collected at the time of the crime before DNA testing was available. As of 2013, over 300 people have been exonerated (freed) through DNA testing, 18 of whom were on death row for crimes they did not commit. DNA testing set these people free. DNA testing can contribute to the more accurate prosecution of criminals within our court system. However, great care must be taken to prevent inaccurate DNA testing from unintentionally convicting innocent people.

CROSS-CURRICULAR CONNECTIONS

ART

Chromatography Art
Repeat the chromatography using entire coffee filters and washable markers in place of food coloring. Mark the filters at the centerfold and run the chromatograms. Fold the coffee filters out from the center to make colored flowers. Attach the flowers to popsicle sticks or straws to make a bouquet.

Draw on filter paper with washable markers, and then use chromatography to create designs. Use the finished chromatograms as paper for cards.

BIOLOGY

Cell Biology
Discuss the parts of the cell and their functions.
Discuss the differences between animal and plant cells.

LANGUAGE ARTS

Mystery Stories
Have students read a mystery book (e.g., Hardy Boys, Nancy Drew, Encyclopedia Brown, or Sherlock Holmes). Report on the techniques used to examine clues.
Check the newspapers for reports of real-life criminal investigations. Have students write a mystery.

SOCIAL STUDIES

Genetically Modified Organisms
Find articles about genetically modified organisms (GMOs). What products contain GMOs? What are the advantages and disadvantages to GMOs? Since this is a controversial topic, stress to students the importance of getting scientific summaries and not just information from advocacy groups.

Discovery of DNA's structure
Scientists knew that information was somehow stored and passed on between generations but did not know the details of the process. Use one of the books listed in the Resources section (page 25) to learn about how DNA's structure was discovered.

Career Connection
Interview or invite a police detective, a criminal lawyer, or a forensic specialist to talk to the class.

RESOURCES

Books

DNA is Here to Stay by F. R. Balkwill
Reading level: kindergarten to 4th grade
This book gives a simple explanation of what DNA is and what it does in the body. This author also writes a series called "Enjoy Your Cells." This book is scientifically accurate and good for all ages.

One-Hour Mysteries and More One-Hour Mysteries by M. Carr
Reading level: 4th to 8th grade
Each book provides instructions for teachers and students to solve five different mysteries; they focus on logic as well as scientific principles to solve crimes.

Usborne Internet Linked Introduction to Genes and DNA by A. Claybourne et al.
Reading level: 4th to 8th grade
Beautiful artwork takes you deep inside a cell. This book also explains genetically modified foods, the Human Genome Project, gene therapy, designer babies, and DNA testing.

Crime Scene Investigations: Real Life Science Activities for the Elementary Grades by P. Walker and E. Wood
Reading level: 3rd to 6th grade
A teacher resource book containing instructions for 60 different activities related to technology, earth, life, and physical science. Students investigate and solve crimes through scientific activities.

Web

Cracking the Code of Life
In this video, NOVA tells the story of the genome triumph and its profound implications for medicine and human health.
http://www.pbs.org/wgbh/nova/body/cracking-the-code-of-life.html

Build your own electrophoresis chamber
This site explains what an electrophoresis chamber is and how it is used in DNA testing. It also gives detailed instructions on how to build your own chamber!
http://learn.genetics.utah.edu/content/labs/gel/build_gel_box.pdf

GLOSSARY

Bacteria	Very small organisms each made up of just one cell.
Capillary action	The tendency of small tubes to draw liquid up into them, against the force of gravity, due to the attraction of water to the molecules on the sides of the tubes.
Cell membrane	A thin barrier that surrounds the contents of plant and animal cells; provides structure and organization to the cell and controls the passage of water and other chemicals both into and out of the cell.
Cell wall	The rigid outermost barrier that surrounds the cell membrane; found in all plants and some algae, bacteria, and fungi; absent from all animal cells.
Chromatogram	A paper showing a mixture separated using chromatography.
Chromatography	A process scientists use to separate, analyze, or purify mixtures.
Diploid	Having two copies of genetic material.
Dissolve	When the molecules of a solid separate and become completely surrounded by the molecules of a liquid.
Deoxyribonucleic Acid (DNA)	A long molecule found in the nucleus of a cell and shaped like a double helix; associated with the transmission of genetic information.
DNA profile	A chromatogram of an individual's DNA, used to identify individuals or to diagnose diseases.
DNase	An enzyme that breaks down DNA; "-ase" stands for enzyme.
Enzyme	A complex protein produced by cells; acts to speed up a specific biochemical reaction.
Forensic scientist	Someone who can use a wide variety of sciences to answer questions of interest to a legal system.
Gel electrophoresis	A process that uses gel and electricity to separate a mixture into its component parts; used primarily for DNA, proteins, or other biological molecules.
Lyse	To break open or split.
Membrane	A thin film that forms a barrier.
Mixture	Two or more substances that are mixed together but are not chemically bonded.
Nuclear membrane	Similar to the cell membrane; surrounds the contents of the nucleus, separating it from the rest of the cell.
Nucleus	A compartment inside the cell that contains the cell's genetic information.
Paper chromatography	A process that uses paper and liquid to separate a mixture into its component parts.
Precipitate	To come out of a liquid solution as a solid.
Protein	A large, complex biological molecule found throughout the body; hormones, enzymes, and antibodies are all proteins, as are many of the structural parts of the body.
Soluble	Able to dissolve in a particular substance.

THINK ABOUT IT

DNA CLUES

"...The little things are infinitely the most important."

—Sherlock Holmes, *A Case of Identity*

Think about the experiment that you just completed. Was any part of the process difficult or confusing? How would you do it differently the next time?

How do you think DNA evidence could have been useful to detectives in Sherlock Holmes' time?

THE INTERNATIONAL EXHIBITION OF SHERLOCK HOLMES

DNA CLUES

"To a great mind, nothing is little."

—Sherlock Holmes, *A Case of Identity*

A blade of grass, a patch of mud, a wisp of hair—just the sort of **trace evidence** that Sherlock Holmes would collect to identify who had visited the scene of a crime. *Modern detectives have another kind of trace evidence to help them identify*

WHO WAS AT THE CRIME SCENE

DNA is a tiny molecule that is found in the cells of our bodies. Every person has a unique genetic code in their DNA, which can identify them just like a microscopic fingerprint. If detectives can find a tiny sample of sweat, hair, dandruff, saliva, scraped off skin, or blood at the scene of a crime, they may be able to extract DNA from that sample.

Here's your chance to extract DNA from some of the cells in your own saliva. Follow the directions carefully. The game is afoot!

THE INTERNATIONAL EXHIBITION OF SHERLOCK HOLMES

EXPERIMENT

DNA CLUES

Procedure

1. Label the clear, empty cup “cheek cells” and write your name on it.
2. Take a sip of the water and swish it around your mouth for 30 seconds to remove cells from your cheek.
3. Carefully spit the water into the clear cup labeled cheek cells.
4. Add one spoonful of the soap mixture into the same cup.
5. Add a pinch of salt into the cheek cell cup and stir **slowly** with a Popsicle stick.

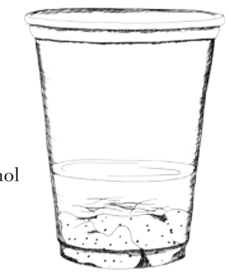
HOW HAVE THE CHEEK CELLS CHANGED AT THIS POINT?

EXPERIMENT

DNA CLUES

6. SLOWLY pour alcohol so it runs down the side of the cup and gently floats on top of the cheek cell mixture.

You can tilt the cheek cell cup to make this easier. Continue to carefully pour until about 1” of alcohol is on top of the cheek cell mixture.



Put the cup down and wait 30–60 seconds.

WHAT IS HAPPENING TO THE CHEEK CELL MIXTURE?

7. Clean up your area.

THINK ABOUT IT

CHROMATOGRAPHY

"You know my method. It is founded upon the observation of trifles."

—Sherlock Holmes, *The Bascombe Valley Mystery*

Think about the procedure that you just completed. Was any part of the process difficult or confusing? How would you do it differently the next time?

If a person's DNA is found at the scene of a crime, does that always prove that they are guilty? Why or why not?

THE INTERNATIONAL EXHIBITION OF SHERLOCK HOLMES

An INTRO to CHROMATOGRAPHY

"There is nothing like first-hand evidence."

—Sherlock Holmes, *A Study in Scarlet*

You can learn a lot from comparing tiny details. Sherlock Holmes was famous for this—in the stories, he could analyze a fleck of ash and know what kind of cigar it had fallen from. Nowadays, real-life detectives have even more tools to help them compare and identify crime scene evidence.

CHROMATOGRAPHY IS A TECHNIQUE THAT LETS YOU dissolve a mixture of chemicals and record how the different ingredients in that mixture separate. Comparing the pattern of separation can help you identify the original mixture. Similarly, the technique of **electrophoresis** uses an electric field to separate out the different particles in a sample of DNA. Looking carefully at the patterns of separation can identify who the DNA came from.

In this exercise, you will practice separating the chemicals in a mixture. Follow the step-by-step instructions and then see if you can match the pattern and identify the sample. Elementary!

THE INTERNATIONAL EXHIBITION OF SHERLOCK HOLMES™

EXPERIMENT

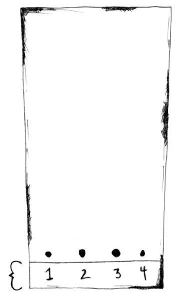
CHROMATOGRAPHY

1. **Use a pencil** to draw a line across the filter paper ½ inch from the bottom edge. Then, write the numbers #1 to #4 below the line. The numbers should be at least ½" apart.

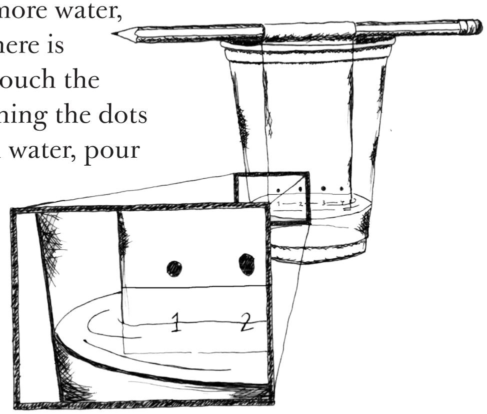
2. Above each number, and above the line, use a toothpick to place a small dot of each suspects' "DNA" sample. Sample #1's dot should be directly above the #1, and so on.

3. Tape the top (the opposite end from the dots) of the filter paper to a pencil.

4. Add about ½ inch of water to the cup. Slowly lower the paper into the cup until the pencil rests on the edge of the cup, making sure that only the bottom edge of the strip (below the pencil line) is wet. Do not let the water cover any part of the samples! If the bottom edge of the strip doesn't touch the water, remove the pencil and paper, add a little more water, and try again. Repeat this until there is just the right amount of water to touch the bottom of the paper without touching the dots on the paper. If there is too much water, pour some out before trying again.



MAKE SURE the dots are at least ½" from the bottom



Only the very end of the paper should touch the water. **DO NOT** let water touch your ink spots.

EXPERIMENT

CHROMATOGRAPHY

5. Watch the water soak upwards until it is about an inch from reaching the pencil. Take the pencil and paper off the cup and set the paper aside to dry.

HOW ARE ALL THE DNA SAMPLES THE SAME? HOW ARE THEY DIFFERENT?

6. On a new piece of filter paper, use a toothpick to place a dot of the "crime scene DNA." Tape this piece to the pencil and hang inside the cup. Be careful not to let the water cover the sample.

7. After the water reaches 1" from the top, remove the second strip of filter paper and allow it to dry as well. Then compare the two strips.

WAS THERE A SUSPECT SAMPLE THAT LEFT THE SAME KIND OF PATTERN AS THE CRIME SCENE SAMPLE? WHICH SUSPECT DID IT COME FROM?

8. Clean up your work area.

SUPPLY WORKSHEET

DNA Clues

Recommended group size: 1-2

Number of Students: ☐ Number of Groups: ☐

Supplies	Amount Needed	Supplies on Hand	Supplies Needed
Experiment #1			
99% isopropyl alcohol (or 70% rubbing alcohol)	¼ cup per group		
Cafeteria trays (optional)	1 per group		
Freezer or bucket of ice	1 per class		
Goggles (optional)	1 per student		
Liquid dish soap	½ teaspoon per group		
Marker	1 per student		
Masking tape (for labeling)	1 roll		
Paper towels (for cleanup)	1 roll		
Permanent marker (for labeling)	1		
Popsicle stick	1 per group		
Pop-top squeeze bottles (e.g., water or sports drink)	1 per group		
Salt	1-2 tablespoons per class		
Small drinking cups	1 per student		
Sponges (for cleanup)	1 (or 1 per group)		
Tall, clear, narrow plastic cups (8 oz. or 12 oz.)	2 per group		
Teaspoon measure (or spoon)	1 per group		
Toothpick (optional)	1 per group		

Supply Worksheet continues on next page.

SUPPLY WORKSHEET

Chromatography

Recommended group size: 1–3

Number of Students: ☐ Number of Groups: ☐

Supplies	Amount Needed	Supplies on Hand	Supplies Needed
Experiment #2			
Apron or smock	1		
At least four different food colors; neon colors work best and can be found at many large grocery stores	1 set		
Cafeteria trays (optional)	1 per group		
Clear, plastic cups (8 oz. or 12 oz.)	1 per group		
Disposable gloves	1 pair		
Goggles (optional)	1 per student		
Long rigid object to lay across the top of cup (pencils, pens, wooden craft sticks, etc.)	1–2 per group		
Paper towels (for cleanup)	1 roll		
Pencil (or pen, marker, or similar)	1 per group		
Pop-top squeeze bottles (e.g., water or sports drink)	1 per group		
Ruler (optional)	1 per group		
Scissors (optional)	1 per group		
Sponges (for cleanup)	1 (or 1 per group)		
Toothpicks	1-2 per student		
Water	¼ cup per group		
Watercolor paper cut into 2" x 3" strips, or cone-shaped #2 size coffee filters, or 2" x 3" strips of fine-grained paper towels	2–3 per group		
Small containers with lids (baby food jars or plastic containers with sealing lids)	5		

SHERLOCK HOLMES

THE EXHIBITION

Curious Contraptions

Pre-Exhibit Field Trip: Grades 6-8

In this engineering design activity, students will design, test, and build a "haunting machine" to solve a Sherlockian mystery.

LEARNING OBJECTIVES

- Students will experience the engineering design process, including the importance of planning, creating a prototype, recording data, and making improvements to an original design
- Students will practice using open ended problem-solving skills

TIME REQUIRED

Advance Preparation	Set Up	Activity	Clean Up
15 minutes the day before	**15 minutes**	**50-60 minutes**	**15 minutes**

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	5 min
Design, Test, Improve	Partner Activity	35-45 min
Wrap-Up	Large group discussion	10 min

SITE REQUIREMENTS

- A room with plenty of floor space is preferred (i.e., a cafeteria, gym, multi-purpose room, etc.). It is helpful to have tables and/or chairs so that students may incorporate height and the pull of gravity into their designs.

NEXT GENERATION SCIENCE STANDARDS

Practices
1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
6. Constructing explanations and designing solutions

Crosscutting Concepts
1. Patterns
2. Cause and effect
4. Systems and system models
5. Energy and matter
6. Structure and function

Disciplinary Core Ideas

	Grade Level:	MS	HS
	Physical Science		
PS1	Matter and Its Interaction		
PS2	Motion and Stability: Forces and Interactions	✓	
PS3	Energy	✓	✓
PS4	Waves and Their Applications in Technologies for Information Transfer		
	Life Science		
LS1	From molecules to organisms: Structures and processes		
LS2	Ecosystems: Interactions, Energy, and Dynamics		
LS3	Heredity: Inheritance and Variation of Traits		
LS4	Biological Evolution: Unity and Diversity		
	Earth & Space Science		
ESS1	Earth's Place in the Universe		
ESS2	Earth's Systems		
ESS3	Earth and Human Activity		
	Engineering, Technology, and Applications of Science		
ETS1	Engineering Design	✓	✓

Topics: Physics, Engineering Design

SUPPLIES

Permanent Supplies	Amount	Notes
Scissors	1 per group	
Stopwatches or clock	1 per group	Could use classroom clock with a second hand

Consumables	Amount	Notes
Fasteners	Equal amounts per group	Velcro, twisty ties, rubber bands, or similar
Tape (optional)	1 roll or a set amount per group	See note about tape below
Building supplies*	A few of each item per group	See suggested items below

*Many common classroom supplies and recyclables can be used as building supplies in this activity. The ones listed below are only suggestions to give you ideas.

Possible Building Supplies:

- Pipe cleaners
- Rubber bands
- Popsicle sticks
- Straws
- Scrap paper
- Plastic containers (yogurt tubs, water bottles, soda bottles, etc.)
- Scrap cardboard
- String or yarn
- Various size balls (marbles, bouncy balls, tennis balls, ping pong balls, etc.)
- CD jewel cases
- Books
- Dominoes
- Funnels
- Cups (paper or plastic)
- Plastic spoons
- Aluminum foil
- Paperclips
- Toilet paper and paper towel tubes
- Newspaper
- Any other items you can imagine!

A Note on Building Supplies:

When we think of engineering activities for the classroom, it is hard not to think of a huge mess. Piles of craft sticks and puddles of glue or balls of tape and newspaper are not only messy, but also wasteful and expensive. There are some methods you can employ to avoid these problems.

- **Reduce, Reuse, Recycle:** Make sure it is in that order! Encourage your students to use fewer materials by providing a limited amount of materials to start with or by using a budgeting system to encourage the frugal use of materials. Try to eliminate materials or processes that cannot be easily reused for future activities. Collect materials such as soda bottles or paper towel tubes for reuse. If a material cannot be reused, make sure it is recyclable at the end of the activity.

- **Limit Tape and Glue:** These are the two usual suspects of waste. Every teacher has seen students use miles of tape to hold something together when a few inches would have sufficed, and perhaps a few elastic bands would have worked even better. Tape can almost never be reused and can rarely be recycled. The expense quickly adds up, too. Glue can also create waste, because it often prevents the glued materials from being reused or recycled. It is also expensive, messy, and can be replaced in most applications by the clever use of elastic bands.

- **Use Constraints:** In the classroom, students will be constrained by the materials you provide them as well as how the materials are provided. Giving students full access to materials allows them to focus on their design and may encourage more testing and modifications. However, this free rein will also usually lead to students using more materials. By placing limits on the materials your students can use, you can prevent wasteful behavior. As an additional benefit, working with limited resources will force students to think through their plans more carefully. This methodology helps achieves your learning outcomes while also saving money, minimizing mess, and reducing waste.

ADVANCE PREPARATION

Previous Class:

- ❑ To give students a solid foundation and plenty of inspiration for this lesson, it will be useful for them to be familiar with Rube Goldberg machines before beginning the lesson. In the days before teaching this lesson, you may choose to assign students to collect information on Rube Goldberg and his imaginary inventions. Have the students write a paragraph on what a Rube Goldberg machine is, their favorite example of one, and what kind of Rube

Goldberg machine they would like to invent. You may also choose to have students view videos of real-life Rube Goldberg machines either at home or together in class. For example videos, see the Resources section (page 18).

- You may also wish to introduce Sherlock Holmes to the class if students are not yet familiar with this literary character. Students may read one of the original stories or watch an episode of one of the many television shows inspired by Sherlock Holmes. Ask students to pay attention to how Sherlock uses the scientific method to make observations, form a hypothesis, gather data, and draw conclusions.

Building Supplies:

- It may be helpful in the days or weeks before teaching this lesson to set out a collection box for students or co-workers to donate building supplies. Ask for common recyclable materials such as cardboard boxes, plastic yogurt containers, Styrofoam, film canisters, soda bottles, or other similar supplies (washed and clean, of course!). Offering a wide variety of materials will ensure that students can be creative with their designs.
- See the note on materials (page 8) and decide how the supplies will be distributed.

Group Dynamics:

- This activity will be more successful if you put some extra thought into how the student groups are formed. See the Working in Groups section of the Background Information (Page 16) for suggestions on forming student groups.

SET UP

Design, Test, Improve

<u>For each student group:</u>

- Scissors
- Tape (optional)
- Fasteners (Velcro, twisty ties, etc.)
- Stopwatch or clock

<u>At a central location (or with the teacher):</u>

- Wide variety of building supplies

INTRODUCTION

5 minutes

Notes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Suggested script is shaded.
Important points or questions are in bold.
Suggested answers are in italics.

Begin by reading the following story to the students and then presenting them with their challenge:

Sherlock Holmes' latest client is Percy Carlisle, a very nervous man who is convinced that his house is haunted.

"I hear strange noises at night," said Carlisle, "and once, as I was walking past the parlor, I saw a strange object moving across the floor. But there was no one inside the room! It was so eerie that I haven't entered the parlor since." Carlisle mopped his brow with a handkerchief.

"I am at my wit's end, Mr. Holmes. A neighbor of mine has offered to purchase the house, and I am resolved to sell it to him, but I have come to you as a last resort. I can see only two explanations: either my house is haunted, or I have gone insane."

"I suspect there is a third explanation," said Holmes. "Your neighbor is determined to purchase your house, so he devised a contraption, activated by a single touch, that moves on its own and produces the noises that you hear. By the time you investigate the noise, the man has disappeared and the machine is in motion."

"Is such a thing possible?" asked Carlisle, astonished.

<u>The Challenge</u>
Is Sherlock correct? Can you create a device similar to the one being used to haunt this house? Your device can make noises or move objects across the room.

You must follow two rules when designing your machine:
1. It must be set in motion with a single touch.
2. It must continue to "haunt" for as long as possible.

What is a Rube Goldberg machine? *A Rube Goldberg machine is a contraption that takes many often comical, overly-complex steps to perform a simple task.*

Will a Rube Goldberg machine always work on the first try? *It can take many tries before coming up with a design that will work. Rube Goldberg machines depend on each component of the machine working in order for the task to be completed; if one section does not work, the rest of the machine will usually fail.*

What do you think you should do if you get frustrated when creating your design? *Stop, take a break, and relax. Then look at neighbors' designs to get ideas or ask a friend for help. Have a positive attitude!*

Is it OK to use your neighbors' ideas? *Yes! Engineers often take existing ideas and improve on them, or find a new use for an old design. You are encouraged to look at what your neighbors are doing and use their ideas - it might just lead to an even better idea! When you tell us about your designs, be sure to give credit to your neighbors!*

Discuss with students how their designs will be graded. Students should be assessed based on how persistent they are through the testing process, not on how well the machine actually works.

PARTNER ACTIVITY

Design, Test, Improve

35-45 minutes

Students should work in groups of 3-4 students, depending on class size and the amount of building supplies.

The students' challenge is to make a Rube Goldberg-style haunting machine that will make noise or move objects for as long as possible. You may also choose to give the students a more specific challenge such as make three different objects move or make two different sounds. Consider offering awards for the longest machine, the spookiest machine, the most creative design, etc.

Materials

Explain how the students will be allowed to use materials. Possible ways to distribute the materials include:

1. Give each group a set number of each item.
2. Create prices for each item and let students purchase supplies using a budget.
3. Allow students a certain number of items (i.e., 20), but let them choose which items they would like. Allow students to trade items with other groups or with the “bank” at the front of the room.
4. Set out all materials and allow students to take what they need when they need it.
5. Allow students to use whatever materials their group brings in and trade with any groups that agree to a trade.

Use whatever method you think would work best for your students and with the materials you have collected. Make sure to set clear ground rules and expectations for students.

Planning

- Have each group spend 1 minute silently looking at the supplies and thinking of designs. During this first minute of brainstorming, there should be no building or talking.
- Give students 5 minutes to discuss and sketch design ideas with their group. There is still no building at this point.

Building

- Give students 10-15 minutes to begin building their haunting machines.
- Encourage students to build the most finicky parts of the machine at the beginning and the more reliable parts toward the end. This method saves a lot of setup time in between trial runs.
- Younger or inexperienced students may need some hints on how to use the materials to create their machines. Avoid showing these students specific ideas of what to build. Instead, encourage them to think about each section of the machine separately. Ask them questions such as:
  - What do you want this section to do?
  - What parts need to move to make it work?
  - What will set those parts in motion?

- How can this section be connected to the next section to set it in motion?

<u>Testing</u>

- Have students test their prototypes, timing how long the prototypes “haunt”. Be consistent with the number of tries each team gets and when you start and stop the stopwatch. Typically, time should start after all hands are off the machine and stop after the last object stops moving.
- All groups should watch as each prototype is tested and timed. This process will give struggling groups ideas on how to improve their design. Encourage students to use ideas from other groups.

Provide an additional 10-15 minute building period to see if the students can improve on their designs and make their haunting machines work even longer. Repeat as necessary to fill your allotted activity time.

WRAP-UP

10 minutes

Ask for student observations. There is no correct answer. Let students guide the discussion and present their hypotheses before discussing explanations.

Tell us about your design. *Ask specific questions about the number of steps they created for their machine, how they decided on a specific design, or if they tried to improve on any of their neighbors’ ideas. This is also a good opportunity to talk about how the students used the materials. Ask how they improved their design after the first testing step.*

Did you have enough materials? *Students may point out that they ran out of one or two specific materials. Ask how they overcame the shortage. Ask what kind of supplies students think would have been available in Sherlock’s time. What could have been used instead?*

What would you have done if you had more time to work on your machine? *Answers will vary from adding more paths to fixing parts that did not work during testing.*

Groups testing later in the order may reference other teams' designs. Use this opportunity to talk about how engineers do and do not share their designs and the role of "tinkering" in invention.

What were some of the most successful designs? What made them successful? *Answers will vary depending on your classes' designs. Be sure to relate student answers back to the original story. What parts of the machines would have been the spookiest to Mr. Carlisle?*

How could every machine be strung together to create an even longer haunting machine? *Answers will vary. Encourage students to think about how the last step of one machine could be changed to activate the next machine.*

CLEAN UP

Safety and Disposal Information

- Recycle or save materials for future use.

OPTIONAL EXTENSIONS

CLASSROOM-SIZED RUBE GOLDBERG MACHINE

Linking Machines
Have students design a first step for their machines that will allow each machine to be set it in motion by a rolling ball. Tell the students to design a final step for their machines that causes a ball to roll. After each group has completed these two additions to their machines, the entire class will be able to link their machines together so that each machine's final step activates the next machine. This activity will require a minimum of two balls per group. Ideally, the balls should all be the same size and type. Tennis, golf, or racquet balls may work well.

DRAW YOUR OWN CARTOON

Comic Artwork
After viewing a few of Rube Goldberg's famous comics, have students design and draw a mechanism that would solve a problem in their own life.

SIMPLE MACHINES

Deconstructing Machines
After a lesson on simple machines, have students either identify the simple machines they used in their designs or add simple machines to their contraptions. Alternatively, have students identify the simple machines used in one of the example real-life Rube Goldberg machine videos listed in the Resources section (Page 19).

BACKGROUND INFORMATION

This background information is for teachers. Modify and communicate to students as necessary.

History of the Rube Goldberg Machine

Rube Goldberg was a Pulitzer Prize-winning cartoonist, sculptor, and author who lived from 1883 to 1970. He started his career in engineering, but quickly left the field to become an office boy for the *San Francisco Chronicle*. While working, he submitted drawings and cartoons to the editor until finally, one day, his work was published. His cartoons often depicted some complicated contraption that usually accomplished a very simple goal such as moving a ball or turning out a light. As Goldberg himself put it, his cartoon inventions were a "symbol of man's capacity for exerting maximum effort to accomplish minimal results."

After building credibility, Goldberg began publishing his cartoons in the *New York Evening Mail* and his fame grew. Although he never actually built the machines that he drew, many of Goldberg's machines served as inspirations for other people to build similar contraptions. Shortly after his death, the Smithsonian Museum of History and Technology (now the National Museum of American History) debuted the exhibit "Do It the Hard Way." This exhibit featured more than a hundred drawings, song recordings, sculptures, and several bigger-than-life Rube Goldberg machines.

Every year there is a national Rube Goldberg contest, in which groups attempt to create the most creative and complicated machines. This annual tradition has challenged numerous college and high school students to perform simple tasks like popping a balloon or sharpening a pencil in the most complex ways.

The Engineering Design (ED) Process

Similar to scientific inquiry, Engineering Design (ED) is a process. When integrated effectively, the design process can make classroom activities more engaging and relevant, while increasing students' problem solving skills. The Next Generation Science Standards have recognized the importance of the engineering design process by integrating ED practices throughout the standards.

So, what is the Engineering Design process? In the world of professional engineers, the answer depends on context. Similar to the scientific inquiry process, there is no universally agreed-on, concise definition and the process is not necessarily linear. Instead, ED is more accurately described as a system of processes for solving problems. Different types of engineers use different processes, as do different corporations. Different state and national organizations also have different definitions. The definition of the process also gets more layered as students move through their education. However, there are some agreed-on necessary components of ED, including:

- Defining the problem
- Developing a solution
- Evaluating solutions
- Presenting your solution to an audience

Define the Problem
Benjamin Franklin's phrase 'Necessity is the mother of invention' is a perfect example of how the engineering process begins. Someone somewhere recognizes a need. The need could be a better way to bring water to fields in rural Africa or a smaller personal electronic device for listening to music on a bus. The problem may be identified by someone else, but the engineers are the people who dive in and find the solutions. Often, the problem may not be fully articulated and the engineers must work to get to the true root of the problem.

In the classroom, you may provide your students with the problems or needs they are to address. A design challenge is a common tool used to drive innovation. In a design challenge, a very specific need is posed, usually with some specific criteria for success.

Often, the problem you set forth (or that the students develop on their own) is the hook you can use to draw your students in. There are two sub-processes that are a part of defining the problem: identifying constraints and identifying criteria.

- **Identifying Constraints**
  Often, criteria can get confused with constraints. While criteria define the characteristics of a successful design, constraints set the limitations within which an engineer must work. The most common constraints are time and money. However, there may be limitations on size (minimum or maximum), the materials one can use, location, or other requirements specific to the challenge at hand.

  At first glance, it might seem that increasing constraints would make an activity more challenging. While you can use constraints to make simple activities more complex, in some cases constraints can help provide some much-needed guidance. Especially early in their engineering work, your students may become overwhelmed with too many options if you provide a vast array of materials and tools. Being intentional with the materials you provide can help students decide on a design quickly and may encourage creative uses of materials.

- **Identifying Criteria**
  Identifying criteria is the process of determining your measures of success. Using bridge design as a classic example, one rather obvious

criterion is that the bridge must completely cross a river. A bridge halfway across a river would be unsuccessful and likely be the last project an engineering firm is offered.

There are many other criteria for the success of bridges, however. The bridge needs to hold a certain amount of weight; it needs to withstand wind and earthquakes; vehicles and/or pedestrians need to be able to make it across - usually in both directions and often with multiple lanes; the bridge may need to lift up to accommodate tall boats passing beneath.

Discussions about criteria are an excellent opportunity to talk about how engineers must remain mindful of users when developing solutions. For example, pedestrians may be less likely to use a multi-use path if they perceive it as dangerous or are surrounded by the noise of traffic on all sides.

Most importantly, remind your students that the criteria for their engineering project are not necessarily the criteria you use for grading. The fear of failing to meet all of the criteria for the challenge deters students from taking risks and pushing the limits of their creativity. A team of students that clearly understands and applies the relevant science concepts as they work through the design process deserves grades that reflect their effort, regardless of the success of their design.
In our activity, the criteria for success were that the machine be activated by a single touch and that it “haunt” for as long as possible. Discuss with students if there should be other criteria for the machine.

Developing a Solution
During this stage, students are actively working on solutions to the identified problems. This stage of the process is often the most exciting, frustrating, and rewarding. It often includes the hands-on building of models, prototypes, or other physical objects, but it also includes all the planning and design required for construction.

There are two general approaches to this stage. Some students may prefer to think through their design in a very organized format. Others may prefer to ‘just do it’ by grabbing materials and trying things out. Both styles have their strengths and weaknesses. Encouraging your students to learn the strengths and weaknesses of each style is a very valuable lesson.

A team of students that thinks through their design fully before trying anything is typically displaying a better understanding of the ED process and any related scientific content. Often, teams will have discussions about criteria and constraints while they sketch out solutions before touching any building materials. The downside of this approach is that teams may spend too much time working out their design and end up without enough time for testing and refining.

The other approach embraces the idea of ‘failing early.’ Here, students may grab a handful of materials and begin tinkering. This process often produces some interesting ideas and leads to lots of refining of ideas. Activities with wide-open criteria and constraints encourage this type of experimenting. On the negative side, students who tinker may do so independently of their team, creating several different solutions within a single team. This approach may also use more raw materials, as students try and fail more often.

Testing and Refining
As with many parts of the process, testing and refining solutions is heavily integrated with the development phase. There are typically many ‘back to the drawing board’ moments during the process, and designs are constantly being adjusted to improve performance.
The key to testing is data. As your students are collecting data, encourage them to keep a log of the small and large changes they make to their design. Revisions to their designs should be made one at a time, so they can easily see the influence their changes have on the performance of their design. This methodology is equivalent to changing only one variable at a time in a scientific investigation. This technique also allows students to ‘rewind’ their design if the revisions have a negative or even neutral effect.

Evaluating Solutions
This part of the process refers back to the initial criteria. If a design does not meet the defined criteria for success—if, in our case, the machine fails to start with a single touch—the engineers have more work to do. Again, data are central to this process. Evaluations of a design are often based on analyzing data collected during the testing and refining phases. The fact that students are able to interpret the data they gather is arguably more important than the ability to collect the data. This ability is tied closely to how the data are presented.

Facilitating Learning
In a climate where test scores and grades are central to how students measure their success, one of the most critical parts of an engineering lesson is encouraging your students to be comfortable with “failure.” Their idea for a solution may not work, but often the knowledge of what does not work is just as valuable as an instant success. There are many stories of inventors working tirelessly with disastrous or imperfect results, before finally finding the best solution. There are also plenty of stories of inventors who never achieved the solution they were looking for. Often, another engineer would solve the problem by looking at the work done by these struggling predecessors, sometimes generations later.

But how does this process translate into the classroom? First, create an environment in which students are encouraged to develop their ideas, no matter how outrageous they may sound. This does not mean allowing students to take each crazy idea to full prototype, but try to avoid pointing out any obvious flaws in those crazy ideas. Encourage the students to think through the idea more fully, to draw sketches or do more research. Hopefully, the students will discover flaws on their own, but if they do not, let them try. Spectacular failures are often great teachable moments.

Although failing can be an important part of the ED process, in a results-oriented environment such as a school, not finding the solution can make some students anxious. Assure the students that you will be grading them on the process they go through and not on their results. A major part of that process is examining results and making recommendations. Taking this into account, the only way students could fail would be to give up and stop making attempts to modify their design.

As your students work to solve the problems in front of them, they will often work independently within their groups. As a facilitator, your role is to help the students articulate what they are working on. Check in with groups regularly to ask them to describe what they are working on. Not only does this methodology give you a chance to assess their progress, it also forces students to self-assess their solution. Finally, asking your students to regularly describe their process will provide practice for when they need to communicate their final recommendations.

Working in Groups

A common misconception is that engineering is a solitary process, carried out by individuals working in isolation. However, engineering is almost entirely team-based. While specific individuals may work on small deliverables, their efforts contribute to larger team-based projects. Group work is a necessary part of the process for engineers and will contribute to social learning for your students.

Students may gravitate toward particular roles when they work in groups. One member may assume a leadership role in the group, while another may be content to take on the majority of the construction. While this fact is an accurate representation of how engineering teams operate in the workplace, it is important to give students the opportunity to rotate through a variety of roles over time in order to build a broader understanding of engineering teams. Ensuring that each student is taking part in the process in a way that is personally challenging and rewarding is not always easy.

In particular, it is important to encourage a wide range of individuals to take on leadership roles. As you get to know your students, identify those who naturally assume the role of group leader and those who to sit back and follow. Try shifting the students out of their comfort zones by placing them in groups with other students with similar dispositions. A group comprised entirely of students with leadership tendencies may struggle initially as they learn the fine art of following and how to work in a support role. The students less inclined to leadership roles may find that it is easier for their voices to be heard and will often step up to the challenge.

There are several explicit strategies you can mix and match to make working in groups a positive experience and a valuable addition to your curriculum.

1. ***The whole group works together on each part.*** In this format, the educator actively encourages the groups to avoid taking on roles. Instead, each element of the process must be done by consensus.
   Pros: each student gets to try different parts of the process; no complaints about wanting a different role; requires little planning by the educator or groups of students; can provide insight into areas where students need more experience or subjects that students are particularly interested in.
   Cons: requires regular check-ins by the educator; feels less authentic; students have less ownership over specific parts of their work; less room for individual approaches.

2. ***Student-selected roles.*** Here, the students can decide within their groups what parts of the process they would like to work on.
   Pros: allows students to focus on their interests and strengths; provides excellent experience with team-based work and group dynamics.
   Cons: may create conflicts about who has specific roles; some roles may be undesirable; students may not gain as much experience in the roles they do not select; may require extra time for the students to work out the roles.

3. ***Assigned roles.*** There are many variations to this approach, from selecting just the team captain to specifically selecting each team member and the roles they will assume.
   Pros: allows for a rotation system, giving students the opportunity to work in different roles; assigning teams based on known personalities may reduce conflicts.
   Cons: less student control; may require more preparation by the educator; may create disappointment in assigned roles.

Most importantly, remember to include group dynamics as part of your discussions following the activity and in your assessments of how the students performed during the activity. Some sample questions you may wish to include:

- How was your team successful?
- What challenges did your team face?
- How did your group divide the work between members?
- What was it like acting as the (insert role)?

The groups could also conduct a group or self-evaluation that you collect after the activity to gain insight on what worked and did not work for the students.

CROSS-CURRICULAR CONNECTIONS

HISTORY

Ghost Stories
Have students research the era of the Sherlock Holmes stories (late 1800s to early 1900s). What did people think about ghosts at this time in history? What are some ghost stories from Victorian London?

LANGUAGE ARTS

Sherlock Stories
Watch *The Case of the Haunted Gainsborough* (http://www.hulu.com/watch/106663) or read *The Adventure of the Sussex Vampire* to see Sherlock Holmes in action as he debunks the mystical beliefs of his peers.

CAREER CONNECTION

Haunted House Tour
Try to arrange a behind-the-scenes tour of a real life haunted house. There are some amazing contraptions engineered for some haunted houses and seeing how these contraptions work would be a very memorable experience for students.

RESOURCES

Web

Engineering Design Process
NASA has provided a great overview of how the engineering design process works. Details for each step are provided and the overview focuses on the design of a lunar plant growth chamber.
http://www.nasa.gov/audience/foreducators/plantgrowth/reference/Eng_Design_5-12.html

Engineering is Elementary
The Museum of Science in Boston developed one of the leading engineering curricula in the nation. Twenty units connect engineering process activities to science topics, while storybooks provide context and offer cross-curricular connections to language arts and cultural studies.
http://www.eie.org/

Kids Invent!
Provides innovation-based learning kits for students ages 7-15.
http://www.kidsinvent.com/

Books

Dr. Ed Sobey's books
Dr. Ed Sobey is the author of more than 20 books about technology, innovation, and education. He provides professional development workshops around the world. The following link is to Amazon where his books are available for purchase.
http://www.amazon.com/Ed-Sobey/e/B002N2HSYO

Video

Honda Cog
This two-minute advertisement features a Rube Goldberg machine designed from car parts.
http://www.youtube.com/watch?v=_ve4M4UsJQo

Ok Go: This Too Shall Pass
Not just an ordinary music video, this video will leave students imagining what they can create.
http://www.youtube.com/watch?v=qybUFnY7Y8w

2D Photography Rube Goldberg Machine
This advertisement, for a photography studio, took the form of a Rube Goldberg machine using only photography equipment and cameras!
http://www.youtube.com/watch?v=qKpxd8hzOcQ

GLOSSARY

Contraption	A machine or device that appears strange or unnecessarily complicated.
Engineering	The branch of science and technology concerned with the design, building, and use of engines, machines, and structures.
Innovation	The process of thinking of and creating a new method, idea or product.
Prototype	A first or preliminary model of something, from which other forms are developed or copied.
Rube Goldberg Machine	A machine that is a deliberately over-engineered to perform a very simple task in a very complex way.
Tinkering	Attempting to create, repair, or improve something in an informal way.

SUPPLY WORKSHEET

Curious Contraptions

Recommended group size: 3-4

Number of Students: [ ] Number of Groups: [ ]

Supplies	Amount Needed	Supplies on Hand	Supplies Needed
Scissors	1 per group		
Stopwatches or clock	1 per pair (or 1 on a classroom wall)		
Fasteners (Velcro, twisty ties, rubber bands, etc.)	1 roll or 2 handfuls per group		
Building supplies (See note in Supplies Section on Page 4)	A few of each item per group		
Tape (optional)	1 roll or a set amount per group		

SHERLOCK HOLMES
THE EXHIBITION

A Matter of Spatter

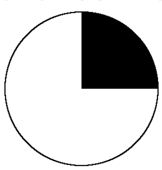
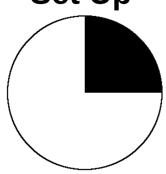
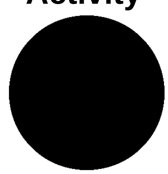
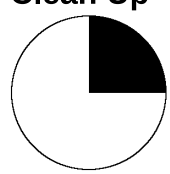
Post-Exhibit Field Trip: Grades 6-8

In this math-based activity, students will experiment to find how height and angle affect spatter and then use this knowledge to solve a crime.

LEARNING OBJECTIVES

- Students will understand the mathematical relationship between the size of a drop of spatter and the height from which it fell
- Students will understand the mathematical relationship between the shape of a drop of spatter and the angle at which it hit
- Students will learn how spatter evidence from a crime scene can be analyzed to learn information about the crime

TIME REQUIRED

Advance Preparation	Set Up	Activity	Clean Up
			
15 minutes the day before	**15 minutes**	**50–60 minutes**	**15 minutes**

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large Group Discussion	5 min
Height of Spatter	Partner Activity	15-20 min
Angles of Spatter	Partner Activity	15-20 min
Crime Scene Application	Partner Activity	10 min
Wrap up	Large Group Discussion	5 min

SITE REQUIREMENTS

- Ideal to have access to a sink

NEXT GENERATION SCIENCE STANDARDS

Practices
1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence

Crosscutting Concepts
1. Patterns
2. Cause and effect
3. Scale, proportion, and quantity
4. Systems and system models

Disciplinary Core Ideas

	Grade Level:	MS	HS
	Physical Science		
PS1	Matter and Its Interaction		
PS2	Motion and Stability: Forces and Interactions	✓	
PS3	Energy	✓	
PS4	Waves and Their Applications in Technologies for Information Transfer		
	Life Science		
LS1	From Molecules to Organisms: Structures and Processes		
LS2	Ecosystems: Interactions, Energy, and Dynamics		
LS3	Heredity: Inheritance and Variation of Traits		
LS4	Biological Evolution: Unity and Diversity		
	Earth & Space Science		
ESS1	Earth's Place in the Universe		
ESS2	Earth's Systems		
ESS3	Earth and Human Activity		
	Engineering, Technology, and Applications of Science		
ETS1	Engineering Design	✓	✓

Topics: Forensics, Physics, Mathematics, Trigonometry

SUPPLIES

Permanent Supplies	Amount	Notes
Rulers	1 per student	
Protractors	1 per student	
Yardsticks	1 per group	Could be shared between groups
Clipboards	1 per group	Or use a notebook, binder, or cardboard
Calculators	1 per group	
Sponges	2-4	For cleaning
Cafeteria trays (optional)	1 per group	

Consumables	Amount	Notes
White index cards, cardstock, or construction paper	10 per group	Cut into half sheets, about 8x5" each
Tempera paint	2-3 mL per group	Any color will work; red if simulating blood spatter
Plastic pipettes or glass droppers	1 per group	1-3 mL size (1 mL preferred)
Newspaper or tablecloths	1 stack	Enough to cover testing area (about one sheet per group)
Disposable cups	1 per group	
Paper towels	1 roll	For cleaning
Scotch tape	1 roll	
Height Testing Procedure booklet	1 per student	On pages 24-25
Angle Testing Procedure booklet	1 per student	On pages 26-27
Angle of Impact Chart (optional)	1 per student	On page 32
Crime Scene Packet	1 per student	On pages 28-30

ADVANCE PREPARATION

Simulated Blood Solution:
- Mix washable tempera paint with water in a 1:1 ratio. Use red paint mixed with a few drops of blue or purple for a blood-colored solution, or any preferred color.

Testing Sheets
- Cut testing sheets into about 20 cm by 12 cm (8 inch by 5 inch or half of a standard paper sheet) rectangles. There should be enough for at least 10 sheets per group. Students will be dropping spatter on the testing sheets from different heights and angles. For best results, the sheets should be white or light in color and thicker than printer paper (e.g., large index cards, cardstock, or construction paper).

Student Worksheets:
- Print the *Height Testing Procedure booklet* and the *Angle Testing Procedure booklet* (1 per student, pages 24-25 and 26-27) and fold each in half.
- Print the three-page *Crime Scene Packet* (1 per student, pages 28-30) and staple.
- Optional: if students are not yet familiar with trigonometry (able to determine the arcsin of an angle), print the *Angle of Impact Chart* (1 per student, page 32).

SET UP

Cafeteria trays are an excellent way of passing out complete lab setups to each group. Set out trays (1 per student group) for each activity with the following items on each:

Angles and Height of Spatter

For each student group

- 1 plastic pipette or glass dropper
- 1 small cup filled with 2-3mL simulated blood solution
- 10 testing sheets (index cards or half sheets of card stock or construction paper)
- 1 protractor
- 1 clipboard, piece of cardboard, or similar (to hold testing sheets)
- 1 calculator (optional)
- 1 ruler
- 1 yardstick
- 1 sheet of newspaper or tablecloth
- *Height Testing Procedure booklet*
- *Angle Testing Procedure booklet*

At a central location (or with the teacher)

- Sponges and towels for clean up
- Masking or scotch tape

Crime Scene Application

For each student

- 1 three-page *Crime Scene Packet*
- *Angle of Impact Chart* (optional)
- 1 Protractor
- 1 Ruler

INTRODUCTION

5 minutes

Notes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Suggested script is shaded.
Important points or questions are in bold.
Suggested answers are in italics.

Today, we are going to be forensic scientists analyzing spatter at a crime scene. Spatter (not splatter) is composed of small droplets. In the context of a crime scene, spatter is often small droplets of blood, but it could be any liquid such as paint, spit, water, etc.

What information do you think a forensic scientist could gather from observing spatter at a crime scene? *How tall the person bleeding was, where they were standing when injured, what kind of weapon they were injured with, what direction the injury came from, etc.*

How accurate and reliable do you think the information is that is taken from spatter? *Many forensics TV shows portray spatter analysis as a precise science with one right answer. However, it can be very complicated and even experts often disagree about the spatter analysis. Students will gain an appreciation of the difficulty of accurately analyzing spatter in this class.*

PARTNER ACTIVITY

Height of Spatter

15–20 minutes

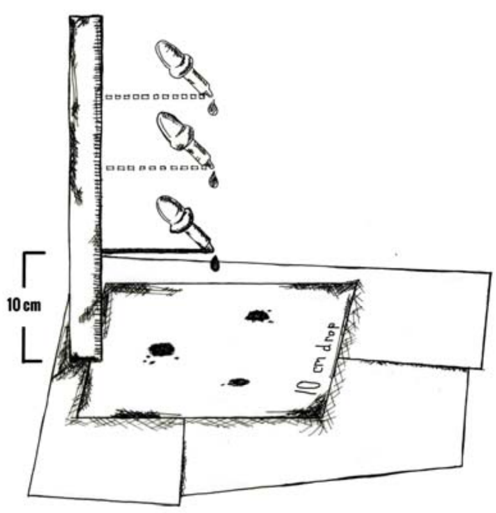
How do you think spatter would look different if dropped from a small height vs. a large height? *Answers will vary. The idea is not to give students the answer, but allow them to form a hypothesis.*

Depending on age and ability of students, lead them in designing an experiment that would test what drops of blood look like after falling from different heights. Ask students why it might be a good idea to do more than one drop at each height to discuss how more data points will increase accuracy.

Alternatively, pass out the materials and the *Height Testing Procedure booklet* (on pages 24-25) and have them follow along. Model how partners should work together to hold the ruler and dropper so that the drops come from an accurate height. For each height, students should test five drops on one testing sheet (the half sheets of construction paper or cardstock). Encourage younger students to practice letting just one drop at a time fall from the dropper back into the paint cup before doing it on their testing sheets.

After completing the experiment, students will be asked to calculate the average diameters of their drops. Depending on student ability, you may wish to remind students how to find the average and/or write the following formula on the board:

$$\frac{(\text{drop \#1}) + (\text{drop \#2}) + (\text{drop \#3}) + (\text{drop \#4}) + (\text{drop \#5})}{5}$$



Procedure:

1. Cover the testing area with newspaper or tablecloth.

2. Take 5 Testing Sheets and label them as follows:
Testing Sheet #1: “10 cm drop”
Testing Sheet #2: “30 cm drop”
Testing Sheet #3: “50 cm drop”
Testing Sheet #4: “70 cm drop”
Testing Sheet #5: “100 cm drop”

3. Place Testing Sheet #1, labeled “10 cm drop” in the center of your testing area. Hold a dropper of liquid 10 cm above your Testing Sheet. Allow one drop of liquid to fall from the dropper. Repeat in different spots around the testing sheet so that there are a total of 5 separate drops. Do not let the drops overlap.

4. Repeat Step 3 for each of your labeled Testing Sheets. Be sure hold the dropper at the distance you labeled for each Testing Sheet (for example, 30 cm for Testing Sheet #2). Remember to drop 5 separate drops on each testing sheet.

5. Allow each Testing Sheet to dry.

6. Measure the diameter of each of the droplets and record the measurements on the chart.

7. Calculate the average of your 5 measurements at each height.

Discussion Questions:

- *How does the spatter change as the height increases?*
- *Can you tell how far spatter traveled from the size of the drop?*

Running Suggestions

- ❑ Monitor students to see how much paint they are using. They should only be allowing one drop at a time to fall, not squeezing out a large amount of paint.
- ❑ Make sure students are labeling their testing sheets before dropping the spatter.
- ❑ While students are waiting for their spatter to dry (step 5), have them move on to the angle activity. While they wait for their angle spatter to dry, they can begin to measure their dried height spatter.

Did the shape of the spatter change as the height changed? *In general, students should find that the greater the distance that the drop fell from, the larger the spatter. Drops that fall greater distances may also have more ragged edges and/ or smaller secondary drops that form as the liquid bounces off the paper.*

If we know that spatter at a crime scene was caused by a nosebleed, could we use the size and shape of the spatter to determine the height of the person from which it came? *Experts may be able to replicate the conditions at the crime scene and estimate from what height the spatter fell. However, that height does not necessarily translate to the height of the person from which it came. Guide students to the understanding that spatter can come from someone taller than the height of the drops (who could be bent over or kneeling), but most* *likely will not have come from someone shorter than that height.*

How accurate do you think your height estimates in the classroom would be when compared with spatter found at a real crime scene? What factors can cause the relationship between height and spatter diameter to differ from the lab to the crime scene? *Inaccuracies in drop height estimates can arise from a variety of sources, including inaccurate measurement of diameters or drop heights, too few data points collected, differences in the amount of liquid used in each drop, and differences between the experimental and actual conditions.*
Some of the differences in actual conditions at a crime scene may include the speed at which the drops are traveling, the type of surface the drops are hitting, and the environmental conditions at the scene such as temperature, wind speed, and humidity.

PARTNER ACTIVITY

Angle of Spatter

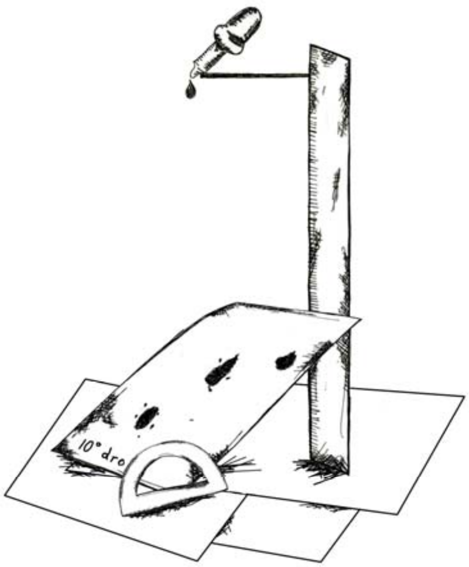
15–20 minutes

Note: The following procedure requires students to use a protractor to measure angles. If students are not yet familiar with angles or protractors, this activity may be omitted or performed as a teacher demonstration.

How do you think spatter from drops that fall straight down will look vs. spatter from drops that hit at an angle? *Answers will vary. The idea is not to give students the answer, but allow them to form a hypothesis.*

Depending on age and ability of students, lead them in designing an experiment that would test what drops of blood would look like from different angles. Explain to students that this experiment will be simulating drops of spatter that are moving at an angle and hitting a wall or the floor. Since this would be difficult to replicate in a lab, we will be letting drops fall straight down and hit an angled surface.

Alternatively, pass out the *Angle Testing Procedure booklet* (on pages 26-27) and have them follow along. Demonstrate how to measure the angle of the testing sheet using a protractor and how to keep the height of the dropper consistent. Students should use one testing sheet for each angle and place five drops on each testing sheet from the same angle.



Collecting the Data

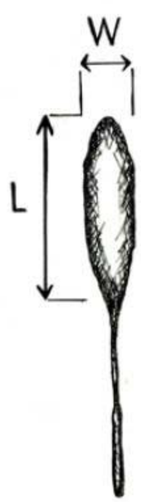
1. Label a Testing Sheet “10 degrees (10°)”. Attach it to a clipboard or piece of cardboard and place it flat on your testing area (0°).

2. With your team, collect spatter data at 10° as follows:

- *Student 1*: Hold the protractor along the table surface and observe at eye level.
- *Student 2*: Raise the Testing Sheet until it reaches the 10° mark on the protractor as observed by student 1. Hold the Testing Sheet steady.
- *Student 3*: Allow five drops of liquid to fall on the Testing Sheet from 20 cm above the center of the sheet. Do not let your drops overlap.

3. Set the Testing Sheet aside to dry.

4. Repeat steps 1–3, labeling four Testing Sheets:
- 30 degrees (30°)
- 45 degrees (45°)
- 60 degrees (60°)
- 75 degrees (75°)



Analyzing the Data

5. Measure the length and width of each drop (hint: the width is the smaller measurement). If the drop has a tail, only measure the oval part, not the tail.

6. Divide the width by the length. This number gives you the “roundness ratio”. (A drop with a roundness ratio of 1 is perfectly round.) Record the roundness ratio of each drop on the chart below.

7. Calculate the average of your roundness ratios to determine the average roundness ratio of spatter at each angle.

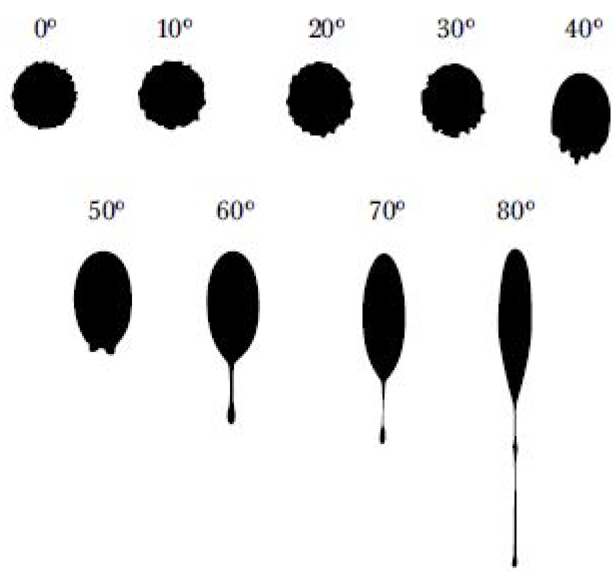
Discussion Questions:

- *How does the spatter change shape as the angle increases?*
- *Can you tell which direction spatter traveled from the shape of the drop?*

General Suggestions:

- Decide if students will be allowed to use calculators or not. If they are not using calculators, you may suggest they round each measurement to the closest whole number. Alternatively, you can instruct students to leave the roundness ratio as a fraction and use this as an opportunity to practice simplifying fractions or converting fractions to decimals.
- To shorten this activity, assign each group a different angle to test. After each group has finished the experiment, the class can compile the results from each group.
- For older students familiar with trigonometry, see the Optional Extensions (page 16) for ways to increase the level of math necessary for this experiment.

Did the shape of the spatter change as the angle changed? *Students should note that the lower the angle of the testing sheet, the more round the spatter is (high roundness ratios). Higher testing sheet angles create more oblong spatter (low roundness ratios).*



Did any drops of spatter have a "tail" at one end? Does the tail point in the direction the drop was moving, or does it point in the opposite direction? *Students should determine that the tail of a drop of spatter points in the same direction the spatter was moving. It typically is visible at a low angle of impact (30° or less.).*

How accurate do you think your angle estimates in the classroom would be when compared with spatter found at a crime scene? What factors can contribute to inaccuracy in your estimate? *Inaccuracies in angle of impact estimates can arise from a variety of sources, including inaccurate or imprecise measurement of test drops and angles, too few data points collected, and differences between the experimental and actual conditions. It can also be difficult to determine where the oval ends and the tail begins when measuring roundness ratios for high testing sheet angles.*
To emphasize the variation in angle of impact estimates, ask students how close their own measurements were for the five drops they created at each angle. Most students will find that the roundness ratio will vary between drops at the same angle. Also ask students to compare results between groups to see how similar the results are.

Why did we drop the liquid from 20 cm each time? Does the height matter in this experiment? *This is an excellent opportunity to discuss the idea of isolating variables with students. The height is one variable - we tested it first. The angle is a separate variable. To get the most accurate results in an experiment, we need to change one variable at a time. If we changed the height and the angle at the same time, we may not be able to tell which changes in the spatter were caused by which variable. We chose to do all our angle drops at 20 cm not because 20 cm is an important height, but so that all tests will be done from the same height.*

PARTNER ACTIVITY

Crime Scene Application

10 minutes

The Crime:
The victim, Mr. Johnson, was writing an assignment on the chalkboard while his students painted at their desks. At approximately 1:52 p.m., the victim reported feeling something fly past his head and hearing two distinct smacks hit the chalkboard. He believes someone flung paint across the room, narrowly missing his head. Mr. Johnson reports that he spun around to see who the culprit was, but all suspects appeared to be hard at work at their desks.
The forensics department has collected evidence from the crime scene including an accurate sketch of the classroom and up-close photographs of the spatter found at the scene. Your job is to analyze the spatter and use the information collected to identify the culprit.

Pass out the three-page *Crime Scene Packet* (on pages 28–30) including the police report, the crime scene overhead sketch, and the chalkboard with spatter. Depending on student age and ability, they may be able to analyze the scenario on their own, or they made need to be guided. Some suggestions to guide the students include:

- Before beginning the activity, draw a sample spatter on the board and demonstrate how to measure the width and length to find the roundness ratio. Then, demonstrate how to use the *Angle of Impact Chart* (on page 32) to estimate an angle and show students how to draw that angle using a protractor.
- Point out the direction of the tail. Remind students that the tail points in the direction the spatter was traveling. This fact will show the students the spatter was moving from the right side of the room toward the left and will also rule out students on the left side of the room as possible culprits.
- Next, have students measure the roundness ratio of the two drops of spatter found at the crime scene. They will use the included *Angle of Impact Chart* to find the closest angle of impact. Their exact roundness ratio may not be on the chart so they may have to find the closest estimate. Students should

determine approximate roundness ratios of .6 for drop 1 and .8 for drop 2.

- After determining the angle of impact for each drop of spatter (approximately 38° and 51°), students should use a protractor and ruler to draw the **trajectory** of the paint spatter.
- Students should find that the trajectory of the two droplets intersect at one desk (desk #16, see *Crime Scene Overhead View: Answers for Teachers* on page 31).
- It may be helpful to write the following information on the board and have students copy it onto their papers to use when collecting data:

  Drop #___
  Width (mm) _______
  Length (mm) _______
  Roundness Ratio (w/l) _______
  Angle (°) _______

- More observant students may discover that the drop with the smaller roundness ratio (drop 1) has a smaller angle of impact than the drop with the larger roundness ratio (drop 2). This relationship is the opposite of what they discovered in the Angle Testing Procedure. The reason for this is that students did not technically calculate the angle of impact in the Angle Testing Procedure; instead, they found the angle of the testing sheet. The relationship between the angle of the testing sheet and the angle of impact is

(angle of the testing sheet) + (angle of impact) = 90°
or
angle of impact = 90° - (angle of the testing sheet)

The angle of the testing sheet was used in place of the angle of impact purely to simplify the activity.

WRAP-UP

5 minutes

Ask for student observations. There is no correct answer. Let students guide the discussion and present their hypotheses before discussing explanations.

Which desk did the spatter come from? *Students will likely hypothesize the spatter came from the desk where the trajectories of the two drops of paint intersected (desk #16).*

Did every student get the same results? *Poll the class to see who agrees or if anyone determined the culprit was at a different desk. Bloodspatter analysis is not an easy or always precise science. Often there are enough sources of error or differences in interpretation of the evidence to cause reasonable doubt. Ask students if they would be able to use this evidence to convict the culprit if the "experts" (students) disagree on who the evidence points to.*

Is this the only way to interpert the spatter analysis? Is there any other scenario that could have caused the same spatter? *Emphasize to students that the interrpretation of spatter can be subjective and may vary a great deal between experts. Is it possible that the paint was flung by two different students,(perhaps the two students in desks 28 and 29)? Spatter analysis can help forensic scientists gather information about a crime, but it is not always possible to determine exactly what happened at a crime scene solely from the spatter. Typically, spatter evidence is used as just one piece of the puzzle.*

CLEAN UP

Safety and Disposal Information

- If available, goggles are recommended for this activity.
- Tempera paint will wash off with water. Have students help clean any excess spatter.

OPTIONAL EXTENSIONS

HEIGHT EXTENSION

Allow students to repeat the height testing procedure using different types of surfaces (e.g., carpet, cardboard, concrete, etc.) to find out how spatter changes from one surface to another. This extension is great for students who are not yet familiar with angles and unable to do the angle portion of the activities.

PYTHAGOREAN THEORM

Have students use the formula $A^2 + B^2 = C^2$ to determine the distance that the spatter traveled in the crime scene. Using the grid on the crime scene sketch, they will know how far the culprit was from the board (A) and they will be able to estimate how far the two drops of spatter were from the culprit (B). Using this information, they should be able to calculate how far each drop of spatter traveled (C).

COORDINATE PLANE

To practice using a coordinate system, provide students with a list of student names and desk locations in the form of "John sits at X = 3, Y =5" (this would be desk #12). Students will use the crime scene sketch as a coordinate plane and determine the location of each student.

GRAPHING RELATIONSHIPS

After filling in the charts on the *Angle Testing Procedure booklet* (page 26-27) and the *Height Testing Procedure booklet* (pages 24-25), have students create a graph that shows the relationship between height and diameter or between the angle and roundness ratio.

For more advanced students: what type of line best fits the relationships graphed (linear, exponential, logarithmic, etc.)?

Before class begins, create an example spatter from a height or angle that students did not test. Have them use their graphs to predict the height or angle the drop came from.

SPATTER EXTENSION

For classes interested in a more in-depth study of bloodstain pattern analysis, students can create a variety of different bloodstain patterns using Goldenrod paper. This paper is an acid/base indicator and will turn bright red in presence of a base such as baking soda in water or ammonia. Students can fling the liquid at the paper, wipe their hands or other objects across it, or hit a sponge soaked in the liquid to create more authentic bloodstain patterns with relatively little mess.

TRIGONOMETRY EXTENSION

For older students who are familiar with trigonometric functions, identify the relationship between the width/length ratio and the angle of impact:

arcsin (width/length) = angle of impact
or
width/length = sin (angle of impact)

Ask students to calculate the expected width/length ratio from the angles they tested using this equation. How close were their experimental results to these calculated expected results?

NOTE: the angles used in the angle testing activity were not technically the angle of impact. To simplify the activity, we used the angle of the testing sheet (not the angle of impact) for our observations. In order to perform this extension, students will need to first convert their testing sheet angles to angles of impact using the formula:

(angle of the testing sheet) + (angle of impact) = 90°
or
angle of impact = 90° - (angle of the testing sheet)

BACKGROUND INFORMATION

This background information is for teachers. Modify and communicate to students as necessary.

Bloodstain Pattern Analysis

When studying a crime scene, everything becomes important, even the tiniest drops of blood. As a result, the science of bloodstain pattern analysis (BPA) was developed. This science brings together the fields of biology, physics, chemistry, and mathematics to examine what happened at a crime scene. By focusing on factors such as the size, shape, and location of bloodstains at a crime scene, scientists can often determine important information such as the direction or distance blood traveled and the type of weapon used. Scientists can also often use BPA to find the **trajectory**, or path, of a bullet. These factors, when correctly analyzed, can help rebuild the crime or confirm the truthfulness of statements provided by suspects, victims, and witnesses.

History of Blood Spatter Analysis

One of the earliest scientific studies of blood spatter occurred in Poland and was conducted by Dr. Eduard Piotrowski. He published the first serious text on the topic in 1895: "Concerning the Origin, Shape, Direction and Distribution of the Bloodstains Following Head Wounds Caused by Blows." The science behind this work, however, was not commonly used in crime scene investigations until decades after the publication of Piotrowski's book.

Conan Doyle, an innovator of his time, incorporated bloodstain pattern analysis into several of his Sherlock Holmes stories, including *A Study in Scarlet*, in which Holmes is tasked with determining who poisoned a man and wrote a message in blood on a wall. Sherlock is even credited in this story with devising a test to reliably tell if a stain is in fact blood (although such a test did exist at the time). Conan Doyle recognized the importance of examining blood stains at a crime scene many decades before it was commonly studied by law enforcement.

While the field of bloodstain analysis has continued to grow and develop into an entire branch of crime scene investigation work, this scientific discipline is still relatively new. The methods that guide this field require detailed, careful work that is far from the quick analyses often portrayed on TV crime shows. It is now standard practice for law enforcement to include bloodstain analysis in their work and more crime labs are becoming equipped to accurately analyze bloodstains. However, bloodstain analysis is subjective in many ways and experts do not always agree about the interpretation of spatter at crime scenes. Many factors such as viscosity (thickness) of blood and environmental conditions like wind and humidity can affect the BPA. These variables can be impossible to isolate, causing some to question the validity of BPA.

Patterns of Blood Spatter:
After many years of studying bloodstains both at crime scenes and in controlled environments, experts have been able to identify consistencies in the patterns formed by bloodstains:

- Blood striking an object at angles less than 90 degrees results in a tear-drop shape. A 90 degree impact angle will produce a circular shape.

- If the spatter has any kind of "tail," it will always point in the same direction as the blood was traveling.

- Drops that fall simply by the force of gravity (called **passive drops**) leave a different pattern than bloodstains that were caused by another force.

- The greater the distance that a drop falls from, the wider and more spread out the spatter will be. This trend will continue until the drop falls from such a large height that it has time to reach **terminal velocity** – the fastest velocity that it will attain.

- The speed at which spatter forms can reveal a lot of information. **Low-Velocity Impact Drops** usually fall from an open wound at the speed of normal gravity. They are larger drops - typically 4 mm or more. **Medium-Velocity Impact Drops** are produced with more energy or force then normal gravity. This kind of impact causes the blood to form many smaller spatters and is usually the result of blunt force, stabbings, or **secondary spatters** (when one drop falls on another). **High-Velocity Impact Drops** never measure more than 2mm and require a speed of over 100 feet per second. These drops will usually form a "mist-like" pattern and are found in cases where explosives or gunshots are involved.
  - Note: in this activity, all of the tests were performed with low-velocity impact drops subject only to the force of normal gravity. As the velocity increases with medium- or high-velocity impact drops, the spatter becomes smaller because the extreme force breaks up bigger drops into many tiny droplets.

- If a bloody object comes into contact with another surface, it will often leave a pattern similar to the object called a **transfer pattern**, such as a footprint in a pool of blood.

Crime Scene Investigation Protocol
When entering a crime scene, forensic scientists follow a strict protocol in order to maintain the integrity of the area. In general, the steps taken include:

1. *Identify potential safety risks or other hazards*
   - It is important to assess the environment in case a dangerous situation still exists.

2. *Block off and guard the area*
    - The scene is roped off and secured to make sure there is only one point of entry. This method both ensures that curious onlookers are kept at bay and that the culprit cannot escape if he or she is still at the scene of the crime.

3. *Document and walk through the scene*
    - Crime scene investigators will take many photographs of every element of a crime scene to ensure an accurate record of evidence. For a science like bloodstain pattern analysis, photos are an important source of material since the bloodstain evidence cannot always be physically brought to a lab. Photographers must take great care to make sure that they have taken photos of all stains from varying distances to give an overall picture of the scene as well as an up-close view of the spatter. As demonstrated by this activity, the size of spatter can be extremely important in the analysis. In order to determine the accurate scale from a photograph, it is vital that close-up photos include a way to find the correct scale such as including a ruler in each photograph.
    - The investigators review the scene to check the point of entry, investigate displaced items, and record other potentially useful information about the scene.
    - From the general overview of the scene, investigators form a hypothesis of the events based on the physical evidence observed.

4. *Gather the evidence*
    - It is not until the end of the review that evidence is actually taken away from the crime scene, so as to avoid disturbing the evidence for as long as possible.

CROSS-CURRICULAR CONNECTIONS

ART

Action Painting
Mix washable paint with a small amount of glue in recycled squeeze bottles. Create any number of different bottles according the amount of colors you would like the students to use. Then, have students use a sweeping motion to spray various colors onto a thick piece of paper or canvas. Allow time to dry, and students will have created an abstract spatter art piece.

SOCIAL STUDIES

Career Connection
Interview or invite a police detective, a criminal lawyer, or a forensic specialist to talk to the class. Ask how someone would become a forensic scientist and why he/she chose this field.

LIFE SCIENCE

The Four Parts of Blood
Have students learn about and identify the four parts of blood in the human body. The following lesson from the University of Houston's history department provides a comprehensive overview of how to teach this lesson that includes group work and closing activities:
http://www.history.uh.edu/cph/tobearfruit/__docs/curriculum/ms/science/4partsofblood/lessonplan_4partsofblood.pdf

LANGUAGE ARTS

Sherlock Stories
Read or watch one of the many versions of Conan Doyle's *A Study in Scarlet*. This is the first novel depicting Sherlock Holmes and contains many instances of Sherlock examining blood for clues.

RESOURCES

Web

How Blood Works
This website gives a comprehensive overview of the science of blood in general and could serve as a great introductory tool for an anatomy class or unit.
http://science.howstuffworks.com/life/human-biology/blood.htm

The Science Channel Presents: Blood Spatter
This is a great video of a criminal justice school that teaches police officers about the importance of BPA.
http://science.discovery.com/tv-shows/science-channel-presents/videos/discoveries-this-week-blood-splatter.htm

Bloodstain Analysis Tutorial
This tutorial includes examples of origin determination and impact velocity calculations.
http://www.bloodspatter.com/bloodstain-tutorial

Books

The Science of Sherlock Holmes by E.J. Wagner
Recommended for Advanced Readers
Using well-known Sherlock Holmes stories as her starting point, Wagner blends familiar examples from Conan Doyle's stories into a history of forensic science, pointing out where fiction strayed from fact.

GLOSSARY

Angle of impact	The acute angle formed between the direction of a blood drop and the plane of the surface it strikes.
Bloodstain	Evidence that liquid blood has come into contact with a surface.
Bloodstain pattern analysis (BPA)	A branch of forensic science that studies the deposition of bloodstains at a crime scene.
Forensic science	The application of a broad spectrum of sciences and technologies to investigate and establish facts of interest in relation to a crime scene.
High-velocity impact drops	Drops that fall faster than 100 feet per second.
Low-velocity impact drops	Drops that fall at a speed simply due to gravity.
Medium-velocity impact drops	Drops that fall at a speed faster than due to gravity.
Passive drop	Bloodstain drop(s) created or formed by the force of gravity acting alone.
Spatter	A spray or splash of something. In forensics, this typically refers to a spray or splash of blood.
Terminal velocity	The maximum attainable speed of an object falling due to the force of gravity alone.
Trajectory	The path of a projectile flying or an object moving under the action of given forces.
Transfer pattern	The bloodstain left behind when a bloody object comes into contact with another surface.

DOES DISTANCE CHANGE SPATTER?

A MATTER OF SPATTER

HOW DOES THE SPATTER CHANGE AS THE HEIGHT INCREASES?

CAN YOU TELL HOW FAR SPATTER TRAVELED FROM THE SIZE OF THE DROP?

THE INTERNATIONAL EXHIBITION OF SHERLOCK HOLMES

A MATTER of SPATTER

Does distance change spatter?

THE INTERNATIONAL EXHIBITION OF SHERLOCK HOLMES

A MATTER OF SPATTER

1. Cover the testing area with newspaper or table cloth.

2. Take 5 “Testing Sheets” and label them as follows:

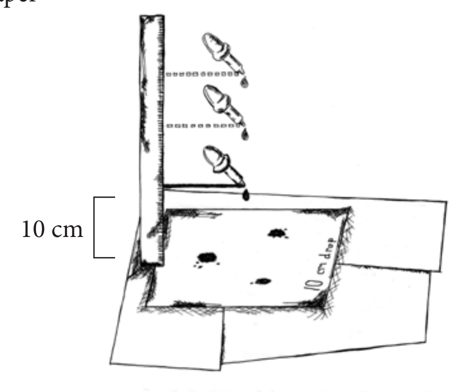
   Testing Sheet #1: “10 cm drop”

   Testing Sheet #2: “30 cm drop”

   Testing Sheet #3: “50 cm drop”

   Testing Sheet #4: “70 cm drop”

   Testing Sheet #5: “100 cm drop”



3. Place Testing Sheet #1, labeled “10 cm drop” in the center of your testing area. Hold a dropper of liquid 10 cm above your Testing Sheet. Allow one drop of liquid to fall from the dropper. Repeat in different spots around the testing sheet so that there are a total of 5 separate drops. Do not let the drops overlap.

4. Repeat Step 3 for each of your labeled Testing Sheets. Be sure hold the dropper at the distance you labeled for each Testing Sheet (For example, 30 cm for Testing Sheet #2). Remember to drop 5 separate drops on each testing sheet.

5. Allow each Testing Sheet to dry.

DOES DISTANCE CHANGE SPATTER?

A MATTER OF SPATTER

6. Measure the diameter of each of the droplets and record the measurements on the chart below.

7. Calculate the average of your 5 measurements at each height.

Data Collection Chart: Diameter of Spatter

	10 cm Height	30 cm Height	50 cm Height	70 cm Height	100 cm Height
Drop 1					
Drop 2					
Drop 3					
Drop 4					
Drop 5					
(Total)					
Average					

A MATTER OF SPATTER

HOW DOES THE SPATTER CHANGE SHAPE AS THE ANGLE INCREASES?

CAN YOU TELL WHICH DIRECTION SPATTER TRAVELED FROM THE SHAPE OF THE DROP?

A MATTER of SPATTER

Does the direction change spatter?

THE INTERNATIONAL EXHIBITION OF

SHERLOCK HOLMES

A MATTER OF SPATTER

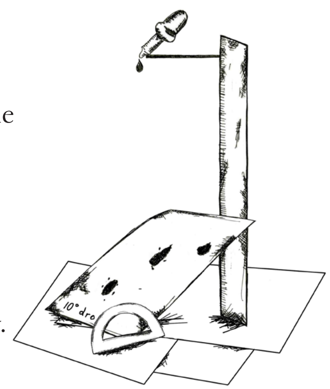
Collecting the Data

1. Label a Testing Sheet "10 degrees (10°)." Attach it to a clipboard or piece of cardboard and place it flat on your testing area (0°).

2. Student 1: Hold the protractor along the table surface and observe at eye level.

   Student 2: Raise the Testing Sheet until it reaches the 10° mark on the protractor as observed by student #1. Hold the Testing Sheet steady.

   Student 3: Allow five drops of liquid to fall from 20 cm above the Testing Sheet. Do not let your drops overlap.



3. Set Testing Sheet aside to dry.

4. Repeat Steps 1-3 labeling four Testing Sheets:
   - 30 degrees (30°)
   - 45 degrees (45°)
   - 60 degrees (60°)
   - 75 degrees (75°)

DOES THE DIRECTION CHANGE SPATTER?

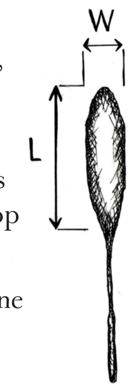
A MATTER OF SPATTER

Analyzing the Data

5. Measure the length and width of each drop (hint: the width is the smaller measurement). If the drop has a tail, only measure the oval part, not the tail.

6. Divide the width by the length. This gives you the "roundness ratio". (A drop with a roundness ratio of 1 is perfectly round.) Record the roundness ratio of each drop on the chart below.

7. Calculate the average of your roundness ratios to determine the average roundness ratio of spatter at each angle.



Data Collection Chart: Roundness Ratio of Spatter

	10°	30°	45°	60°	75°
Drop 1					
Drop 2					
Drop 3					
Drop 4					
Drop 5					
(Total)					
Average					

THE METROPOLITAN POLICE

REPORTING OFFICER: ______________________________

LOCATION of INCIDENT: MR. JOHNSON'S ART CLASS

CASE NO: 5221859221B

Date: MONDAY AFTERNOON, 1:52 P.M.

OBSERVATION of EVIDENCE

Details of incident

The victim, Mr. Johnson, was writing an assignment on the chalkboard while his students painted at their desks. At approximately 1:52 p.m., the victim reports feeling something fly past his head and hearing two distinct smacks hit the board. He believes someone flung paint across the room, narrowly missing his head. Mr. Johnson reports that he spun around to see who the culprit was, but all suspects appeared to be hard at work at their desks.

Actions taken

The forensics department collected evidence from the crime scene, including an accurate sketch of the classroom and up-close photographs of the spatter found on the chalkboard. The spatter needs analysis to determine which of the suspects is responsible.

Evidence (Attached)

One (1) overhead sketch of the crime scene, showing the location of each suspect's desk, the chalkboard where the victim was standing, as well as the location of the two drops of spatter.

One (1) photograph of the spatter found on the chalk board. Each drop has been magnified for analysis.

Questions for Anaylsis

Which side of the room did the paint come from?
What was the trajectory of the paint spatter?
What desks could the paint have come from?

Officer's conclusion

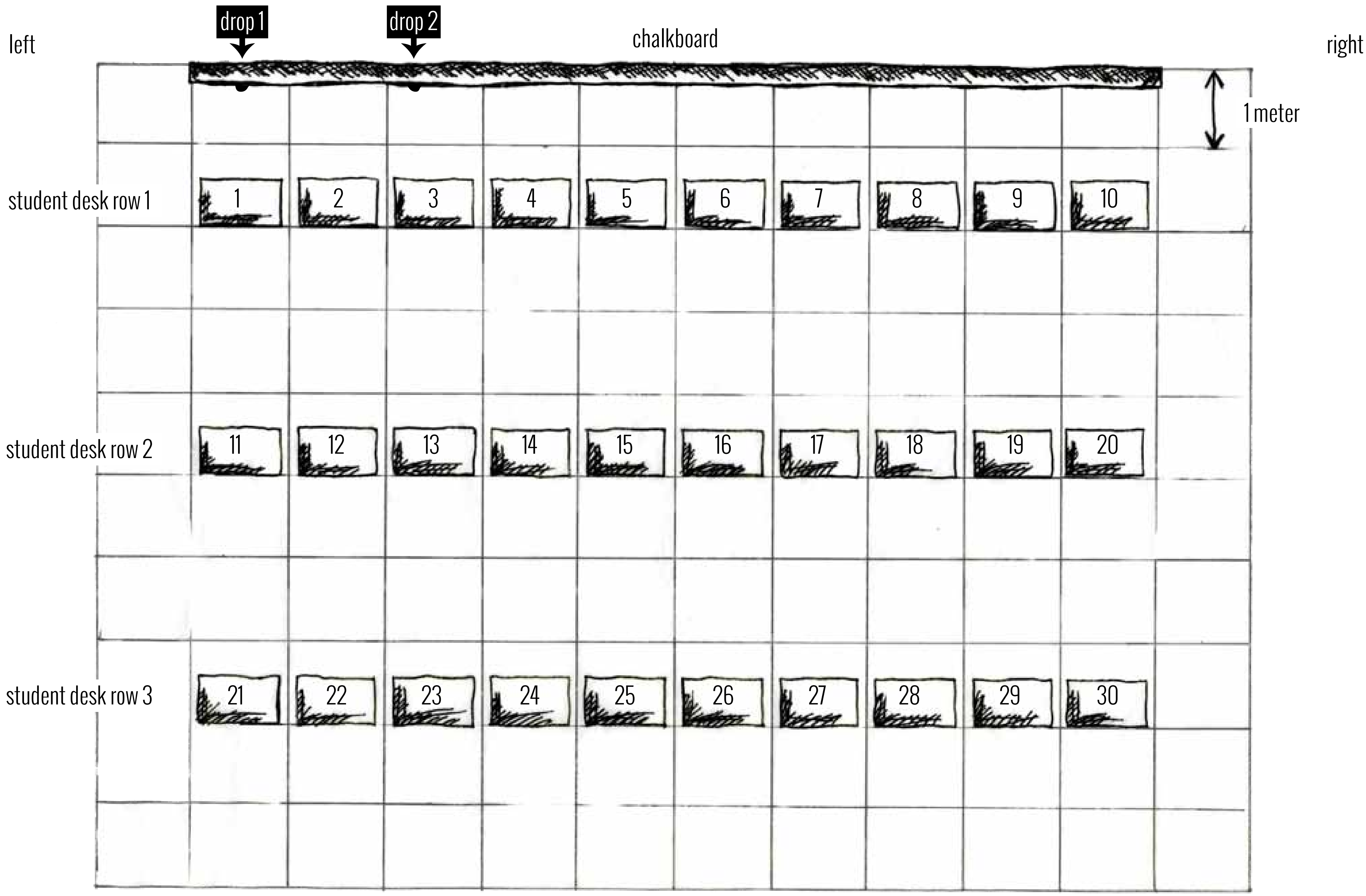
____

____

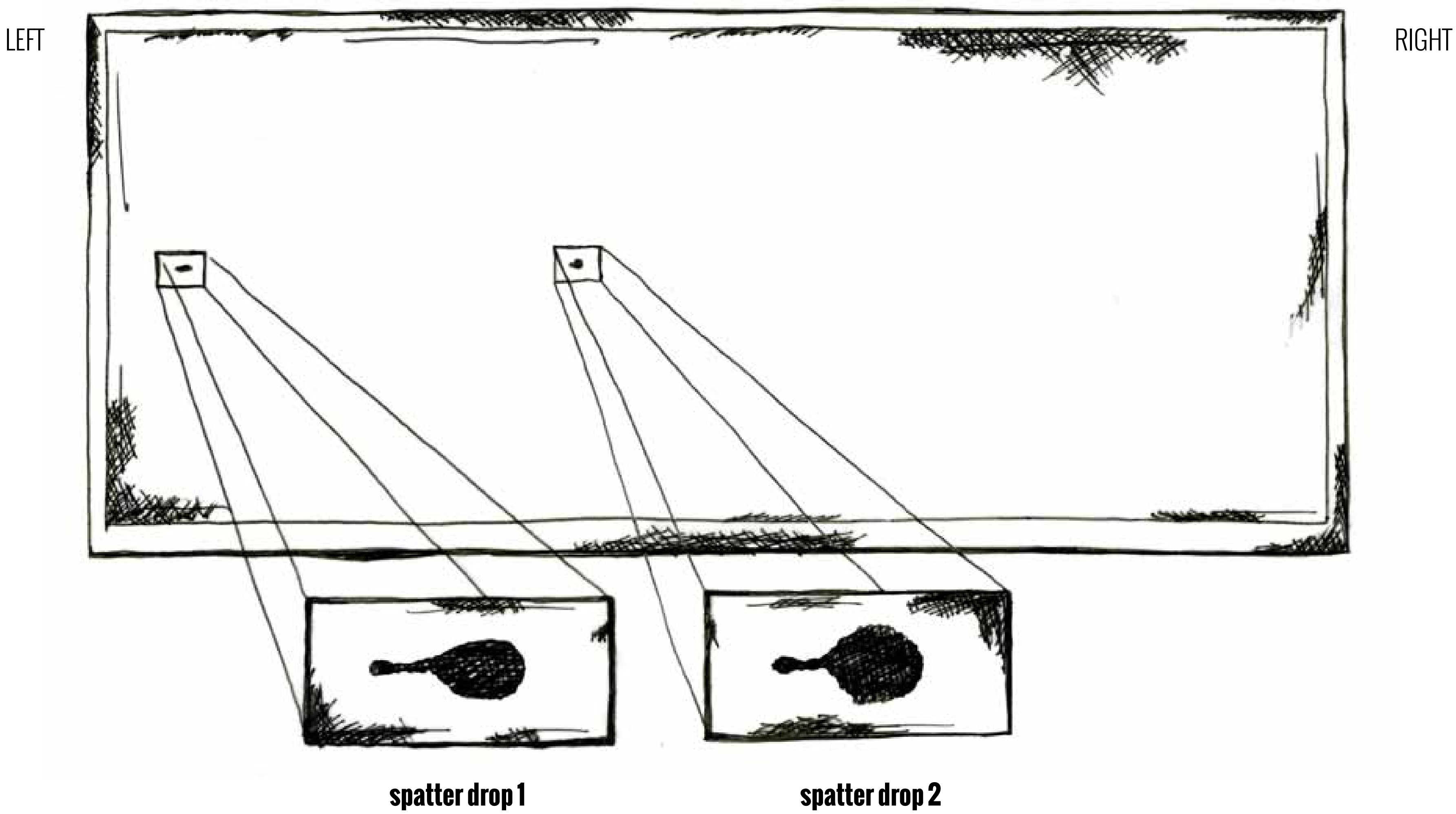
____

____

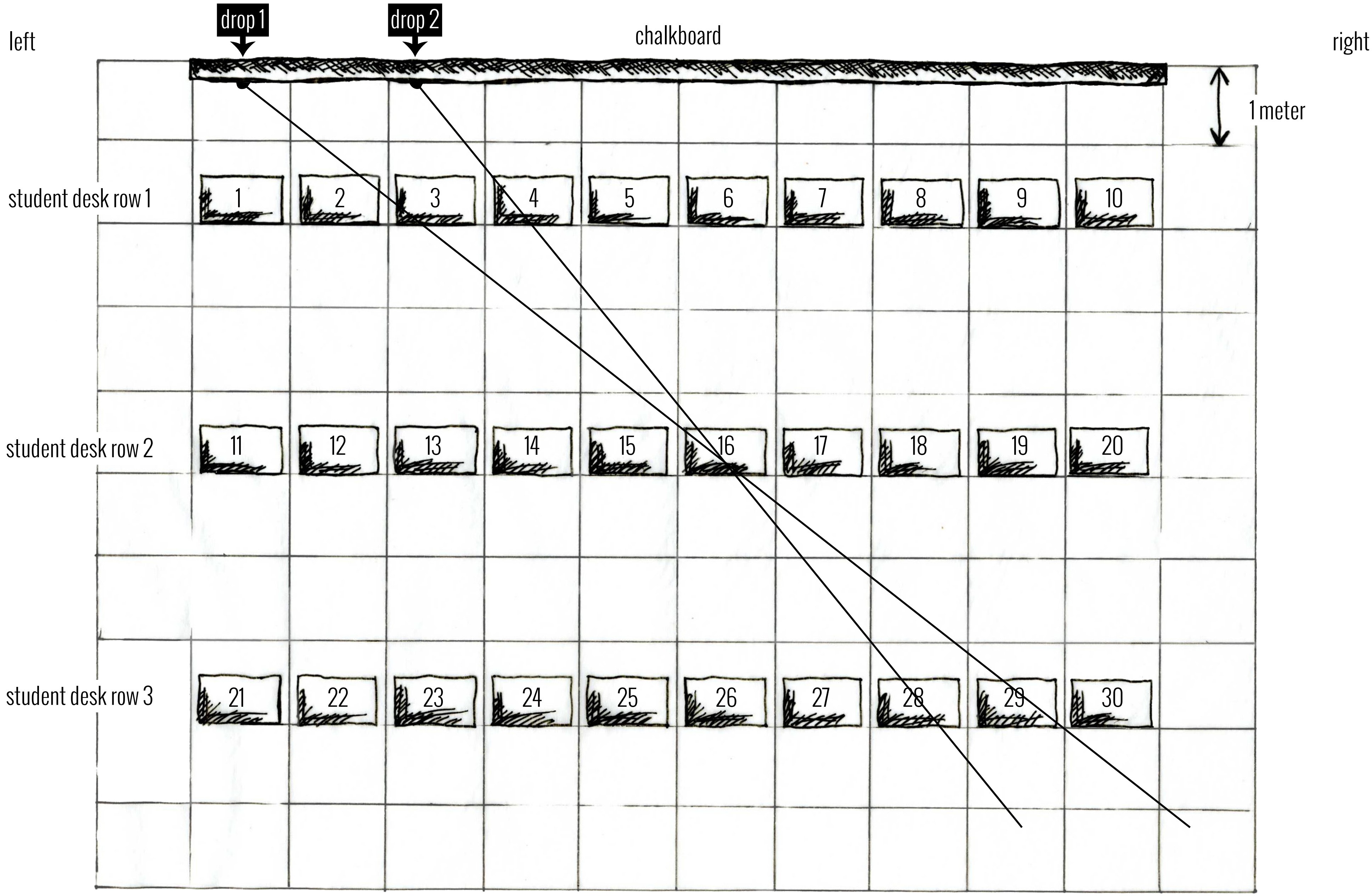
Crime Scene Overhead View



Chalkbaord with spatter



Crime Scene Overhead View: Answers for Teachers



Angle of Impact Chart

Roundness Ratio	Angle of Impact
.1	6°
.17	10°
.2	11°
.26	15°
.34	20°
.41	24°
.5	30°
.6	38°
.71	45°
.8	51°
.87	60°
.9	65°
.94	70°
.98	80°
1	90°

Roundness Ratio	Angle of Impact
1/10	6°
1/6	10°
1/5	11°
1/4	15°
1/3	19°
2/5	24°
1/2	30°
3/5	38°
2/3	41°
4/5	51°
5/6	57°
9/10	65°
19/20	71°
99/100	82°
1	90°

SUPPLY WORKSHEET

A Matter of Spatter

Recommended group size: 3–4

Number of Students: [ ] Number of Groups: [ ]

Supplies	Amount Needed	Supplies on Hand	Supplies Needed
Calculators	1 per group		
Clipboards (or use a notebook, binder, or piece of cardboard)	1 per group		
Disposable cups	1/group		
Newspaper or tablecloths	1 stack		
Paper towels	1 roll		
Plastic disposable pipettes or glass droppers (1-3mL size; 1 mL preferred)	1 per group		
Protractors	1 per student		
Rulers	1 per student		
Scotch tape	1 roll		
Sponges	2–4		
Tempera paint (any color will work; red if simulating blood spatter)	2–3 mL per group		
White index cards, cardstock, or construction paper (cut into half sheets, about 8”x5” each)	10 sheets per group		
Yardsticks	1 per group		

SHERLOCK HOLMES

THE EXHIBITION

On the Trail of a Mystery

Pre-Exhibit Field Trip: Grades 6-8
Extensions for Grades 9-12

Sir Arthur Conan Doyle once called "The Adventure of the Speckled Band" his favorite Sherlock Holmes story. Indeed, it is a classic and enduring example of the mystery form. In this activity, students will learn about mystery vocabulary and structure, learn to identify those elements in the story, and craft a persuasive response that predicts their own solution to the mystery.

LEARNING OBJECTIVES

- Learn "mystery" vocabulary and identify those elements in "The Adventure of the Speckled Band"
- Cite evidence from the text to support analysis
- Generate a persuasive essay that uses textual elements to support a claim or argument

TIME REQUIRED

Pre-Lesson:	Lesson Plan:	Post-Lesson:
Reading Assignment	~60 minutes	Writing Assignment

PROGRAM FORMAT

Segment	Format	Time
On the Trail of a Mystery	Group Discussion and Activity	30 min
Make Your Case!	Individual Writing Activity	20 min
Revealing the Solution	Video Clip and Discussion	10 min

COMMON CORE STANDARDS

CCSS.ELA-Literacy.RL.6.1 CCSS.ELA-Literacy.RL.7.1	Cite textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text.
CCSS.ELA-Literacy.RL.8.1	Cite the textual evidence that most strongly supports an analysis of what the text says explicitly as well as inferences drawn from the text.
CCSS.ELA-Literacy.RL.6.3	Describe how a particular story's or drama's plot unfolds in a series of episodes as well as how the characters respond or change as the plot moves toward a resolution.
CCSS.ELA-Literacy.RL.7.3	Analyze how particular elements of a story or drama interact (e.g., how setting shapes the characters or plot).
CCSS.ELA-Literacy.RL.8.3	Analyze how particular lines of dialogue or incidents in a story or drama propel the action, reveal aspects of a character, or provoke a decision.
CCSS.ELA-Literacy.W.6.1 CCSS.ELA-Literacy.W.7.1 CCSS.ELA-Literacy.W.8.1	Write arguments to support claims with clear reasons and relevant evidence.

SUPPLIES

Supplies	Amount	Notes
"The Adventure of the Speckled Band" Short Story Part I	1 per student	See the Resources section.
"The Adventure of the Speckled Band" Short Story Part II	1	Teacher may read aloud.
"Sherlock Holmes and the Speckled Band" video or video clip (optional)	1	
"On the Trail of a Mystery" Resource	1 or 1 per student	See the Resources section.

ADVANCE PREPARATION

Previous Class:

- The students may read the first section of "The Adventure of the Speckled Band" or, if time permits, the students may read it in class following the discussion of mystery elements.

Notes and Hints:

- The students will read **the first three-quarters** of the story and write a persuasive paragraph that predicts the story's solution. The recommended "cut-off" point for Part I is after the sentence: "Then he turned down the lamp, and we were left in darkness." It is recommended that the instructor omit the last section of the story completely, so the students are not tempted to "spoil" the story for themselves.

- If the students are reading the first section of the story for homework, encourage them not to seek out the rest of the story online or elsewhere. If a student has read the story previously, he or she may choose to posit an "alternate ending" to the story for his or her persuasive response.

INTRODUCTION

5 minutes

Notes

Suggested script is shaded.
Important points or questions are in bold.
Suggested answers are in italics.

By now, you are likely familiar with mysteries. Was anyone familiar with Sherlock Holmes before you read this story? You might have seen modern movies or television shows based on Sherlock Holmes. Even if you are not familiar with Sherlock Holmes, maybe you have read the 39 Clues series or *The Westing Game*? Can you name some mysteries?
Students list books, movies, video or computer games, etc.

So we are very familiar with mystery as a form, even if we do not realize it. What does a mystery need to have? What are the common ingredients in a mystery?
Students will likely list clues, a crime, a detective, etc.

Write down the list on the board as the students generate ideas. Most students will have an intuitive knowledge of a mystery and may provide information that overlaps with the "On the Trail of a Mystery" resource.

GROUP DISCUSSION AND ACTIVITY

On the Trail of a Mystery

25 minutes

1. Review the "On the Trail of a Mystery" resource with students.

We have listed many of these terms already, but here we present an overview of how a mystery is usually structured. This structure is not necessarily how *every* mystery is arranged, but many of them follow this formula.

Exposition
In this section, we meet some of the **characters** (usually the main character, the **detective**), and the **setting** of the story is established. When you think of setting, think about "setting the table." When you set a table, you lay out everything you need before you sit down to a meal. A story's setting should provide all the background you need before the action of the story begins. A well-written story will continue developing characters

and providing rich descriptions and context throughout, but establishing a clear and vivid setting at the beginning is crucial to the reader's understanding of everything that follows.

Ask the class to consider:
- What kind of information do we need before the "action" of the story begins?
- Do the students prefer a lot of exposition, or do they like when a story gets right to the "action?" What is different about the two reading experiences?

Rising Action
The introduction of the central problem or **conflict** sets off a chain of events and actions that constitute the rising action of the story. The detective might encounter a **victim**, a **witness**, or a **suspect** and discover **clues**. This series of discoveries and events will build logically and, if the writer is skilled, the reader will feel tension, excitement, and a drive to discover the solution to the mystery.

Ask the class to consider:
- Does the writer need to provide all the clues necessary for the reader to solve the mystery?
- How does a writer create the feeling of tension and excitement in a story?
- What purpose does a **red herring** serve in the story?

Climax
In a mystery, the **climax** could be the high point of physical action in the story or simply the moment when the detective discovers a pivotal clue. Students may differ in their opinion of what the climax of a story is, but a useful characterization of the term is "the point at which an irrevocable change is made."

2. Have the students go through their copies of Section I of "The Adventure of the Speckled Band" and identify as many vocabulary terms as possible (for example, the dummy pull, the bowl of milk, and the ventilator can all be identified as *clues*; Dr. Roylott is a *suspect*.)

3. The class comes together to share their responses.

INDIVIDUAL ACTIVITY

Make Your Case!

20 minutes

We have studied the elements of the mystery, but we still have not covered the most crucial part: the solution! The solution to the crime is usually revealed in the story's resolution.

Resolution
The resolution ties up the loose ends in the story. Often the detective will describe his or her process of **deduction**, reveal the full **solution** to the mystery, and prove that a suspect is now, undoubtedly, the **perpetrator**. Often the fates of the victim and perpetrator are revealed.

Ask the class to consider:

- What do we mean when we say a resolution is "satisfying"? What elements does a resolution need to satisfy us, particularly in a mystery story?

I will reveal Sir Arthur Conan Doyle's solution to the mystery at the end of class, but for now, I would like to hear your solutions! Consider the clues you have identified in the story. What do you think that they mean? Is Dr. Roylott the murderer? Could someone or something else be responsible?

1. Have the students write a short persuasive response (1-2 paragraphs) predicting the outcome of the story. Encourage the students to utilize mystery vocabulary.

2. If time permits, have the students share their responses and predictions.

GROUP DISCUSSION

The Solution is Revealed!

10 minutes

1. When the students have finished their responses, play the video clip from "Sherlock Holmes and the Speckled Band" (see the Resources section for more information.) In the clip, Sherlock and Watson encounter the snake and learn the fate of Dr. Roylott. On the train ride home, Holmes describes his process of deduction. If the video is unavailable, read the end of the story aloud to the students.

2. Find out if anyone guessed the solution correctly!

Ask the class to consider:

- Was the solution "guessable"?
- Did Conan Doyle give all the information necessary to solve the case?
- Was the resolution a satisfying one?
- What do the students think about the fate of Dr. Roylott?

FOLLOW-UP ASSIGNMENT

Make Your Case! Part II

If the students were unable to finish their persuasive paragraphs in class, they may complete them for homework and learn the story's solution in the next class.

For an additional assignment, have the students write a short persuasive response defending either Dr. Roylott or Sherlock Holmes. Were Holmes' methods justifiable? Was Dr. Roylott a victim?

EXTENSIONS

THE MANY FACES OF SHERLOCK HOLMES

Comparing Characters
Have the students generate a list of the characteristics of Holmes and Watson. Ask the students to seek out other representations of Holmes and Watson (in other books, movies, TV shows, cartoons, comics, etc.) and compare the characters. How have the characters changed? What has remained the same?

THE EVOLUTION OF MYSTERY

Mystery Form
Have the students read Edgar Allen Poe's "The Murders in the Rue Morgue" and a contemporary mystery story of their choosing. How has the form changed? What has remained the same?

WRITING EXPOSITION

Telling vs. Showing
Ask students to experiment with different ways of writing exposition: through dialogue, emails or letters, descriptive

language, summary, etc. Discuss the distinction between “telling” and “showing.”

WRITE A MYSTERY

Exploring Structure
Ask the students to write their own short mysteries, employing mystery terms and structure. Or, have the students write a mystery that inverts the structure.

BACKGROUND INFORMATION

This background information is for teachers. Modify and communicate this information to the students as necessary.

Sherlock Holmes is unquestionably the world's most famous literary detective, but he was not the first. Sir Arthur Conan Doyle was inspired by Edgar Allan Poe, who created what is widely considered the first modern detective story, "The Murders in the Rue Morgue." Poe's story introduces many familiar features of the detective story: a brilliant, eccentric hero, an admiring assistant, a complex crime. Poe's detective, C. Auguste Dupin, also employs logical, methodical thinking (what Poe referred to as "ratiocination") to solve the case. Dupin would appear in two other Poe stories, but the first of these, "The Murders in the Rue Morgue," is notable for its originality and its establishment of what would eventually become detective story tropes.

Conan Doyle, a great admirer of Poe's, built on this framework. Sherlock Holmes is a champion of logical thought, but also a man of science. Holmes' firm belief in the problem-solving power of science was typical of the Victorian era, which saw great scientific and technological advancement. Holmes was based on Dr. Joseph Bell, a professor of medicine at Edinburgh University, where Conan Doyle studied. Bell dazzled the students there with his casual observational prowess, a habit Conan Doyle borrowed for Holmes.

Conan Doyle also believed that the reader should be given all the relevant information necessary to understand the solution—there should be no clues that the reader is unaware of or uncanny coincidences. Holmes always reveals the logical process of deduction that led to the mystery's solution, another use of figurative language that is well-observed in modern detective fiction.

RESOURCES

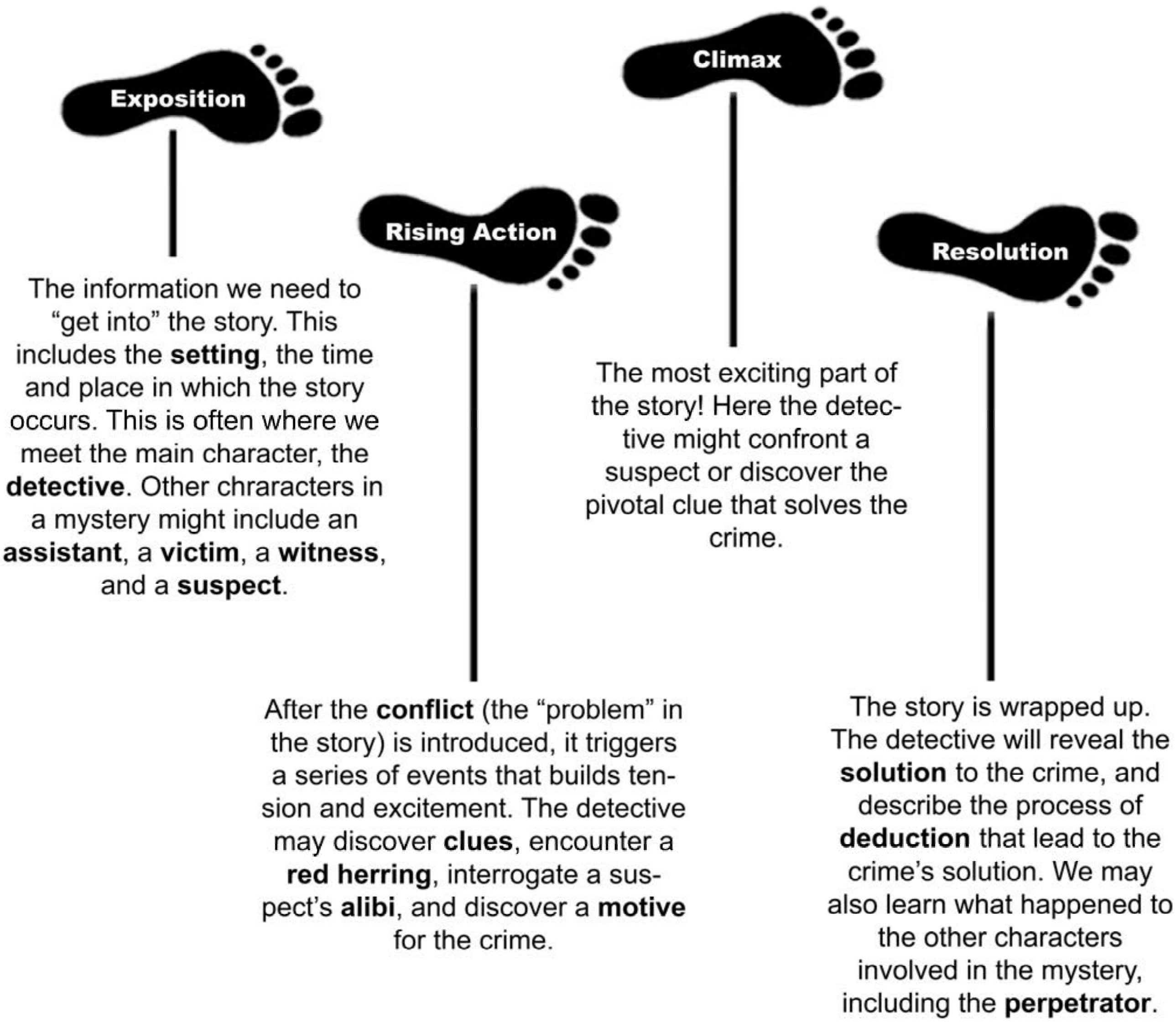
"The Adventure of the Speckled Band"
The Adventures of Sherlock Holmes, the collection that this story appears in, is in the public domain and is available in a variety of formats via the Project Gutenberg or Google Books websites. The Edgar Allan Poe story referenced in the Background Information section ("The Murders in the Rue Morgue") is also available there.
http://www.gutenberg.org/
http://books.google.com/books

Audio recordings of *The Adventures of Sherlock Holmes* and “The Murders in the Rue Morgue” are available via LibriVox.
http://librivox.org/

The Adventures of Sherlock Holmes Series: “The Speckled Band”
This 1984 episode of *The Adventures of Sherlock Holmes* TV series stars Jeremy Brett (one of the iconic portrayers of Holmes). The series is available on DVD and the individual episode can be purchased on iTunes and Amazon. A clip of the final scene can be found on YouTube.

Mystery Timeline
This Mystery.net article follows the trajectory of the modern mystery story, from Edgar Allan Poe to Hawaii 5-O and beyond. The site is also a rich resource for other information on the mystery form.
http://www.mysterynet.com/timeline/history-of-mystery/

On the Trail of Mystery! Resource



Exposition: The information we need to "get into" the story. This includes the **setting**, the time and place in which the story occurs. This is often where we meet the main character, the **detective**. Other chraracters in a mystery might include an **assistant**, a **victim**, a **witness**, and a **suspect**.

Rising Action: After the **conflict** (the "problem" in the story) is introduced, it triggers a series of events that builds tension and excitement. The detective may discover **clues**, encounter a **red herring**, interrogate a suspect's **alibi**, and discover a **motive** for the crime.

Climax: The most exciting part of the story! Here the detective might confront a suspect or discover the pivotal clue that solves the crime.

Resolution: The story is wrapped up. The detective will reveal the **solution** to the crime, and describe the process of **deduction** that lead to the crime's solution. We may also learn what happened to the other characters involved in the mystery, including the **perpetrator**.

GLOSSARY

Alibi	A reason why a suspect could not have commited a crime.
Character	The characters interacting in a narrative.
Climax	The most exciting and pivotal part of the story, in which a major change occurs.
Clue	A piece of potential evidence of a crime.
Conflict	The “problem” in the story. This event or issue causes the events of the story to happen.
Deduction	The process of using reasoning to arrive at a conclusion.
Detective	Often the main character in a mystery. A detective, often with the help of an assistant, investigates and tries to solve a crime.
Exposition	The background information in a story. In this part of the story, the setting is established and some characters are introduced.
Motive	The reason a person might have committed a crime.
Perpetrator	A person who *did* commit a crime.
Red Herring	A piece of potential evidence that suggests an incorrect solution to the crime.
Resolution	The end of the story, in which the “problem” is solved.
Rising Action	The series of events caused by the conflict.
Setting	The time and place in which a story occurs.
Solution	The answer to a problem.
Suspect	A person who *may* have committed a crime.
Victim	A person who was negatively affected by a crime.
Witness	A person who saw a crime take place.

SHERLOCK HOLMES
THE EXHIBITION

The Game is Afoot!

Post-Exhibit Field Trip: Grades 6-8
Extensions for Grades 9-12

In "The Adventure of the Red-Headed League," Sir Arthur Conan Doyle uses precise, vivid language to bring the characters, settings, and action of the story to life. In this activity, students learn to recognize descriptive language, analyze its function in a narrative, and employ it in their own writing.

LEARNING OBJECTIVES

- Utilize observation and descriptive language skills in a short writing prompt and a creative writing assignment
- Recognize the myriad functions of descriptive language in "The Adventure of the Red-Headed League"
- Cite evidence from the text to support analysis

TIME REQUIRED

Pre-Lesson:	Lesson Plan:	Post-Lesson:
Reading Assignment	**~60 minutes**	**Writing Assignment**

PROGRAM FORMAT

Segment	Format	Time
Introduction	Writing Prompt Instructions	5 min
The Game is Afoot!	Individual Writing Activity	20 min
Functions of Description	Group Activity and Discussion	35 min

COMMON CORE STANDARDS

CCSS.ELA-Literacy.RL.6.2	Determine a theme or central idea of a text and how it is conveyed through particular details; provide a summary of the text distinct from personal opinions or judgments
CCSS.ELA-Literacy.RL.6.4	Determine the meaning of words and phrases as they are used in a text, including figurative and connotative meanings; analyze the impact of a specific word choice on meaning and tone.
CCSS.ELA-Literacy.RL.6.5	Analyze how a particular sentence, chapter, scene, or stanza fits into the overall structure of a text and contributes to the development of the theme, setting, or plot.
CCSS.ELA-Literacy.RL.7.1	Cite several pieces of textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text.
CCSS.ELA-Literacy.RL.7.4	Determine the meaning of words and phrases as they are used in a text, including figurative and connotative meanings; analyze the impact of rhymes and other repetitions of sounds (e.g., alliteration) on a specific verse or stanza of a poem or section of a story or drama.
CCSS.ELA-Literacy.RL.8.1	Cite the textual evidence that most strongly supports an analysis of what the text says explicitly as well as inferences drawn from the text.
CCSS.ELA-Literacy.RL.8.4	Determine the meaning of words and phrases as they are used in a text, including figurative and connotative meanings; analyze the impact of specific word choices on meaning and tone, including analogies or allusions to other texts.
CCSS.ELA-Literacy.W.6.3 CCSS.ELA-Literacy.W.7.3 CCSS.ELA-Literacy.W.8.3	Write narratives to develop real or imagined experiences or events using effective technique, relevant descriptive details, and well-structured event sequences.

SUPPLIES

Supplies	Amount	Notes
“The Adventure of the Red-Headed League” short story	1 per student	See the Resources section.
Shoes of various sizes and styles (or other comparable personal items or pieces of clothing)	1 per group; ~10 total	For best results, the shoes should be of varying sizes and styles.
“On the Trail of a Mystery” Resource (optional)	1 per student	See the Resources section.

ADVANCE PREPARATION

Previous Class:

- Students should read “The Adventure of the Red-Headed League” or, if time permits, the students may read it in class.
- The instructor may distribute and discuss the “On the Trail of a Mystery” resource to give the students a sense of the typical structure of a mystery story. If students have completed the “On the Trail of a Mystery” Pre-Exhibit Lesson Plan, they will already be familiar with mystery structure and vocabulary.

Notes and Hints:

- If you do not have access to a variety of shoes, you can have the students bring in one of their shoes or the shoes of a parent or sibling. The exercise can be done with any piece of clothing or personal object, but shoes are great because they can effectively convey age, gender, and personality. Sherlock Holmes is often preoccupied with feet: tracking footprints, identifying a specific kind of mud on a shoe, etc.

SETUP

- Place the shoes on various student desks throughout the room before class begins. There should be 3-4 students per shoe. Keep groups relatively small so each student has time to examine the shoe.

INTRODUCTION

5 minutes

Notes

Suggested script is shaded.
Important points or questions are in bold.
Suggested answers are in italics.

In "The Adventure of the Red-Headed League," Sherlock Holmes is able to deduce an astonishing amount of information by carefully observing Jabez Wilson's appearance.

This is a good time to have the students pull out their copies of the story. Have a student read the section in which Wilson's clothes are described and Sherlock reveals what he has deduced about Wilson from his appearance.

INDIVIDUAL ACTIVITY

The Game is Afoot!

20 minutes

Imagine you are Sherlock Holmes. Your group's shoe is an important clue - consider it carefully! Look at it, touch it; you can even smell it, if you dare! Make a detailed list of your observations about the shoe. Be as specific as possible!

1. Let the students pass the shoe around, then place it in a central location so all the group members can see it.

2. Ask the students to write for five minutes in a notebook or writing journal, describing the shoe in as much detail as they possibly can. Though the students will be grouped around a shoe, they will be writing individually.

Now that we have noted our observations about the shoes, I would like you to imagine who the shoe might belong to. Is it a woman's shoe? A child's shoe? What is the owner like? Give the person a name and a history. What do they look like? How do they behave? What kind of work do they do? And why did they leave the shoe behind? Be as detailed as possible.

3. The students will write for 10 minutes about the owner of the shoe.

Ask the class to keep in mind:

- What conclusions are they drawing from the physical evidence?
- What characteristics do they only have a hunch about?
- What characteristics are drawn from their imagination?

GROUP ACTIVITY

What Can Description Do?

When we examine something carefully, using all five senses, the way you did when you wrote about your shoe, we can use those observations to make our writing much more dynamic.

1. Ask the students to share some examples of the descriptive language from their writing. Have them hold up their shoe as they read.

A great description makes a subject come alive, even something boring, like an old shoe. And we can apply the same observational skills to characters, settings, and actions. Writers use descriptive language to make their stories feel "real," but descriptive language can do much more than that.

2. Ask the students to consider what functions description can perform in a story. Give a relevant example from "The Adventure of the Red-Headed League." The section they have read previously, in which Jabez Wilson is described, is a good place to start:

"Our visitor bore every mark of being an average commonplace British tradesman, obese, pompous, and slow. He wore rather baggy gray shepherd's check trousers, a not over-clean black frock-coat, unbuttoned in the front, and a drab waistcoat with a heavy brassy Albert chain, and a square pierced bit of metal dangling down as an ornament. A frayed top-hat and a faded brown overcoat with a wrinkled velvet collar lay upon a chair beside him. Altogether, look as I would, there was nothing remarkable about the man save his blazing red head, and the expression of extreme chagrin and discontent upon his features."

What is Doyle implying in his initial description of Wilson? What does he want us to think about the character? *Wilson is a ridiculous or absurd character; Wilson isn't very rich or sophisticated; Watson, who is narrating the story, perceives Wilson as lower-class.*

A description can tell us what the author wants us to know, but also what the author wants us to know about the narrator. For example, Wilson is described derisively by Watson.

How does Watson describe Holmes? What does it tell us? *Holmes is described as "hawk-like" and "relentless, keen-witted, ready-handed." Watson admires Holmes.*

Descriptive language is not limited to concrete details. A character's statements can also tell us a great deal about that character.

What are some examples of dialogue that also acts as descriptive language? *"I beg that you will not touch me with your filthy hands" –John Clay. Clay is a snob who thinks he is above the law; "My life is spent in one long effort to escape from the commonplaces of existence. These little problems help me to do so." –Sherlock Holmes. Holmes is bored, brilliant and perhaps a bit arrogant, dismissing this complicated case as "a little problem".*

Descriptive language can be a "clue," too. For example, Jabez Wilson describes his assistant as particularly keen to get him through the crowd to apply to join the Red-Headed League: "How he did it I could not imagine, but he pushed and pulled and butted until he got me through the crowd, and right up to the steps which led to the office." At this point, we (and Holmes) might note the assistant must have a good reason for being so pushy.

3. As the students read examples of descriptive language from the story, create a running list of descriptive functions on the board. These may include:

- Creating a vivid and realistic setting
- Building tension or creating a "mood"
- Reinforcing a theme
- Illuminating a character, through description or dialogue
- Making action more exciting
- Acting as a "clue;" foreshadowing
- Telling us what the narrator thinks about other characters

FOLLOW-UP ASSIGNMENT

Step into a Mystery!

Ask the students to incorporate the shoe and the character it inspired into their own short mystery story. Encourage students to utilize rich descriptive language throughout. For a revising exercise, have the students work in groups to read, solve, and improve each other's mysteries.

OPTIONAL EXTENSIONS

EXPLORING TONE

Comparing Stories
Have the students read a Sherlock Holmes story that has a different tone than "The Adventure of the Red-Headed League" (for example, "The Adventure of the Speckled Band"). Have the students compare the tone of this relatively lighthearted story with a more serious one. How does Conan Doyle establish the different tones?

ANALYZING LANGUAGE

Word Clouds
Have the students create "word clouds" for each character in the story. Have the students create their word clouds for other famous characters or figures and see if the other students can guess who they are based on.

EXPERIMENT WITH PERSPECTIVE	**A New Narrator** Have students rewrite “The Adventure of the Red-Headed League” from the perspective of Jabez Wilson or John Clay.
WRITING RICH DESCRIPTION	**Writing with Senses** Have the students write descriptions of an object without describing its physical appearance. Have the students focus on texture, smell, sound, function, connotation, etc.

BACKGROUND INFORMATION

This background information is for teachers. Modify and communicate this information to the students as necessary.

Aspiring writers are often told to “write what they know” and indeed, students may find that their most effective, resonant description is inspired by familiar subjects -people they know, local settings, frequently used objects, etc.. Students are able to draw on their sensory memory and, in some cases, their emotional connection to the subject. Memory and connection make for vivid, authentic writing.

In the quest to create an indelible character, sometimes inspiration is close to home. The character of Sherlock Holmes was inspired by Dr. Joseph Bell, a professor of medicine at Edinburgh University, where Sir Arthur Conan Doyle studied. Bell was a fervent believer in the power of observation—like Holmes, he was able to deduce a great deal of information about a person by simply observing them. Bell believed that perception was a critical part of practicing medicine and he insisted that his students develop the skill. Conan Doyle also borrowed some of Bell’s physical characteristics - piercing eyes, a hawkish nose - for his iconic detective and perhaps some of his own awe of the great man for the character of Watson.

Conan Doyle drew from his own world in many ways. His medical experience gave him an intimate knowledge of poisons, wounds, and maladies. He encountered patients from all walks of life, helping him populate Sherlock Holmes’ London with a rich tapestry of characters. Writing a mystery can seem like a daunting concept, but students may be reminded that their own lives can be rich sources of inspiration.

RESOURCES

“The Adventure of the Red-Headed League”
The Adventures of Sherlock Holmes, the collection that this story appears in, is in the public domain and is available in a variety of formats via Project Gutenberg, Google Books, and many other websites.
http://www.gutenberg.org/
http://books.google.com/books

Audio recordings of *The Adventures of Sherlock Holmes* are available via LibriVox.
http://librivox.org/

Writing Powerful Descriptions
Lit Reactor article with a great guide to writing descriptive language.
http://litreactor.com/columns/writing-powerful-descriptions

Description and the Brain
New York Times article about how the brain interprets certain words and descriptions. For example, reading the word "lavender" excites the part of the brain that deals with smells!
http://www.nytimes.com/2012/03/18/opinion/sunday/the-neuroscience-of-your-brain-on-fiction.html?_r=4&src=me&ref=general&

SHERLOCK HOLMES
THE EXHIBITION

"Cheap, Healthful Literature"

Pre-Exhibit Field Trip: Grades 9-12
Extensions for Grades 6-8

Many of the Sherlock Holmes stories were first published in "The Strand," a popular British literary and lifestyle magazine. Students will view "The Strand" online, explore short story structure, and participate in a collaborative writing project.

LEARNING OBJECTIVES

- View a Sherlock Holmes story in its original published form and explore historic periodicals
- Learn the structure of a short story
- Contribute to a collaborative short story composed by the class

TIME REQUIRED

Pre-Lesson:	Lesson Plan:	Post-Lesson:
Reading Assignment	~60 minutes	Writing Assignment

PROGRAM FORMAT

Segment	Format	Time
Introduction	Viewing *The Strand*	10 min
The Short Story	Group Discussion	20 min
Building a Mystery	Group Writing Activity	30 min

COMMON CORE STANDARDS

CCSS.ELA-Literacy.RL.9-10.5	Analyze how an author's choices concerning how to structure a text, order events within it (e.g., parallel plots), and manipulate time (e.g., pacing, flashbacks) create such effects as mystery, tension, or surprise.
CCSS.ELA-Literacy.W.9-10.3	Write narratives to develop real or imagined experiences or events using an effective technique, well-chosen details, and well-structured event sequences.
CCSS.ELA-Literacy.RL.11-12.3	Analyze the impact of the author's choices how to develop and relate elements of a story or drama (e.g., where a story is set, how the action is ordered, how the characters are introduced and developed).
CCSS.ELA-Literacy.RL.11-12.5	Analyze how an author's choices concerning how to structure specific parts of a text (e.g., the choice of where to begin or end a story, the choice to provide a comedic or tragic resolution) contribute to its overall structure and meaning as well as its aesthetic impact.
CCSS.ELA-Literacy.W.11-12.3	Write narratives to develop real or imagined experiences or events using an effective technique, well-chosen details, and well-structured event sequences.

SUPPLIES

Supplies	Amount	Notes
"The Adventure of the Copper Beeches" short story	1 per student	See the Resources section.
Internet access (optional)	1 per student or 1 web-enabled projector	If internet access is unavailable, print sources can be substituted.
Selected Sherlock Holmes' stories from *The Strand* (optional)	1 per student	See the Resources section.

ADVANCE PREPARATION

Previous Class:

- Students should read "The Adventure of the Copper Beeches," in class or for homework.

Notes and Hints:

- This lesson can be modified to accommodate varying levels of classroom technology access. Scans of *The Strand* are available via the Internet Archive (see web address in the Resources section), so if access is available, have students peruse the archive on their own or in groups. Or, if a computer-connected projector is available, the instructor may show the class a few selections from the archive. If computer access is unavailable, the instructor can print out a few of the Sherlock Holmes stories from the archive ahead of time.

- *The Strand*, as a document from the turn of the 19^{th} century, reflects some outdated attitudes about culture, race, and gender. If you are allowing the class to explore the archive freely, it might be helpful to mention this fact.

SETUP

The instructor may pass around or display "The Adventure of the Copper Beeches" in its original published form. (See the Resources section on page 10 for the specific web address.)

INTRODUCTION

10 minutes

Notes

Suggested script is shaded.
Important points or questions are in bold.
Suggested answers are in italics.

Where do we get our entertainment? How do we learn about the world around us?
Online, in books or graphic novels, in movies, on TV.

In the 1890s, which is when "The Adventure of the Copper Beeches" was published, what do you think people did for entertainment? How did they learn about culture, science, and the world around them?
Newspapers, the theater, books.

At the turn of the 19th century, one very popular source of information and entertainment was *The Strand*.

This is a good time to display *The Strand* archive on a projection screen, have the students scroll through the archive on laptops or class computers, or pass around a printout of the original "The Adventure of the Copper Beeches" story. Ideally, some other sections of the magazine should be examined as well, for context.

The magazine, founded in 1891, published short stories, interviews, puzzles, portraits, and articles about celebrities, science, fashion, and fads. Does that sound familiar to you? It's a lot like the blogs or magazines we know today, right?

Herbert Greenhough Smith, the first editor of *The Strand*, said his mission was to provide "cheap, healthful literature" to the British public. Many of the Sherlock Holmes stories, including the one you read, "The Adventure of the Copper Beeches," were first published in *The Strand* magazine.

What is the most popular TV show right now? What do you just have to watch every week, where you cannot miss an episode? *Answers will vary.*

That is what the Sherlock Holmes stories were like. They were a sensation. So every time a new issue of *The*

Strand came out, people were eager to see what case Sherlock was going to solve next.

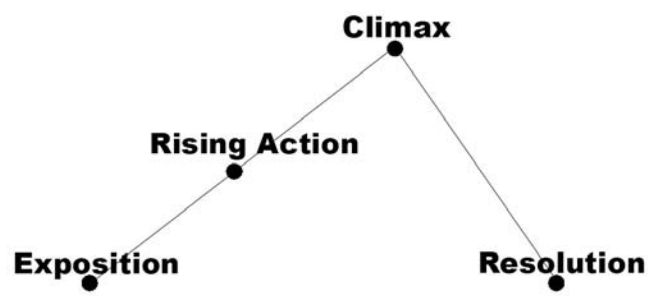
GROUP DISCUSSION

The Short Story

20 minutes

Although Conan Doyle also wrote Sherlock Holmes novellas and novels, most of the Sherlock stories take the form of a short story.

1. The instructor draws or displays a basic "story structure" graph.



Once you learn the structure of a short story, you will see these basic elements repeated in all kinds of narratives: novels, movies, television episodes, comic book issues, etc. If a narrative is missing one of these elements, we notice it, sometimes consciously, but often on the subconscious level. In a novel or a longer work, we might see a much more complicated structure, but a short story really only needs these basic elements.

Let us take a look at very basic story that everyone knows, like "The Ugly Duckling." We have our main character, the character we are going to relate to, the Ugly Duckling. We have a setting (a nest of ducklings), a conflict or problem (the Ugly Duckling is not accepted by the other ducklings because he looks different), a climax (the Ugly Duckling discovers he is really a swan), and the resolution (the Ugly Duckling finds his family and lives happily ever after.)

Even though the structure seems like a simple one, for a short story to really succeed, each of those elements has to be really strong. Conan Doyle's Sherlock Holmes' stories are some of the world's most famous and beloved stories. What makes them so successful?

2. The students take out their copies of "The Adventure of the Copper Beeches."

3. Work with the class (or have them break into partners or groups) to identify how the story follows the graph on the board.

Since the students will each be contributing a part of a collaborative mystery, it is helpful to discuss the different ways Conan Doyle engages the reader at every stage of the story. The students may want to take notes during this section, or the instructor may write them on the board so that students can reference the notes later when they are thinking about the collaborative story.

Exposition/Setting
For example, you might discuss how Conan Doyle begins the story right in the middle of a conversation between Sherlock Holmes and Dr. Watson. Did the students think this technique was successful? Students might discuss how the strong characterization of Holmes and Violet Hunter helps ground the reader in the story and make the subsequent mystery more engaging. For example, Violet Hunter is portrayed as capable and bright, which makes her urgent summons ("Do come! I am at my wit's end.") all the more significant.

Rising Action
The students might discuss where in the story they think the "rising action" begins. Does Violet Hunter's initial visit to Holmes signal the beginning of the rising action, or is it part of the story's exposition? Does "rising action" have to be "physical" action? You might ask the students when they first felt "invested" in the story, and what detail or event piqued their interest, and why.

Climax
What do the students consider the climax of the story to be? You might have the students identify the most climactic section of the story, then the most climactic

paragraph, then the most climactic sentence. Of course, opinions will vary! Ask the students how the rising action contributed to the climax and how the language in the climax itself contributes to its success. Is the language different then it was in the setting and rising action? Has the pace of the story changed? How did Conan Doyle create a feeling of “excitement” in this section?

Resolution

What does a resolution need to do? Where does the story’s resolution begin? The students may discuss if they thought the resolution of the story was satisfying and if there was anything else they wanted to know. Was there a change in the language of the story?

GROUP ACTIVITY

Building a Mystery

30 minutes

1. Following the discussion of “The Adventure of the Copper Beeches,” write the four basic sections of the story on the board: Exposition, Rising Action, Climax, and Resolution. Tell the students they will be collaboratively composing their own mysteries, but each story will have some similar elements, which the students will provide, “Mad Libs” style.

2. Have the students call out suggestions for the following questions:

- Where does the story take place? Name three characteristics of the setting (geographic location, era, building, etc.)
- Who is solving the mystery? Name three characteristics of the detective.
- Who is the victim of the crime? Name three characteristics of the victim.
- How does the detective find out about the crime?
- What is the nature of the crime? (Burglary, murder, fraud, etc.) Where did the crime take place?
- Name three items that are important clues in the story. Name one red herring.
- Who has committed the crime? Name three characteristics of the perpetrator.

- Where does the story's climax take place?

Write the questions and the suggestions provided on the board or have students write them down.

3. Break the students into groups of four. The students will work together to conceptualize their version of the story, but each student will be responsible for one section of the story: the exposition, rising action, climax, or the resolution. Students should keep in mind the notes they took during the discussion about what makes each section "work" in a story. Students can write in class, if time permits. The sections of the story may not line up perfectly—but that's part of the fun!

4. Student can share their stories aloud in class.

FOLLOW-UP ASSIGNMENT

Write a Collaborative Mystery!

If the students are unable to complete their stories in class, they can complete their sections of the story for homework and re-group during the next class to discuss, revise, and refine the story that they produced. The students can share the stories aloud in class or integrate them in the suggested project below.

For a more robust project, students can work in groups to produce their own mini versions of *The Strand*. This project can include the story that the students wrote and other original work such as photographs, drawings, or stories about local or school events. For a more history-focused version, students can research various trends, events, and literature of Conan Doyle's era and contribute original articles about the politics, fashion, science, and culture of the time to create a more "authentic" *Strand*. The students will "publish" their issues in a variety of ways, depending on classroom technology. Options include publishing via a website, using a program like Publisher or Microsoft Word, or via a collage or cut-and-paste.

EXTENSIONS

DISSECTING A MYSTERY

Modern Media
Have students plot the structure of a Sherlock Holmes story on the short story structure graph, and then have them try it with the plots of popular movies or TV episodes. How are the narratives similar? How do they differ?

COLLAPSING THE NOVEL

Short Stories
Have the students try to rewrite one of their favorite novels as a short story. Which elements are most important to keep in? Which elements could be removed?

SERIALIZATION

A Group Story
It was very common for authors during Conan Doyle's time to publish a longer story or novel in installments. Have the students "serialize" a story by having each student contribute a paragraph or two to an ongoing story

BACKGROUND INFORMATION

This background information is for teachers. Modify and communicate this information to the students as necessary.

The Sherlock Holmes stories appeared in some of the most prominent publications of Sir Arthur Conan Doyle's era, including *Harper's Weekly* and *Collier's.* But Conan Doyle's most enduring relationship was with *The Strand*, a magazine devoted to fiction, popular culture and science, and interviews, which was founded in 1891. *The Strand's* mix of popular subjects, lavish illustration and photography, and what editor Herbert Greenhough Smith called "cheap, healthful literature," would define the magazine for the next sixty years. Throughout its history, it would publish mystery greats such as G.K. Chesterton and Agatha Christie and legendary literary figures such as P.G. Wodehouse, Rudyard Kipling, and H.G. Wells.

"A Scandal in Bohemia" was the first of the Sherlock Holmes stories to appear in *The Strand* and it was an instant success. Readers clamored for more, and Conan Doyle would provide: between 1891 and 1927, over fifty Sherlock Holmes stories were published in *The Strand,* including a serialized version of *The Hound of the Baskervilles.* Although the magazine was shut down in 1950 (and revived in 1998 with exclusively mystery-focused content), archival copies of *The Strand* are available for perusal online. They are a tremendous artifact of their age—full of information about popular topics, innovations, and attitudes at the turn of the 19th century.

RESOURCES

"The Adventure of the Copper Beeches"
The Adventures of Sherlock Holmes, the collection that this story appears in, is in the public domain and is available in a variety of formats via Project Gutenberg, Google Books, and many other websites.
http://www.gutenberg.org/
http://books.google.com/books

Audio recordings of *The Adventures of Sherlock Holmes* are available via LibriVox.
http://librivox.org/

***The Strand* Archive Online**
The archive features various full issues of *The Strand* in various formats.
http://archive.org/details/TheStrandMagazineAnIllustratedMonthly

A direct link to the issue featuring “The Adventure of the Copper Beeches”:
http://archive.org/stream/TheStrandMagazineAnIllustratedMonthly/TheStrandMagazine1892aVol.IiiJan-jun#page/n7/mode/2up

SHERLOCK HOLMES
THE EXHIBITION

Cracking an Ancient Case

Post-Exhibit Field Trip: Grades 9-12
Extensions for Grades 6-8

In "The Adventure of the Musgrave Ritual," a criminal's trail leads Sherlock Holmes to an ancient treasure. In this lesson, students apply Holmes' methods to academic sources and explore a real-life historical mystery.

LEARNING OBJECTIVES

- Learn to "interrogate" different sources and assess their strengths and validity
- Cite textual information in support of an argument
- Produce a persuasive and informative essay with proper citations

TIME REQUIRED

Pre-Lesson:	Lesson Plan:	Post-Lesson:
Reading Assignment	**~60 minutes**	**Writing Assignment**

PROGRAM FORMAT

Segment	Format	Time
Introduction	Solving a Riddle	5-20 min
Interrogating a Source	Group Discussion	20 min
The Investigation	Group or Individual Activity	10-20 min

COMMON CORE STANDARDS

CCSS.ELA-Literacy.RI.9-10.1	Cite strong and thorough textual evidence to support analysis of what text says explicitly as well as inferences drawn from the text.
CCSS.ELA-Literacy.RI.9-10.8	Delineate and evaluate the argument and specific claims in a text, assessing whether the reasoning is valid and the evidence is relevant and sufficient; identify false statements and fallacious reasoning.
CCSS.ELA-Literacy.W.9-10.1	Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
CCSS.ELA-Literacy.W.9-10.2 CCSS.ELA-Literacy.W.11-12.2	Write informative/explanatory texts to examine and convey complex ideas, concepts, and information clearly and accurately through the effective selection, organization, and analysis of content.
CCSS.ELA-Literacy.W.9-10.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
CCSS.ELA-Literacy.RI.11-12.1	Cite strong and thorough textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text, including determining where the text leaves matters uncertain.
CCSS.ELA-Literacy.RI.11-12.7	Integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) as well as verbally in order to address a question or solve a problem.

CCSS.ELA-Literacy.W.11-12.1	Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
CCSS.ELA-Literacy.W.11-12.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

SUPPLIES

Supplies	Amount	Notes
"The Adventure of the Musgrave Ritual" short story	1 per student	See the Resources section.
Internet access (optional)	1 per student or 1 web-enabled projector	If internet access is unavailable, print sources can be substituted.
Various examples of "good" and "bad" print sources (optional)	1 per student	

ADVANCE PREPARATION

Previous Class:

- Students should read "The Adventure of the Musgrave Ritual," in class or for homework.

Notes and Hints:

- This lesson can be modified to accommodate varying levels of classroom technology access. It is increasingly common for students to use web sources for research, so it is particularly useful to have the students use laptops or classroom computers to complete the lesson, but an instructor can easily lead the discussion with a computer-connected projector. If computer access is limited or unavailable, the lesson can also be done with a variety of print sources.

SETUP

- Write the following riddle on the board. (See the Resources section on page 13 for the solution.)

Who was he?
A notable Boar.

Who was his foe?
A red Rose.

What did he take?
Edward's seat.

Who told his tale?
Avon's son.

Where did he rest?
Beneath Jaguars and Vauxhalls.

INTRODUCTION

5-20 minutes

Notes

Suggested script is shaded.
Important points or questions are in bold.
Suggested answers are in italics.

We have provided a riddle for students to solve that echoes the style of the riddle in "The Adventure of the Musgrave Ritual." Students can work in groups to solve it, using web searches, the books in the school library, or other reference materials.

The answer to the riddle is King Richard III, whose bones were recently discovered beneath an English parking lot. While the students are solving the riddle, the instructor can queue up one of the videos listed in the Resources section, which discuss the excavation and discovery of the King's remains and the forensic science used to confirm his identity. This discovery was set in motion by The Richard III Society, a group of historians and laypeople, a great example of how anyone can help solve a "mystery from history"!

Write the riddle on the board. Break the students into groups and have them work to solve the riddle. Once the riddle is solved by one of the groups, bring the class together.

In "The Adventure of the Musgrave Ritual," Sherlock Holmes follows an ancient riddle, discovers an attempted burglary, solves a murder, and uncovers a priceless treasure. In reality, the crown of Charles I was almost certainly melted down following his execution in 1649. But scientists, archeologists, and historians are still solving historical mysteries using the methods employed by Holmes in the story: careful observation, deductive reasoning, and a little imagination. And there are plenty of mysteries left to solve!

Ask the "winning" group to reveal the answer to the riddle. Students can then view the clip (or clips) of the discovery of Richard III's bones or the instructor can read from an article about the discovery. Suggestions for relevant clips and articles can be found in the Resources

section below.
What are some other "mysteries from history?" *Who built Stonehenge; who was Jack the Ripper; what happened to the colony at Roanoke, etc.*

Tell the students that their eventual assignment will be to choose an "unsolved mystery" from any point in history and investigate it using a variety of different sources.

GROUP DISCUSSION

Interrogating a Source

20 minutes

When Sherlock Holmes is investigating Richard Brunton, he wants to know everything he can about the man. The more he learns, the more accurate his deductions are. He can make predictions about Brunton's behavior that are founded on an understanding of the man's character. He is then able to confirm these guesses. When we are trying to solve our own mysteries, we want to make sure that we have the most reliable and accurate information supporting our deductions. We have to treat every source as a suspect.

<u>Thoughts for discussion:</u>

Is the source relevant?
That is, does the source pertain to the topic you are researching, or is there only a passing mention of the topic? It is alright to only take only one or two facts from an article, book, or website, but a resource that is specially focused on your topic is likely to be more accurate.

How old is the source? Is it possible the source is outdated? Is this edition the newest version of the source?
An older source is not necessarily a bad source! However, a more recent source is more likely to have up-to-date information, especially if the subject relates to technology or science. Try to find the most recent edition of a source, if possible.

Is there an author listed? What do we know about the author?
An author biography, in a book or via an online search, is full of clues about the author's credibility. A biography may note that this topic is a specialty of the author's or that the author has an academic connection to the topic. If an author is not listed, be wary of the source. For example, Wikipedia can give you a quick answer, but the information on the site is crowd sourced, which means that any person can contribute to it, regardless of their qualifications. When an author puts his or her name on a book or article, he or she takes responsibility for the information in it.

If the author's name is unavailable, the information can still be valid. Does the information come from a government body, university, or museum?

Does the information deviate significantly from the other sources?
A source with new information or a different slant on a topic does not mean the source is untrustworthy. However, information that contradicts the "conventional wisdom" on a topic should be vetted very carefully. Was the source recently published? Is the author reputable? If an author is presenting revolutionary information, he or she should address that fact and be able to defend the new information or theories.

How is the information in the source presented? Has the author used correct spelling, grammar, and punctuation? Does the publication "look" professional?
A qualified author or journalist will present the information in a professional manner. If the article is on a website that does not seem professional (i.e., a personal blog or a public forum), this source is probably not an ideal starting place for research.

Where was the source published? How do we know if a website or publication is a credible one?
Just because a publication is well known or popular, it does not necessarily mean that the information is correct. Seek out publications that are specific to your topic. Academic and professional journals are an excellent source of information. Many of these publications require

peer review, which means that an unbiased source will check to make sure the claims in an article are accurate. Your library likely has access to a number of databases that can connect you to reliable sources.

Does the author provide a list of their own sources?
Academic authors will usually list the sources that they used for their research in a Bibliography or References section. This method allows other scholars to check their work and keeps the author accountable. Looking at Bibliography or References sections can lead you to other relevant sources from your own research, too.

Is the source “sponsored” by a specific company or organization? How might that affect the source’s orientation?
Check to see if the source is labeled as “Sponsored Content” or is found on the website of an organization that might have an interest in providing a specific “slant” on a topic. Seek out sources that are unlikely to have a bias. For example, a website for a soda company might feature an article on the health benefits of caffeine, but a better source for information on the topic would be a reputable medical journal.

Is the source a “primary” or “secondary” source?
A primary source is a first-hand account, like a report of the results of an experiment, a first-hand description of an experience or time period, or a creative work produced during a certain period. A secondary source refers to analysis or interpretation of a work, or a second-hand account of an experience or time period. Neither type of source is inherently more accurate than the other, but for certain subjects, the distinction is important to consider.

GROUP ACTIVITY

The Investigation

10-20 minutes

Depending on the time and resources available, the students may apply this line of questioning to a web source. Students can do this process individually (if laptops or a computer lab are available), in groups (if only a few computers are available), or the instructor can lead the class in examining a few websites together (if internet projection is available).

For the best results, have a few “good” and “bad” website options for the students to choose from (but do not say which are which!), to avoid unfocused or irresponsible web use. A great example of a “bad” site is the official site of “The Pacific Northwest Tree Octopus,” a hoax website that at first glance appears credible (see the Resources section for the web address).

The students should be encouraged to apply this process to the sources they choose for the research assignment below.

If the students do not have access to the Internet in the classroom, there are plenty of “good” and “bad” print sources for them to evaluate. Some “good” sources might include: academic journals, recently-published books by credible sources, and magazines like *Scientific American*, *Science* magazine, etc. “Bad” sources might include: obviously outdated books or encyclopedias, tabloid papers, or “advertorials” sponsored by corporations.

FOLLOW-UP ASSIGNMENT

Uncover a Mystery from History!

Students research a “mystery from history” of their choosing. They write a short essay discussing their findings, presenting their own conclusions, and defending the sources that they used to support that conclusion. They also discuss their reasoning for rejecting a certain source or theory in the essay.

EXTENSIONS

BASIC SOURCE INTERROGATION

Relevant Sources
For younger students, omit the more complex discussion questions above. This age group can focus on determining if sources are recent, credited to an author, and on-topic.

BUILDING AN ARGUMENT	**Writing a Thesis** Discuss the structure of a research paper with the students, focusing on writing and defending a thesis.
SUMMARY SKILLS	**Mystery from History** Give the students a half hour to study a “mystery from history” of their choosing, online or at the library. Have them write a one-paragraph summary of their findings to present at the end of class.

BACKGROUND INFORMATION

This background information is for teachers. Modify and communicate this information to the students as necessary.

Today's students have unprecedented access to information, but it can be difficult for them to discern which sources are acceptable for academic research. The line of questioning described in the lesson plan is a good start, but students will likely need additional guidance on where to find appropriate sources.

Libraries are excellent sources of printed material like books and periodicals, but they also house two other underutilized resources: online databases and librarians. Many libraries subscribe to a variety of online databases that provide access to academic journals and periodicals that the library does not carry in print. This way is often the best method of accessing a great deal of specific information on esoteric topics. Because these databases can be a little daunting, however, encourage students to ask a librarian for assistance. Librarians are highly trained researchers who can help guide students to the appropriate resources.

Most students will want to begin their research online, which is not necessarily bad. A general online search or even a trip to Wikipedia can help students obtain some very broad information to start with, but it is crucial to emphasize the limitations of crowd-sourced material. Encourage students to seek out research from credited writers who have a vested interest in the accuracy of their claims. Students should avoid information from personal websites or blogs and even major online news sources should be very carefully considered. For example, a news story about a scientific development might be covered on a general news site, but an academic journal or reputable science periodical is likely to have more detailed and accurate information on the topic.

RESOURCES

"The Adventure of the Musgrave Ritual"
The Memoirs of Sherlock Holmes, the collection that this story appears in, is in the public domain and is available in a variety of formats via Project Gutenberg, Google Books, and many other websites.
http://www.gutenberg.org/
http://books.google.com/books

Audio recordings of *The Memoirs of Sherlock Holmes* are available via LibriVox.
http://librivox.org/

The Discovery of King Richard III
The Smithsonian website has two excellent video clips on the subject: one detailing the search for the gravesite and another showing how modern forensics helped identify the king's remains.
http://www.smithsonianchannel.com/sc/web/show/3381029/kings-skeleton-the-richard-iii-revealed#the-search-begins-for-a-slain-king

Tge Pacific Northwest Tree Octopus
A well-known "hoax" site dedicating to "saving" the Pacific Northwest tree octopus, a nonexistent animal. This site is a fun example of how a source that appears reputable may not be.
http://zapatopi.net/treeoctopus/

Riddle

Who was he?
A notable Boar.

Who was his foe?
A red Rose.

What did he take?
Edward's seat.

Who told his tale?
Avon's son.

Where did he rest?
Beneath Jaguars and Vauxhalls.

Key
The riddle refers to the Richard III, the last English king from the House of York. The term "Boar" refers to Richard's personal badge, which was a white boar. The "red Rose" is Henry VII, the first Tudor monarch, who defeated Richard at the Battle of Bosworth. Richard's nephew, Edward V, was declared illegitimate and Richard took the throne, which ultimately precipitated the Battle of Bosworth. "Avon's son" refers to William Shakespeare, who wrote the play *Richard III*. Richard's remains were discovered beneath at parking lot in the English city of Leicester (Jaguar and Vauxhall are British automobile brands.)